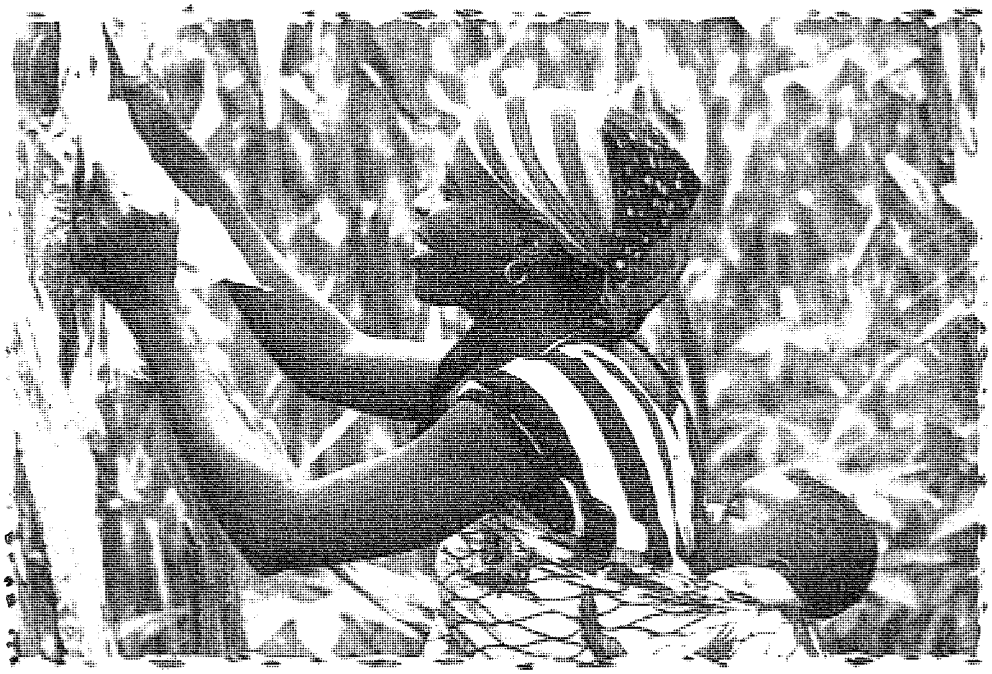
A Field Guide for On-Farm Experimentation

H.J.W Mutsaers, G.K. Weber, P. Walker and N.M. Fischer



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IITA

The International Institute of Tropical Agricultural (IITA) was founded in 1967 as an international agricultural research institute with a mandate for specific food crops, and with ecological and regional responsibilities to develop sustainable production systems in Africa. It became the first African link in the worldwide network as the Consultative Group on International Agricultural Research (CGIAR) formed in 1971.

IITA is governed by an international board of trustees and is staffed by approximately 150 scientists and other professionals from about 40 countries and 1,500 support staff. Most of the staff are located at the Ibadan campus, while others are at stations and work sites in other parts of Nigeria and in the countries of Benin, Cameroon, Côte d'Ivoire, Ghana, Malawi, Mozambique, Tanzania, Uganda and Zambia. Funding for IITA comes from the CGIAR and bilaterally from national and private donor agencies.

IITA conducts research, training and germplasm and information exchange activities in partnership with regional and national programs in many parts of sub-Saharan Africa. The research agenda addresses crop improvement within a farming systems framework. Research focuses on smallholder cropping systems in the humid and subhumid tropics of Africa and on the following major food crops: cassava, maize, plantain and banana, yam, cowpea and soybean.

The goal of IITA's research and training mission is to improve the nutritional status and well-being of low-income people of the humid and subhumid tropics of sub-Saharan Africa.

CTA

The ACP-EU Technical Centre for Agricultural and Rural Cooperation (CTA) was established in 1983 under the Lomé Convention between the African, Caribbean and Pacific (ACP) States and the European Union Member States.

CTA's tasks are to develop and provide services that improve access to information for agricultural and rural development, and to strengthen the capacity of ACP countries to produce, acquire, exchange and utilize information in these areas. CTA's programs are organized around three principal themes: strengthening facilities at ACP information centers, promoting contact and exchange of experience among CTA's partners, and providing information on demand.

ISNAR

The mandate of the International Service for National Agricultural Research (ISNAR) is to assist developing countries in bringing about lasting improvements in the performance of their national agricultural research systems and organizations. It does this by promoting appropriate agricultural research policies, sustainable research institutions and improved research management. ISNAR's services to national research are ultimately intended to benefit producers and consumers in developing countries and to safeguard the natural environment for future generations.

ISNAR was established in 1979 by the CGIAR on the basis of recommendations from an international task force. It began operating at its headquarters in The Hague, the Netherlands, on September 1, 1980.

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August 1997

Citation

Mutsaers, H.J.W., G.K. Weber, P. Walker and N.M. Fisher. 1997. A Field Guide for On-Farm Experimentation. IITA/CTA/ISNAR.

AGROVOC Descriptors

agriculture; research; food production; food security; sustainability, international co-operation

CABI Descriptors

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ISBN 978-131-125-8

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List of Acronyms

ANOVA	analysis of variance
ANCOVA	analysis of covariance
AWC	available water content
CIAT	Centro Internacional de Agricultura Tropical
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo
COMBS	Collaborative Group for Maize-Based Systems Research
CV	coefficient of variation
DSS	decision support system
ECEC	effective cation exchange capacity
FAO	Food and Agriculture Organization of the United Nations
FCC	fertility capability soil classification
GIS	geographic information system(s)
GLM	general linear model
GTZ	Gesellschaft für Technische Zusammenarbeit
ICRAF	International Centre for Research in Agroforestry
IITA	International Institute of Tropical Agriculture
INRA	Institut National de la Recherche Agronomique, Morocco
LSD	least significant difference
LEXSYS	legumes expert system
MPT	multipurpose trees
MRA	multiple regression analysis
MS	mean square
NARS	national agricultural research system(s)
OFR	on-farm research
ORSTOM	Organisation de Recherche Scientifique et Technique Outre Mer
PCA	principal component analysis
PRA	participatory rural appraisal
QUEFTS	quantative evaluation of the fertility of tropical soils
RCB	randomized complete block
RRA	rapid rural appraisal
SS	sum of squares
WAP	weeks after planting

Foreword

This is a completely revised and updated edition of the previous *A Field Guide for On-Farm Research,* which appeared years ago in the heyday of the farming systems research era. At that time, the experience with on-farm experimentation—and the very peculiar design and analytical problems it poses—was still quite limited. The book could therefore only provide a first set of guidelines and analytical techniques.

Much experience has since accumulated, at IITA and elsewhere, and on-farm research has become an integrated part of the work of most national and international research institutes. Many researchers, however, remain insufficiently familiar with the techniques available to draw reliable conclusions from on-farm trials with their unavoidable, or maybe we should say *desirable,* variability. It was therefore thought necessary to bring out a new edition of the book, with emphasis on the experimental aspects of on-farm research, which should help on-farm researchers to arrive at solid conclusions, taking into account, rather than eliminating, variation among farmers. The title of the book has been changed accordingly and it is now called *A Field Guide for On-Farm Experimentation.* It is co-published by IITA and CTA and we are very happy that CTA's participation will open channels of communication to a vast number of researchers in the countries covered by the Lomé convention (in Africa, the Caribbean, and the Pacific).

We would like to thank ISNAR's former director general, Dr. Christian Bonte-Friedheim, for making the institute's excellent publishing facilities available. We are particularly grateful to free-lance editor Judy Kahn and to ISNAR's Richard Claase, Fionnuala Hawes, Elly Perreijn and Kathleen Sheridan for their invaluable contributions to this publication. The publishers of the statistical packages reviewed in the book kindly made available the software and exercised much patience in waiting for results. We thank them very much.

We hope and trust that the book will be of help to the many scientists in national institutes who are devoting themselves to the difficult task of conducting quality research under real farm conditions for the benefit of real farmers.

Doyle Baker
Director
Resource and Crop Management Division
IITA

Chapter

1 On-Farm Research: Objectives, Concepts and Organization

Introduction

The objective of applied agricultural research is to identify new farming practices and materials that will improve the farmers' production system and increase their productivity and well-being in a way that can be sustained. Traditionally, this research has been conducted in research stations, while extension and development organizations were expected to transfer the results to the farmers. The failure of this model in many developing countries has caused agricultural scientists to adopt on-farm research (OFR) as a necessary tool in the development and transfer of appropriate technology. OFR is expected to enhance the relevance of research by taking direct cognizance of farmers' conditions and needs and by choosing new technology in co-operation with farmers and testing it under their local conditions.

In essence, the OFR approach is simple—conducting an important part of applied research together with farmers in their own environment, with the aim of finding adoptable and sustainable solutions for their production constraints. OFR presents peculiar methodological and practical challenges, but a single-minded, motivated group of scientists and extension/development officers will have no difficulty in meeting these. This book provides some tools to facilitate the work of on-farm researchers, but it is no substitute for the attitudes necessary for conducting successful OFR. If researchers have the right attitudes, then it will be easier for them to help farmers find appropriate technologies within their reach which they will also be ready to apply.

The OFR process

The OFR process has three components:

- developing a clear understanding of the farm[1] and its environment as well as farmers' goals, constraints and opportunities (*the diagnostic component*)
- choosing or designing appropriate innovations, in close co-operation with the farmers, and testing them under real farming conditions (*the experimental component*)
- evaluating the performance of the innovations and monitoring their adoption, or analyzing the causes of non-adoption (*the evaluation component*).

The OFR process has often been represented by flowcharts showing these components as sequential stages, starting with diagnosis, continuing through the selection and testing of technology and finishing with technology evaluation. In a new OFR program, this will be the natural order for starting the process. With time, however, new ideas will develop, requiring renewed diagnosis, while various technologies will be at different stages of testing and evaluation. The process will then become an intricate mix of activities involving all three components (Fig. 1.1). We must stress the particular importance of continued diagnosis. Informal surveys are a good technique for making an initial appraisal of the system and developing a first set of hypotheses in a new OFR program. Researchers should be aware, however, that the conclusions can only be preliminary and may even be unfounded or based on prejudice. They should update their opinions continually by making a proper analysis of trial results, by constant interaction with individuals or groups of farmers and, if necessary, by carrying out systematic studies involving more detailed surveys of specific aspects.

We must also stress the importance of adoption studies. All too often, on-farm testing ends with a statistical and economic analysis showing the profitability or otherwise of an innovation.

1. In West African parlance, the word 'farm' often refers to a single cultivated field. In this book, 'farm' is used in the standard English sense, meaning all the land exploited by a farm household, while a single patch of (cultivated) land is called a 'field'.

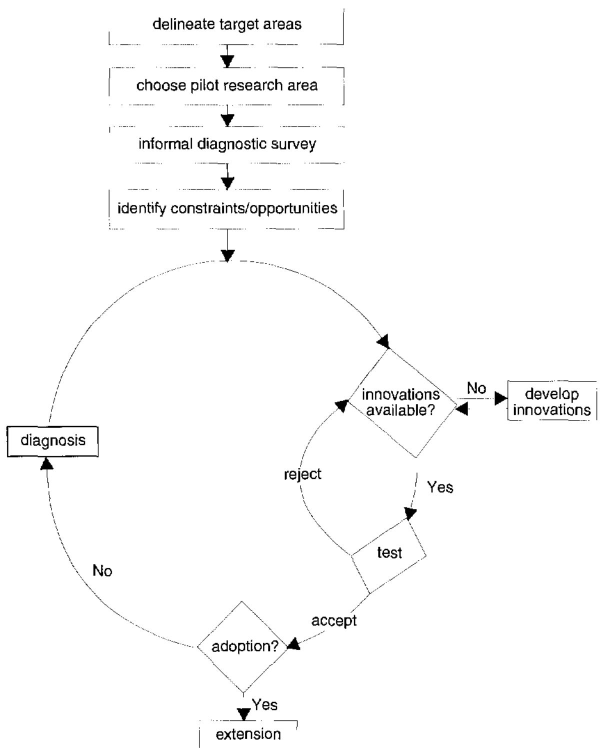


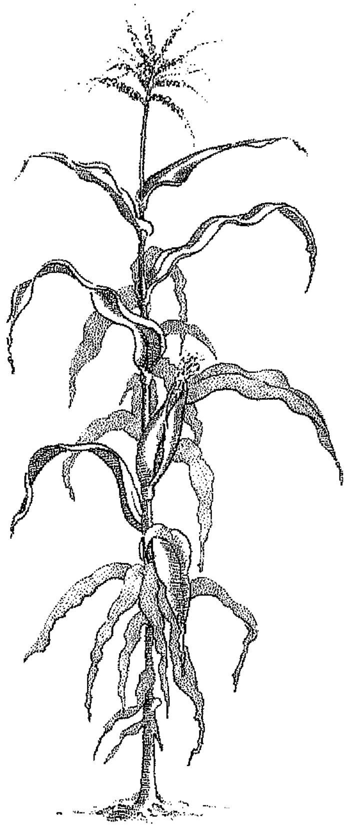
Figure 1.1: The on-farm research process

This kind of analysis does not, and probably cannot, account for all the criteria which may be used by farmers when deciding whether or not to adopt an innovation. The farmers' own opinions and assessments may help to reinforce the conclusions, but, even then, these conclusions will remain tentative.

The only real test is whether the farmers will continue to use the technology after being exposed to it during the trials. If, in spite of a positive evaluation, this is not the case, then the team should find out why.

OFR in relation to an institute's research mandate

OFR is a necessary research tool for any agricultural research institute in developing countries, and the research methods do not differ essentially in different countries or ecologies. An institute's research mandate will, however, affect the way OFR is conducted, in particular the way in which target zones or test



technologies are chosen. The following example will clarify this point:

Let us consider the notional case of an institute with a national mandate for research on cereal crops. The institute will probably have developed a map showing the distribution of the various cereals in the country, their importance and the cropping systems in which they are grown. Let us also assume that the institute is placing its main emphasis on maize production research. Target zones would then be delineated for maize growing which would be more or less "homogeneous" as regards ecology, population density, cropping systems, etc. Diagnosis would emphasize constraints to the production of maize, and innovations would be chosen in order to improve the maize-based production systems. This would, of course, not necessarily exclude other crops from consideration, but the emphasis would be on maize. Situations could also arise where an institute might narrow its focus to a particular type of technology or a particular constraint. These may be legitimate restrictions in view of the institute's objectives.

During the last decade, however, many national institutes have divided the country into agroecological regions and assigned a regional mandate to research centers in the different regions. The task of the regional research centers is to develop improved technology for their assigned region, without specifying *a priori* particular crops or constraints.

It is important that an institute should define the objectives of its OFR program clearly in relation to its overall research mandate.

This can give rise to the following situations:

Commodity-driven OFR

An example was given above where the emphasis was put on maize production. This approach has the advantage of providing a clear focus on which researchers from the different disciplines involved in OFR can readily reach agreement, but it runs the risk of overemphasizing one crop when other crops or resource-management constraints may be more important.

Constraint-driven OFR

OFR can address specific constraints, e.g., Striga or Imperata control. Target zones would be defined in relation to the occurrence and severity of these disorders. IITA, which has an ecoregional research mandate for sub-Saharan Africa, has adopted this approach in some of its OFR activities. This approach has the advantage of giving a high priority to a few major constraints for all disciplines within an institute and of establishing multidisciplinary approaches to these problems.

Technology-driven OFR

The objective is the assessment of the performance of specific technologies under farming conditions. One example is alley cropping. Technology-driven OFR is closely related to the constraint-driven approach, as the technology was developed in order to address certain constraints in the first place. The OFR workers must define the conditions under which the technology is likely to perform well and, which is even more important, those areas where it would seem to have a good chance of adoption. Testing sites would then be chosen in the high-potential areas. The delineation of areas with high potential for the technology can be quite complicated because of the many factors affecting the suitability and adoptability of a technology. National research institutes are unlikely to want to use this approach often, unless a range of technologies with different characteristics is available and can be targeted for different areas in order to overcome a major constraint such as soil fertility.

Multiobjective OFR

Regional research centers are most likely to use a multiobjective approach to identify productive and adoptable technology for certain agricultural regions, without any *a priori* choice as to commodity, constraints or technology. They may, however, have a bias in favor of certain commodities where they have particular expertise. Regions are usually delineated on the basis of broad agroecological criteria. They are generally large and varied and need to be subdivided into more or less homogeneous target zones (see next chapter). Commodities, constraints and technologies are chosen according to the outcome of diagnostic research in each zone and according to the availability of technologies for overcoming various constraints. This approach carries the risk that OFR will try to tackle too many problems at once, if no clear prioritization is made beforehand.

Since multiobjective OFR is the most relevant for NARS, this book will treat OFR from a multiobjective point of view. However, we shall also be considering problems of constraint—or technology-driven OFR where necessary.

OFR as an integrated part of an institute's research

A core group of scientists should be identified, who would co-ordinate OFR as an integrated part of their center's research program. Although OFR is a team activity, the creation of independent OFR teams is not recommended. The core group should have the major responsibility for the OFR task, but its members should not necessarily be involved full-time in on-farm testing. In fact, they can contribute more if they maintain some on-station work in support of the on-farm activities. Our recommendation is that the core team should include at least two experienced research officers—an agronomist and an agricultural economist.

Different and overlapping working groups ('teams') of scientists with different disciplines would be formed, with responsibility for particular target zones where they would be co-operating with the extension or development organization (Fig. 1.2). The composition of each team should reflect the major research issues in the target zone and might include a breeder, a soil scientist, an animal scientist, etc., each of whom would have a different combination of on-farm and on-station responsibilities. In theory, all scientists in the research center would be involved to varying degrees in on-farm research. Each team should also include a senior extension/development officer from the zone. The OFR core group should make up part of each team and guarantee methodological and logistical support. The day-to-day field work in each target zone should be carried out by a team of field assistants living on the research locations, headed by a junior researcher who collaborates with the village extension workers.

OFR, by its very nature, is entering territory that has traditionally been the domain of the extension service. Extension agents have

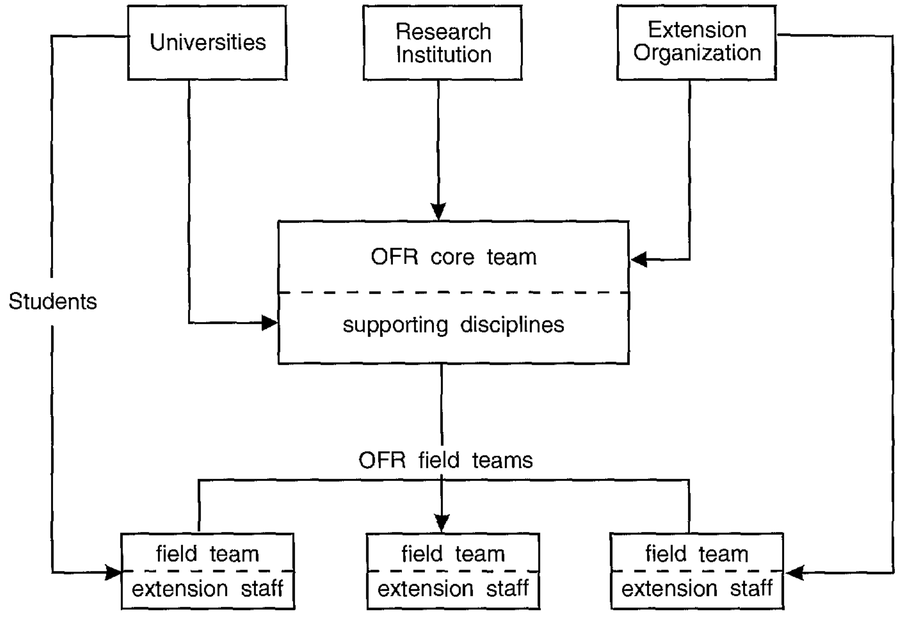


Figure 1.2: Organizational setup of OFR

much to offer from their experience in the community, and they will eventually be responsible for the dissemination of successful innovations. Therefore, the OFR field work should be integrated as much as possible with the activities of the extension or development organization. One or two local extension agents should be associated with the field team, and their supervisor, by virtue of his membership of the senior OFR working group, should ensure the integration of extension agents into the field team.

In practice, difficulties often arise in the area of co-operation between research and extension staff, partly because the latter have other responsibilities as well, and partly because the technology testing and dissemination concept advocated by the extension organization is rarely the same as that of the OFR practitioners. Care should be taken to ensure that the responsibilities of each group are clearly defined. As a general rule, the senior extension officer should share the responsibilities for the OFR program with the scientists, and the extension agents in the field team should share responsibilities for trial supervision and data collection (Eremie et al., 1991).

The best chances of fertile co-operation result from clear contractual arrangements between the research station scientists and the extension or development organization. In such an arrangement, the development organization is the demanding party and the research institute is the supplier of research services. Ideally, the former would provide funding for the services of the latter. This would maximize the development organization's sense of 'ownership' of the OFR program and its results.

Trial sites: scattered or clustered?

In the next chapter, we will discuss the delineation of target zones and the choice of research locations in some detail, but we are concerned here with organization and logistics. Trial sites must be representative of the target zone, and the conventional approach has been to scatter testing (or demonstration) sites across the target zone. We will see later on that there are no strong scientific arguments for this approach. Scattered sites are difficult to monitor, and the amount of travel quickly becomes prohibitive.

We would therefore strongly recommend "clustered sites", located in a "pilot research location", consisting of one or several adjoining villages and hamlets which are representative of a major target zone.

The distance between any two testing sites should not be more than 5 kms. In that way, the whole "pilot research location" may be traveled in one day by field staff on bicycles or mopeds, and this would also save time for supervising staff on their frequent monitoring tours.

Chapter

2 Initial Characterization of Target Zones and Choice of Pilot Research Locations

Introduction

On-farm research is carried out in carefully chosen "pilot research locations" which are representative of a well-defined target zone. The first task of a research center's OFR core group is therefore to define major target zones within their center's mandated region. An OFR working group is assigned to each zone, and the members then choose representative research locations for their field work. We have demonstrated that the criteria for defining target zones depend on the research institute's mandate, but we will assume that most readers are dealing with regional research mandates and that their OFR is of the multiobjective type. In this case, target zones will be delineated within the center's mandated region on the basis of similarities in climate, soil classes, population density and dominant cropping systems. Similar zones would be expected to face similar constraints to agricultural production, and to have similar opportunities to overcome them. The working hypothesis is that the performance of the innovations will be similar across the target zone, and the chances that they will then be adopted by farmers will also be similar.

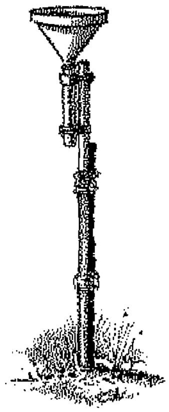
Most research institutes have a research mandate for a large region where several more or less homogeneous target zones can be distinguished. It is probable that some zonation will have already been carried out in the past, but the OFR core group needs to consider whether this is adequate for the purposes of OFR.

In this chapter, we will give an overview of the methods used in zonation and in the choice of representative research locations. In the following chapters, we will give more detailed guidelines for data collection, analysis and interpretation.

Delineating target zones and choosing research locations[1]

Zonation is best done in a stepwise fashion. Initially, a crude zonation is made on the basis of secondary data for climate, soils, population density and any other factors where data of this kind are available. The zonation is then validated through an informal zonal field survey, which will include field observations on major crops, cropping patterns and production constraints.

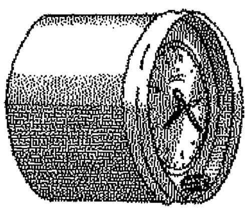
Collection and analysis of secondary data



In the tropics, the overriding environmental factors affecting agricultural production are rainfall, with its seasonal distribution and yearly variability, and altitude. A first zonation can be made on the basis of mean monthly rainfall patterns alone, and this has been done for most countries. There are various ways to characterize rainfall regimes, and perhaps the most agriculturally relevant criterion is the number of growth days. This is defined as the number of days in a year that the rainfall exceeds 50% of potential evapotranspiration. Numerical examples will be given in the next chapter.

For altitude, a zone can roughly be characterized as lowland (<800 m above sea level), mid-altitude (800–1,600 m above sea level) or high altitude (>1,600 m above sea level).

Within a given zone, differentiated on the basis of rainfall and altitude, there may be major differences in soils and population density which would require a further subdivision.

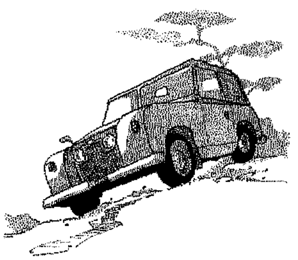


Secondary information on a regional and country scale can be found in maps for precipitation, topography, vegetation and soils. Much of this information is currently being assembled in so-called geographic information systems (GIS). These computer-based systems, if available, can be used to facilitate the team's preliminary zonation.

1. We use the following terminology to distinguish different geographical levels in OFR: (i) 'site' stands for a single field, (ii) 'farm' is the collection of fields belonging to a household, (iii) (research) 'location' is a village or cluster of villages where OFR is carried out, and (iv) 'target area' or 'zone' is the wider area for which the research locations are representative.

It is likely that a particular combination of climate, soils, population density and market access will correspond with one or more typical cropping patterns. We would, therefore, expect that zones which differ as to environmental parameters and population criteria also have different cropping patterns. Information on cropping patterns may sometimes be obtained from secondary data, but field verification must be obtained by means of an informal zonal survey.

Informal zonal surveys



The subdivision of the institute's mandate region into homogeneous target zones on the basis of secondary data is only preliminary. A field survey must then be carried out to verify the assumptions. It may not be feasible to survey the entire mandate region, so the institute must decide at this stage in which of the preliminary target zones it will conduct its on-farm research. The choice would depend on the institute's priorities, for example, 'problem zones' or 'high-potential zones'.

An informal zonal survey is recommended in order to validate the homogeneity of the chosen target zones and to obtain basic information quickly on the major characteristics of the local farming system and its constraints. Village-level group interviews by multidisciplinary teams are widely used for this purpose.

At least 20 villages should be randomly selected across the target zone in consultation with the extension service. Care should be taken to select a truly random sample and not to bias the sample towards villages with easy road access or with extension posts.

Initial contacts with the village community should be organized through the local authorities by the extension service. A day and a time should be set for the interview at the farmers' convenience. The OFR team will prepare a checklist beforehand which provides a guide to the discussion in all the villages and which covers the relevant agroecological and socioeconomic aspects. The village-level group interviews should not exceed two hours, and can be done during the non-cropping season, when farmers and researchers are not so busy in the field. The process of the interview is similar to the one described in chapter 3 under "The informal diagnostic survey". Items indicated in Table 3.1 in the column "Group discussion" can be included in the group-level discussion, although in less detail than in a location-specific field survey.

Choosing research locations

Once the target zones have been delineated and broadly characterized, one, or at most two, representative locations for technology testing must be chosen in each of the target zones where OFR is to be conducted.

An overriding criterion for the choice of research locations should be the presence of a strong extension or development organization with whom the research group can establish a firm contractual partnership or, even better, where there is an effective demand for research services. Without a strong partnership with development, OFR cannot be effective.

In the previous chapter, we recommended clustered, rather than scattered, testing sites for logistical reasons. There are also good scientific grounds for choosing relatively small compact research locations, consisting of a few villages and hamlets. If the target zone is sufficiently homogeneous, the differences between farmers and fields within a location are usually much greater than those between averages of different locations. In other words, differences between farmers across locations are probably similar to those within locations. If the research location is carefully chosen, most of the significant variations of the target zone may be represented within the research location.

If the team feels that the target zone is not sufficiently homogeneous to be covered by this hypothesis, then the zone may be subdivided into two subzones, each with a clustered research location. When choosing representative pilot locations, care should be taken to see that they cover most of the variability of the target (sub)zone, such as differences in access, distance from roads and markets, small-scale soil variations and population density. The team may now be confident that the findings in the pilot locations will also apply across the target (sub)zone (Fig. 2.1).

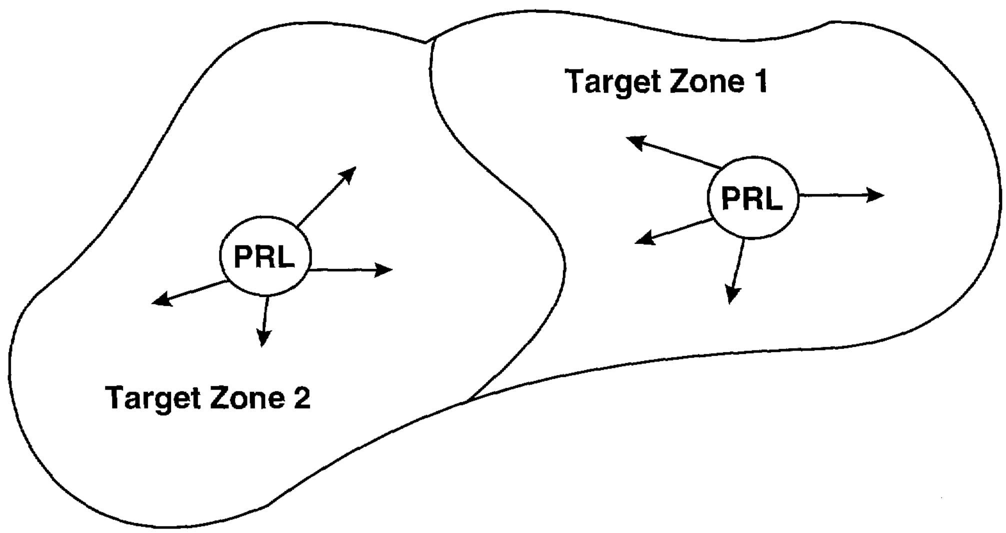


Figure 2.1: Target zones with their representative pilot research locations (PRL). Arrows indicate assumed applicability of the results.

Chapter

3 Informal Diagnostic Survey of the Pilot Research Location

Introduction

Secondary data and a survey of the target zone provided the basis for the choice of representative 'pilot research locations'. More detailed information on the pilot areas will be needed in order to define research priorities and can be collected by means of an informal diagnostic survey by the OFR team responsible for the target zone. The survey consists of direct observation and interviews which bring to life the problems farmers face as well as the opportunities which exist for improvement. Moreover, the team-building element of an exploratory survey is valuable and justifies the investment in time and energy.

The team should look at the farm as an integrated system which interacts with the physical and institutional environment. The diagnostic survey technique is a good tool for developing the necessary insights into how this integrated system operates. The informal diagnostic survey concept was introduced by Byerlee and Collinson (1980), Hildebrand (1981)—who called it 'sondeo'—and Rhoades (1982), and it was further developed by many workers in Africa, Latin America and Asia. The term rapid (or participatory) rural appraisal (RRA or PRA) is being used increasingly instead of diagnostic survey. This reflects the increased emphasis on farmer participation in the collection and interpretation of information (e.g., Ashby, 1990; Lightfoot et al., 1988; Rhoades, 1982, 1994).

The farm as a system

A farming system is the result of all the decisions made to produce output that supports the farm family. 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 any risks that endanger them.

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.

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 prices of outputs and inputs, and it 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 location: credit and marketing conditions; extension services; property rights to land, water, trees, pasture; as well as seed distribution channels, 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.

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.

The informal diagnostic survey

At first sight, land use in Africa may seem impossibly complex and sometimes even disordered, but those who have taken part in informal surveys have always found that the structures gradually take shape, become subject to analysis and reveal previously unsuspected wisdom on the part of the farmers who collectively contributed to them.

Through the survey, the team tries to understand the system, its constraints and potentials in an intensive, informal way, combining field observations, discussions and interviews with farmers.

A single survey allows only an incomplete assessment of a farming system, but from it a first set of objectives can be formulated for field testing and further studies. Subsequent intensive contacts with farmers involved in the testing will improve insights into the farming system.

The diagnostic survey is a critical phase in OFR and all the members of the zone's OFR team should participate, including the field staff. Consider inviting a few additional persons with specific expertise which is not available in the team. A "critical outsider" from a national or international institute with experience in exploratory surveying could be 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 total of seven to 10 days for the survey is adequate. The best period is in the middle of the growing season, when the crops are well established. The survey is informal and the use of questionnaires is not recommended. The team will, however, develop a checklist to keep track of the topics for discussion and exploration. An example is given in Table 3.1.

For recording physical information on individual fields, use a simple data sheet (Fig. 3.1) and complete one for each visited field. Without it, discussions often stray into general topics and by-pass vital information. Carry field notebooks, a soil auger, magnifying glasses and sample bags for plants and soil.

Table 3.1: Sample Checklist of Information to be Collected during the Field Survey

	Field visit	Group discussion
General features of the location		
Ethnic groups, traditional hierarchy, religions		x
Physical infrastructure		
Accessibility, availability of transport		x
Location, frequency, role of markets		x
Schools, water supply, electricity, medical services		x
Climate		
Farmers' perception of rainfall and consequences for cropping	x	x
Vegetation		
Vegetation type (*data sheet, Fig. 3.1*)		
Land, soil and water		
Land form, land types, soils (*data sheet, Fig. 3.1*)		
Soil fertility, erosion	x	
Seasonal availability of water		x
Cropping patterns and land use		
Availability of land	x	x
Distribution pattern of crop fields, fallow fields, virgin bush (*village maps, transects*)	x	x
Number, size and location of fields per household	x	
Accessibility of fields	x	
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	
Rank varieties for importance, their advantages, disadvantages	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 seed/planting material	x	
Use of organic, inorganic fertilizers, household refuse, agrochemicals	x	x
Farm implements	x	
Distribution of labor, peaks, slack periods and bottlenecks	x	x
Estimates of yields	x	
Crop disorders		
Weeds, time and method of control	x	
Pests and diseases and their control	x	
Nutrient deficiencies	x	

Table 3.1: Sample Checklist of Information to be Collected During the Field Survey (contd.)

	Field visit	Group discussion
Postharvest activities and consumption		
Storage facilities (household and community)	x	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
Time of fodder shortages		x
Economic and institutional environment		
Availability and origin of items not produced locally (*market visit*)		
(Urban) migration		x
Availability and prices of capital goods, inputs (*ask traders, distribution centers, etc.*)		
Sources and principal usages of cash	x	
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
Sources and cost of labor, family and hired	x	
Division of labor and decision making by age and gender		x
Health conditions		x
Educational level of farmers	x	
Festivities		x

Before the survey starts, the village leaders should be informed about the date and the purpose of the survey. They are requested to invite a cross-section of the community to participate, avoiding the preselection of progressive or leading farmers.

During the whole process, the team should consider themselves as guests in the farmers' environment, respecting the cultural habits in the village, avoiding socially sensitive issues where possible and not making promises which they will later be unable to fulfil.

Individual Field Record

Date: . . . . **Record nr:** . . . .

Farmer's name: . . . . **Recorder:** . . . .

Age: . . . . **Village:** . . . .

Gender: . . . . **Distance from Village:** . . . .

1. Surrounding vegetation (circle).

dense forest, sparse forest, savannah

2. Field history.

Year	Crops grown or fallow		Fertilizer applied
	1st season	2nd season	
1995			
1994			
1993			
1992			
1991			

- When was the field cleared from long fallow? ....
- How many more crops will be grown until the next fallow? ....
- How long will the next fallow be? ....

Figure 3.1: Sample data sheet for field-level data collection (page 1)

3. Field dimensions and lay-out.

- Draw outline and pace the field, show crop arrangements and spacing.

- Farmer's estimate of field size. ....
- Place in the topography (circle).

  flat land, hillcrest, upper slope, middle slope, lower slope, valley bottom
- Percentage slope. ....

4. Soil (auger to 1m if possible in a few locations).

	Textural class[1]	Color	Gravel	Hardpan /rock
Top soil (0–15 cm)			yes / no	yes / no
Subsoil (15–30 cm)			yes / no	yes / no
> 30 cm			yes / no	yes / no

[1] S = sandy; L = loamy; C = clayey

Figure 3.1: Sample data sheet for field-level data collection (page 2)

Interviews and field visits

Upon arrival in a village, meet with the village head and farmers and explain the purpose of the visit. Ask farmers to help draw a map of the village territory, showing compounds, cropping areas, communal land, valley bottoms, etc., and where they are located. Ask general questions about major crops and cropping patterns. The sample checklist (Table 3.1) gives suggestions about the type of questions which are best asked during these group discussions. Draw a few transects on the village map which cut through the major land-use types (for an example, see Fig. 4.12 in Chapter 4). The meeting should not last for more than an hour.

Split into subteams (two or three members each), assign one of the transects to each, and start the field visits, each subteam being accompanied by a few farmers, preferably those who have crop land along the subteam's transect. Most of the time should be spent in the field, discussing and gathering information about crops and livestock production and other activities. Use the map and the transect to note general information about land use as the group walks along the transect (see Fig. 4.13 in Chapter 4). The checklist suggests which issues may be discussed with the individual farmers, while the field data sheets are used for recording information on specific fields.

After the field visits, reassemble in the village and discuss the findings with the entire group of farmers and inspect village installations. Keep the interviews as informal and free-flowing as possible. Whether women are interviewed separately or simply as part of the farmers' group depends on the cultural setting. Sometimes, only female team members may be able to have access to women. In some areas, migrants may form an important separate group with different farming practices and constraints. Care should be taken to obtain information on them.

During this round-up meeting, ask the group of farmers to list important constraints limiting agricultural production. Make sure that not too much emphasis is given to constraints which research cannot address ("lack of cash", "prices of farm produce too low"). The constraints may be ranked with a semiquantitative matrix-ranking method (Ashby, 1990). Assume, for example, that there are 20 farmers in the group and that four major constraints have been listed. The farmers are first asked to pick the most important constraint. Into cell A1 of Table 3.2, put the number of farmers who picked constraint A as the most important, into cell B1, those who picked constraint B, etc. Next, ask the farmers to pick the second most important constraint, and so on. The completed matrix could look like Table 3.2. The fifth column gives the sum of the products of the number of farmers and their rank. The lower this number, the more important the constraint. The last column is the overall ranking. In this way, an impression is gained of the perceptions of the group of farmers, and this may give different results on different days.

Table 3.2: Imaginary Example of Constraint Ranking by a Group of Farmers; Number of Farmers Ranking a Constraint First, Second, Etc., and Final Overall Ranking

	Individual rank					
Constraint	1	2	3	4	Number x rank	Overall rank
A	4	1	10	5	56	3
B	10	3	6	1	38	1
C	3	14	1	2	42	2
D	3	2	3	12	64	4

Spend at least two successive days in every village. During the first day, the sample of farmers tends to be biased in favor of the more prosperous and influential ones, and the team gets a distorted picture as to the availability of land, the duration of fallow periods, the importance of cash crops, etc. On the second day, this picture can be corrected and the participation, in particular of women, may increase.

In a survey in northern Ghana, for example, the group of farmers interviewed on the first day stated that they could expand their farm if they wished to. The group on the second day could not. The chief had invited well-to-do farmers the first day, but the team had insisted on seeing a group of small farmers the following day.

Guidelines for observations and discussions

The following hints to guide observations and interviews may be helpful. We have followed the order of the checklist, but the actual questions and observations may be made in any order.

Climate and vegetation

Questions should relate to constraints on cropping (short season, dry spells, late start). For example, "Was last year a good season. Why or why not?" Farmers may make a distinction 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 the 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 before. Farmers may have an objective basis for this belief, even if the rainfall pattern itself has not changed. Where intensive cultivation and the physical conditions of the soil have led to more run-off and reduced water retention, the available moisture may well have decreased.

Land, soil and water

Crops are good indicators of soil conditions. In the Alfisol belt, cocoa plantations may be 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 precautions, such as mulching or manuring. Cocoyams *(Colocasia esculenta)* are often (but not always) grown in soils that are temporarily water-logged. Groundnuts in the savannah are often grown on light-textured soil. Note farmers' indigenous soil classification, its classification criteria and relation to cropping patterns. To indicate the position of crops in the topography, the scale used must be large enough. A catena or toposequence will typically cover in the order of 500–1000 m. 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), provided the team agronomist has some experience in 'feeling' the 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 having them analyzed.

Cropping patterns and land use

The key to obtaining a good description of land use is to identify the principal cropping patterns and sequences. Be parsimonious in distinguishing different patterns. It is common to find three or four for the main upland outfields plus perhaps one or two more special patterns associated with distinct land types, such as valley bottoms or homestead gardens. What at first sight may seem to be a separate pattern is often a variant of a general type.

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 savannah 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. The field data sheet (Fig. 3.1) may be used to make records of individual crop fields.

Do not place too much emphasis on minor crops or on minor variations in spatial arrangement. Try to identify the main species. If, for instance, a farmer 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 two or three major crops. Minor crops will then be added and each field may contain a different selection.

Different crops in the same field may belong to different family members. In eastern Nigeria, for example, cassava is interplanted by women in yam fields which belong to the men.

Enquire about land availability, for example: "Could you expand your farm? Has the fallow period always been this number of years?". A shorter fallow period may indicate that land availability is declining, but it can also mean that farmers are not able or willing to clear (secondary) forest. Shorter fallow periods may have led to problems with soil fertility.

Observation can support the answers obtained from farmers. Weedy fields may 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 scarce.

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.

Questions like "Why did you choose this cropping pattern for this plot?" will give an 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 as far as the last fallow period, or for about five years in permanently cropped land (data sheet, Fig. 3.1). Continue by asking what the farmer plans to plant next year and how much longer he or she expects to use the field before it becomes fallow. "How long will it be fallow? Who will use the plot after the fallow period?"

To make a rough estimate of 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 with an area equal to the sketched plot.

Ask farmers about the number of cropped fields they have and which crops they grow on each, in order to estimate the size of their holdings and the importance of the different cropping patterns. Try and visit a number of plots with different cropping patterns in proportion to their importance.

Ask questions about changes in cropping pattern and major crops. Which crops have declined, which have increased in importance and why?

Crop varieties

Question individuals about the variety of every species preferred for each cropping pattern (this can sometimes be important). For instance, vigorous varieties may be preferred for sole cropping if they would be too aggressive in mixtures. Ask the farmer to show any different varieties grown and how to recognize them. Questions about the utilization of the product from the different varieties will also arise naturally at this point. Ask farmers to rank varieties in order of importance and to give the major advantages and disadvantages for each.

Cropping operations and crop calendars

For each cropping pattern, obtain information on the cropping techniques, timing of operations, varieties, etc. Investigate the range of dates for sowing, weeding, staking, harvesting for each item and the relationship of these dates to operations carried out on items sown earlier; for instance, the second crop may be sown during or immediately after the weeding of the first (data sheet). Sowing and harvest dates can be estimated by visual observation of the crops and can be confirmed by the farmer. The farmer is likely to give a time period, "four weeks ago", or in relation to an event, "after the third rain" or "before a particular festival". Find out what criterion the farmer used to decide when to start the operation (rainfall event, number of weeks, etc.).

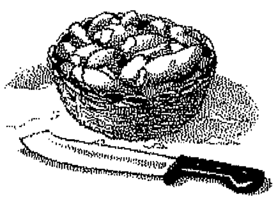
Look into the range of stand densities and the spacing and arrangement of each item. Record information on the data sheet and make a drawing. Questions will naturally follow such as "Why do you use such big heaps in this field?" or "Why is this crop sown at the side of the ridge?" Make it clear to farmers why you are asking these questions.

Inputs and yields

Find out how farmers obtain seed and planting material. In some areas, maize seed is purchased in the market every year because of serious storage problems. This may hinder the introduction of new maize varieties, unless a reliable seed supply can be introduced.

Find out how much and which types of manure and fertilizer are used as well as the techniques and dates of application (data sheet). Assess the tools and techniques used in each operation and record the person(s) normally doing each task (sex, age, relationship to farmer). Obtain some indication of the labor requirement per hectare or for a typical plot size. Also ask about fees for labor, noting any differences according to the operation performed. Find out whether laborers are given meals as part of their wage.

Record special techniques to deal with specific weeds, other crop-protection problems, techniques for providing trellises for climbing crops, and for minimizing labor inputs. Find out why the farmer does or does not use these techniques.

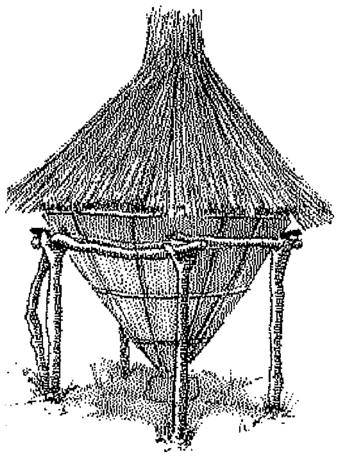


Sometimes yields can be estimated visually if the crop in the field is close to harvest. If not, then the farmer can be asked what yields are expected from the crops. Get estimates of the capacities by weight of the units (bags, bundles, calabashes, etc.) familiar to the farmer. However crude these estimates, they are likely to be better than estimates from official monitoring services.

Crop disorders

Record the important pests and diseases. Investigate whether farmers recognize their symptoms and practice any measures to reduce crop losses (roughing, adjusting sowing dates). Traditional cropping patterns have evolved in answer to problems caused by local pests and diseases. Even the farmers may not be aware of why their ancestors have long since abandoned certain cropping possibilities or crop varieties. The latent pest and disease problems may only become apparent when a new variety or technique is tested or adopted on a wide scale. Some disorder may appear to which local varieties have in-built tolerance or resistance. A good example is the lax-headed late sorghums of the Guinea savannah: they largely escape the head bug and grain mold problems of the new compact-headed, early varieties.

Postharvest activities and consumption



Pay special attention to the postharvest activities such as seed preservation, marketing, processing and storage. Describe individual and community storage methods. Find out what the allowable storage period is, what kind of problems occur with storage and insects, and what techniques are used to minimize losses. Distinguish between produce and seed storage. Investigate whether there are differences in storage problems with crops harvested in different seasons. In southwest Nigeria, for example, the moisture conditions of early season maize is often unfavorable for prolonged storage, compared with second-season maize.

With some crops, farmers can avoid storage problems by leaving the crop in the field, in particular cassava. There are varietal differences in tolerance to prolonged "in-field storage".

Livestock

Note the number of animals owned by a household, sources of feed and provisions to avoid damage to crops (e.g., unplanted buffer zones around villages, village regulations, tethering). Is the dung utilized? Who is responsible for feeding?

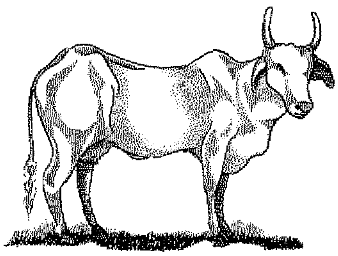
For large animals, two types of livestock-crop interaction may be identified in West Africa. In the first, the livestock are peripheral to the cropping and are mostly owned, or at least herded, by members of an ethnic group other than the crop farmers.

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

Peripheral livestock systems

Questions that are appropriate for the farmer include the following:

- 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 grazing problems for late crops such as cotton? Do farmers harvest and carry home residues such as groundnut and cowpea haulm? If so, what do they use the residue for? 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 the following: are the cattle herded and by whom; where are they corralled; 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. Analyze the time of fodder shortage (if any) and try to obtain information on health problems in cattle and veterinary remedies.

Draft animals

In some areas, animals (camels, bulls, oxen, donkeys) are used both for transport and for tillage. Look into patterns of ownership and hiring and the charges levied. Describe tillage tools and carts. Ask about dry-season feeding and note opportunities for introducing improvements at the beginning of the rains when the animals are in poor condition.

The economic, institutional and social environment

Ask about credit opportunities, private moneylenders and the existence of co-operatives. Frequently, farmers form local credit co-operatives; find out how they work.

Record the availability of any physical inputs which may be supplied by private companies or individuals or government agencies. For machinery, record the location of the supply sources as well as make, size and age. Enquire about the hectarage covered per year or per season and the downtime due to repairs.

Assess the available infrastructure, the goods available in the market, the nutritional state of the people, especially women and children, as well as clothing, wrist watches, bicycles, motorbikes and cars. The team members who visit 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 and corrugated iron roofs indicate prosperity.

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 men. The right to farm the land may not include the right to plant trees. In most cases, the village chief allocates land to migrants. However, the land may be far from the village or of low quality.

Distribution of labor by age and gender within families is influenced by custom. 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?

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

Visits to markets and traders

Much information can be collected from other sources such as local traders and transporters, local markets, agroservice 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 or for other reasons.

Team discussions and brainstorming

At the end of each day, discuss the day's findings, using the checklist to note topics that were insufficiently covered. Keep notes of the discussions. The rapporteurs will later be responsible for drafting the corresponding chapters of the final area report.

When the survey is about halfway through, spend a day discussing preliminary findings, especially any constraints and opportunities for improvement which have been observed, 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. These target groups and land types may later require different innovations.

During the remainder of the survey, test assumptions and hypotheses and discuss them with groups of farmers so that you can focus on addressable problems and opportunities.

Immediately after the survey, analyze the findings in a few round-up meetings and draft the following:

- a typology of farms and fields: classify the farms, perhaps according to size, degree of market orientation, etc. Note the criteria that differentiate the farm types or field types requiring different innovations.
- an analysis of constraints and opportunities: identify, list and prioritize problems in the farming system and the environment that limit productivity and for which solutions may be sought (see chapter 4 for analytical methods). Also, describe those features of the system that could be better exploited to increase productivity.

Return to the villages, present the preliminary findings to the farmers and invite their comments. This will allow the team to confront the farmers' perceptions and priorities with their own.

Writing the area report

We strongly recommend writing a formal report on the secondary data analysis and diagnostic survey. A first draft should be ready before the first on-farm trials are designed.

The next chapter gives guidelines and techniques for analyzing and reporting the information. The chapter may at times appear too ambitious, and the data may not be available to carry out some of the analyses. In that case, do not write more than you really know and leave the gaps for further study later on.

Chapter

4

Analysis and Interpretation of the Survey Data

Introduction

Secondary data in combination with an informal survey provide a basis for understanding the farmers' production system and for choosing appropriate innovations. Specifically, the information should allow the team to :

- *describe the system and understand why farmers have arrived at it*
- *identify both the problems it presents and the opportunities it offers*
- *find solutions which are suited to the environment, compatible with the existing system and geared to farmers' concerns.*

The choice of innovations should follow on logically from the information collected. This requires a systematic approach, whereby both team members and farmers are involved in the analysis and synthesis of the data and in the development of ideas on potentially productive interventions.

This chapter describes some analytical techniques, as well as methods for the systematic use of the information in the choice of innovations.

The physical and biological environment

Climate

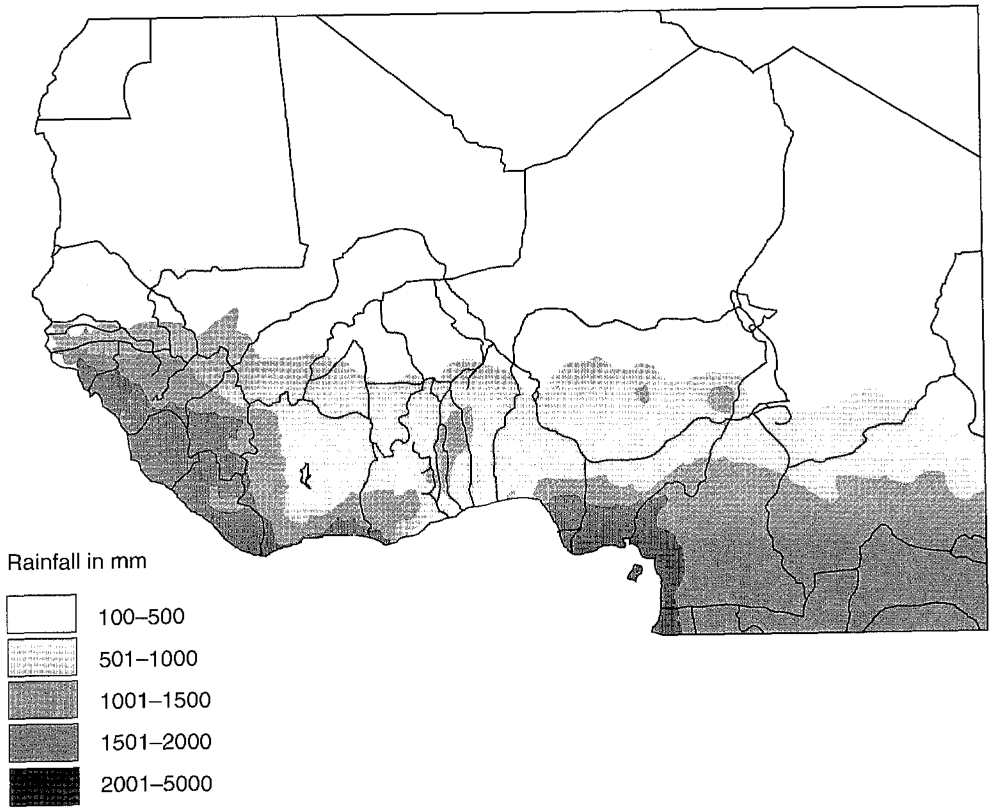
The aim of analyzing the climate is

- to understand why farmers have adopted the crops, cropping patterns and seasonal working patterns observed in the exploratory survey
- to be able to choose improved cropping patterns or practices and crops or varieties suited to the climate

The most important elements in characterizing the climatic conditions of the research area are the components of the water balance, namely rainfall and potential evapotranspiration. Other subsidiary elements are temperature, day length and solar radiation.

Rainfall

An initial orientation can be obtained from a map showing mean annual rainfall (Fig. 4.1), but a more detailed analysis is needed in order to relate cropping patterns to rainfall. The length of the dry season and the reliability of the rainfall are particularly important. Monthly rainfall is published for many rainfall stations, but this period is too long for an analysis of the effect of rainfall for agricultural purposes. If daily data can be obtained for about 15 years, a simple analysis of rainfall reliability can be done. Each month is divided in three periods, 1–10 days, 11–20, and 21 to the end of the month. The rainfall in each period for each available year is added up, resulting in a table of 10-day totals for 36 periods in each of the recorded years. Next, arrange the data for each 10-day period in order of magnitude (Table 4.1). From this table of ranked 10-day totals, find the lower quartile, median and upper quartile rainfall. The lower quartile rainfall is exceeded in 3 out of 4 years (75%), the median in 2 (50%) and the upper quartile in 1 out of 4 years (25%) (Table 4.1). These three statistics represent confidence limits for 10-day rainfall and can be plotted to show trends throughout the year (Figs. 4.2 and 4.3). This rendition of confidence limits has one drawback, namely, that the successive periods are not additive. They apply to each individual period but cannot be combined



Source: Agroclimatology Unit, IITA

Figure 4.1: Rainfall zones for West Africa, 1970-1990

to give the confidence limits for longer periods; this would lead to a serious overestimation of risk. An estimate of potential evapotranspiration, E_t, (see next section) should be superimposed on the graph, which allows an examination of periods with adequate rainfall and risk periods. Since E_t shows much less variation than rainfall, a mean figure is all that is needed, and even 3–4 years' data are adequate.

The analysis can best be done for the most recent period of 15–20 years. If longer series are used, the conclusions may be too optimistic because of the systematic changes in rainfall which seem to be occurring, especially in the northern savannah and Sahel regions (Jagtap, 1995, Fig. 4.4).

An analysis of confidence limits can also be done for monthly rainfall if 10-day totals are not available, but it will not give

Table 4.1: Example of Ranking 10-Day Rainfall Totals for March and April (Three 10-Day Periods Each), Ibadan, Nigeria, 1972-1992. The Ranked Data were Used to Construct the Rainfall Chart of Fig. 4-2

	March			April		
Rank	1–10	11–20	21–31	1–10	11–20	21–31
1	0.0	0.0	0.0	3.8	0.0	1.4
2	0.0	0.0	0.0	6.0	1.4	1.5
3	0.0	0.0	0.8	11.4	5.4	7.8
4	0.0	0.0	1.0	21.8	10.6	14.6
5	0.0	0.0	3.2	22.0	12.7	14.6
6	0.0	2.3	13.1	24.5	14.9	18.4
7	0.0	10.9	20.0	25.1	16.8	24.2
8	0.0	12.0	25.5	25.6	21.4	25.4
9	0.7	14.7	25.6	32.1	23.2	27.2
10	1.0	15.6	29.6	38.5	23.9	27.7
11	2.6	21.6	39.6	42.6	33.8	37.0
12	3.2	27.5	42.4	44.1	35.9	52.4
13	5.4	27.6	48.3	44.2	36.2	57.1
14	13.4	29.3	50.9	55.5	36.4	62.8
15	14.4	35.5	52.9	61.6	38.7	71.2
16	14.5	36.5	54.7	68.9	39.5	77.5
17	26.8	36.6	55.4	69.1	50.6	79.4
18	53.1	54.6	56.3	69.2	54.6	101.5
19	79.5	61.4	58.6	76.6	90.4	119.5
20	93.6	83.4	68.8	118.3	180.5	138.0
lower quartile	0.0	0.6	5.7	22.6	13.3	15.6
median	1.8	18.6	34.6	40.6	28.9	32.4
upper quartile	14.5	36.3	54.3	67.1	39.2	75.9

a good indication of dry spells, nor can the length of the growing season be precisely determined.

Frequently, official rainfall data will not be available or will not span 15-year periods. Rainfall records may be available, however, from extension offices, schools, large-scale farms or plantations and mission stations. Where data for less than 15 years are available, do not try to estimate confidence limits, but show the mean (which, here, is better than the median). If the series

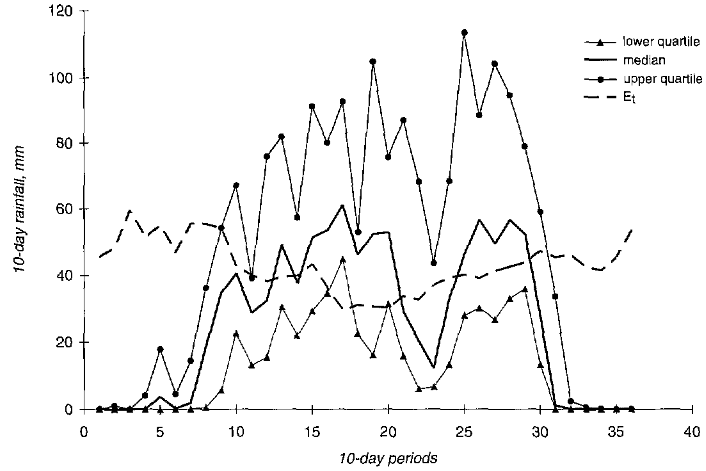


Figure 4.2: Confidence intervals for 10-day total rainfall and average potential evapotranspiration (E_t), Ibadan, 1972–1992

is very short (less than 10 years), the mean 10-day totals may be adjusted, using data from a rainfall station outside the study area, but close enough to have similar annual fluctuations:

$$r' = r \times \frac{d_1}{d_2}$$

where r′ is the adjusted mean for any 10-day period, *r* is the unadjusted mean, d_1 is the long-term mean for the 10-day period at a distant station, and d_2 is the mean at the distant station for the same years as the data which are available within the research area. This will adjust the available data if they were collected in unusually wet or dry years.

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 an adequate estimate of the water requirements for optimal crop growth.

E_t is assumed to be related in a simple manner to potential evaporation (E_0), which is defined as the rate of evaporation

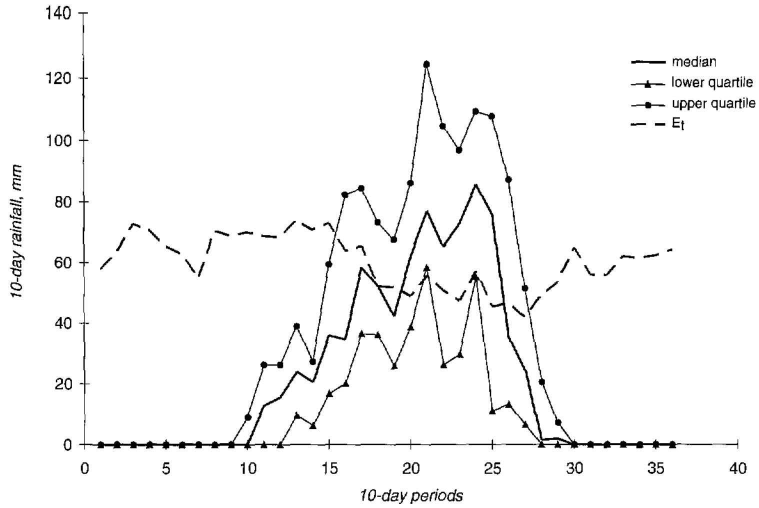


Figure 4.3: Confidence intervals for 10-day total rainfall and average potential evapotranspiration (E_t), Samaru, 1972-1992

from a large open water surface. When consulting published sources, ascertain whether the estimate given is of E_t or E_0. If it is E_0, then multiply by 0.8 to obtain an estimate of E_t. Generally, the published values of E_0 are based on evaporation measured with a US Weather Bureau Class A pan. Class A pan evaporation must be multiplied by a correction factor which has to be determined for each location in order to obtain an estimate of E_0. This factor varies from as low as 0.4 in low humidity, strong winds and in a barren area, to 0.85 for high humidity, light winds and a vegetated area.

Estimates of E_0 based on Class A pan evaporation are often far from ideal, but calculation procedures based on weather data have their own drawbacks, such as data requirements (e.g., Penman) or unreliability. Doorenbos and Pruitt (1975) give a full account of the methods available. If no data are available, an estimate for use in West and Central Africa at sites below 1000 m is given in Table 4.2. A smooth transition may be assumed between the extremes of Table 4.2. These are averages based on average atmospheric conditions. During dry spells in the rainy season, actual evapotranspiration may be up to 30% higher.

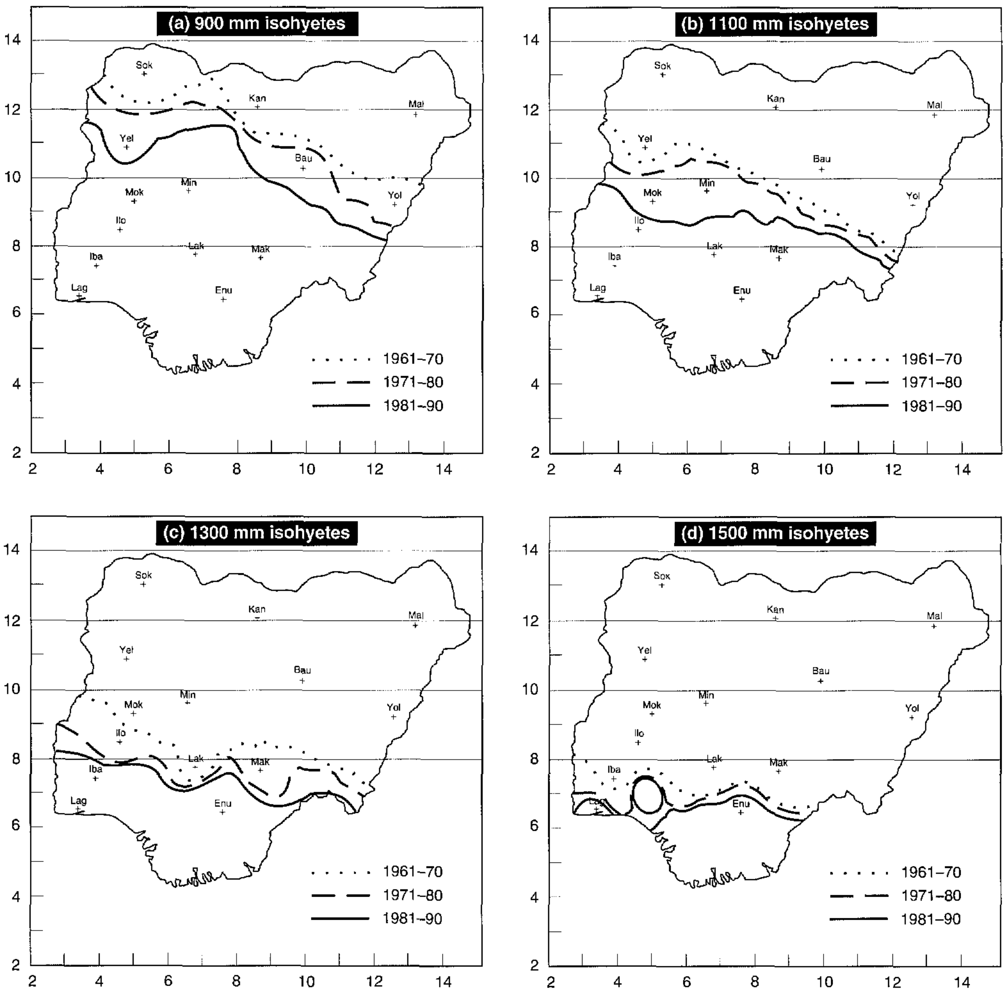


Figure 4.4: Shift of isohyetes in Nigeria in the period 1961–1990 (Jagtap, 1995)

Interpretation of climate data

Diagrams such as Figs. 4.2 and 4.3 help in the understanding of current cropping systems and the design of new ones. When the median rainfall exceeds E_t, crops will not suffer water stress. If the lower quartile falls below E_t, crops will then probably suffer if they are at full leaf canopy or at a sensitive stage of growth. Crops require less water than E_t at the beginning and end of their growth periods. 0.3 E_t may be

Table 4.2: Approximate Potential Evapotranspiration (mm day^{-1}) at Five Latitudes in West and Central Africa for the Driest and Wettest Months (Locations below 1000 m Altitude)

Latitude °N	Driest month	Wettest month
6	4.7	2.7
8	5.0	3.0
10	5.4	3.3
12	5.9	3.6
14	6.5	3.9

used to represent the potential evapotranspiration of bare soil or young crops. 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. We will look at two examples in some more detail.

In the monomodal rainfall regime at Samaru (Fig. 4.3), median rainfall rises to a peak and then falls rapidly. Double (sequential) cropping of unirrigated uplands is generally not possible in such a situation. 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, is available from store and this, together with the remaining rainfall, represents 20–35 days' water supply. This means that the ideal crop would reach physiological maturity between the middle and end of October. It would thus have a total duration of about 140–160 days. Few such ideal crops exist, and a crop mixture or relay cropping strategy is more appropriate for realizing the potential inherent in the rainfall regime. Relay cropping of millet, sorghum and cowpeas, as practiced by farmers, for example (Fig. 4.10), uses the available moisture very well.

In the two-peak category, represented by Ibadan (Fig. 4.2), the option of double cropping is available, and the dry period in August may be helpful in reducing spoilage of the first grain crop (maize). This could be planted by 10 April, earlier in favorable years, and reach physiological 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.

The rainfall is likely to be sufficient for a second crop to be sown immediately after harvest, about 20 August, and this should be physiologically mature by about 15 November and must therefore be of 80–90 days duration.

Although double cropping is technically possible, farmers generally use a mixed cropping strategy, which is probably less risky than growing two crops in sequence. A common mixture 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. It is neither likely nor desirable that such mixed cropping patterns be totally replaced by two single crops.

Farmers' perceptions of the rainfall and climatic change

Analyze how farmers perceive rainfall, how it limits their cropping options, 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 patterns. Farmers almost invariably complain about early-season drought, especially in savannah environments. This is at least partly due to the farmers' practice of starting crop planting with the first rains, thereby accepting the risk of crop failure. The team should also be aware that farmers may interpret plant wilting as due to water shortage, while, in fact, it may be caused by other factors. A case of early-season drought symptoms in maize in the Guinea savannah, for example, was found to be caused by root-feeding insects such as millipedes.

Other climatic factors

After rainfall, temperature is the most important climatic variable for crops. Temperature variation is much less localized than rainfall, and the research station will usually have a temperature regime similar to that of the research area. 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.

Many crops grown at latitudes of more than 5° from the equator are sensitive to day length 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

Vegetation is a useful guide if expertly interpreted but is often misleading. Vegetation maps have largely been based on foresters' assessments of the climax. Today, climax vegetation is 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.

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, short savannah species can survive only if they are fire-tolerant.

Despite the virtual disappearance of the vegetation as traditionally described, some generalizations can be made.

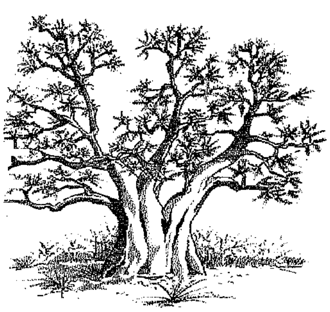
In the forest zone of West Africa, mean annual rainfall exceeds 1400 mm, is distributed with one or two peaks and falls between March and November. In bimodal rainfall regimes, forest may persist at an annual rainfall of as low as 1250 mm. In unimodal areas, when the dry season is longer, the lower limit is at about 1350–1400 mm. 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 wetter parts. *Chromolaena odorata* ('eupatorium' or Siam weed) has invaded fallow land all over the West and Central African humid zone.

In some high rainfall areas, human intervention has resulted in the almost complete disappearance of the forest, e.g., in eastern Nigeria, central Congo, and the Bandundu area of Zaire. Fallow vegetation is dominated by tall grasses *(Panicum, Rotboellia, Hyparrhenia)*, but may eventually be replaced by speargrass *(Imperata cylindrica)*, which makes farming practically impossible. There are signs in many other areas of a shift in this direction due to farming practices which involve the complete removal of trees.

In the savannah-forest mosaic and derived savannah found in areas with 1250-1400 mm mean annual rainfall (uni- or bimodal), forest outlayers persist on sites less prone to fire, while the savannah areas are similar to the southern Guinea savannah.

In the southern Guinea savannah, mean annual rainfall ranges from 1100 to 1300 mm and falls from April to October. The two rainfall peaks tend to coalesce. Vegetation is fire-tolerant; locust bean *(Parkia clappertoniana)* and sheabutter trees *(Butyrospermum parkii)* are preserved in cultivation, while *Lophira lanceolata* and *Daniellia oliveri* trees and tall grasses of the genera *Hyparrhenia, Andropogon* or *Pennisetum* dominate the fallows.

In the northern Guinea savannah, mean annual rainfall is from 800 to 1100 mm and falls from May to October. Locust bean *(Parkia clappertoniana)* and, to a lesser extent, sheabutter *(Butyrospermum parkii)* and tamarind *(Tamarindus indica)* trees are preserved in cultivation, and *Isoberlinia doka* is common in the fallows. The tall grasses are found but are often heavily grazed, and smaller species like *Digitaria ciliaris*, become more important.



In the Sudan savannah, 500–800 mm falls from June to September. Locust bean and baobab *(Adansonia digitata)* are left standing, and uncultivated land is often dominated by *Acacia* and *Combretum* thorn bush. The species of grass from the genera *Digitaria, Eragostis, Cenchrus* and *Pennisetum* are short and, because of the grazing pressure, are rarely allowed to develop.

In the Sahel, which has less than 500 mm mean average rainfall, the season is short, rain being confined to July and August in some years. There are few trees, with acacia thorn bush and very short grasses dominating the uncultivated land.

Besides farming practices, other factors which can modify the vegetation are

- topography, where valleys usually support richer vegetation than the water-shedding uplands
- soil type, where the soils with better water retention favor richer vegetation

Local variations are of paramount importance in descriptions for OFR. Therefore, report what you see rather than what the maps tell you.

Describe the height and density of trees and scrub (bushes) and the luxuriance of the herbaceous layer. Confirm any suspected differences in the soil by taking auger samples. A treeless, grass-dominated vegetation sometimes indicates seasonal water logging or a high water table, and very sparse vegetation indicates shallow soils where an iron pan or rock formation comes close to the surface.

As with climate, add notes about farmers' perceptions of the vegetation and particularly the signs they look for in fallow vegetation. Also relevant 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.

Soil classification and physical soil properties

In order to get a general idea, consult a small-scale soil map that shows the dominant soil types, but keep in mind that they do not show local variations such as alluvial soils along rivers and other small-scale differences.

The three most generally used soil classification systems are the USDA Soil Taxonomy, the FAO soil classification and the French INRA/ORSTOM system. Table 4.3 gives some indicative characteristics for the highest level (soil orders) in the USDA Soil

Table 4.3: Major Soil Orders in Africa According to the USDA Soil Taxonomy, Correspondence with other Classifications and Broad Characteristics

Soil order	Ecology/distribution	Corresponding units		Soil characteristics
		FAO/UNESCO	INRA/ORSTOM	
Oxisols	Mainly humid/subhumid climates, "stable" landscape	Ferralsols	Sols ferralitiques fortement désaturés	Strongly weathered; uniform; deep and porous
Ultisols	Mainly humid climates, less stable landscapes	Acrisols, Dystric Nitosols	Sols ferralitiques moyennement désaturés	Coarse to medium surface layer, clayey B-horizon, exchangeable base saturation <50%: generally acidic (pH<5)
Alfisols	Wet-dry climates, savannah and forest-savannah 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 savannah with plinthite and hardened laterite; pH 5.5-7.0
Entisols and Inceptisols	Occur in association with other orders in both savannah 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 savannah; 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

Taxonomy with the approximately equivalent units in the other two systems. The simplified USDA Soil Taxonomy map of Africa of Fig. 4.5, for example, does not show the fairly extensive Vertisol areas occurring in the Republic of Benin, Togo (Depression de la Lama), Ghana (Accra plain) and around Lake Chad. Even where one soil order such as Alfisols is dominant, several other soil orders are always associated with them in a toposequence (Fig. 4.6). For more detailed information in a given area, large-scale maps at 1:250,000 to 1:50,000 are required.

For an initial assessment, the broad characterizations must be supplemented with additional information. The fertility capability soil classification (FCC) (Buol and Couto, 1981; Sanchez et al., 1982) provides 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:

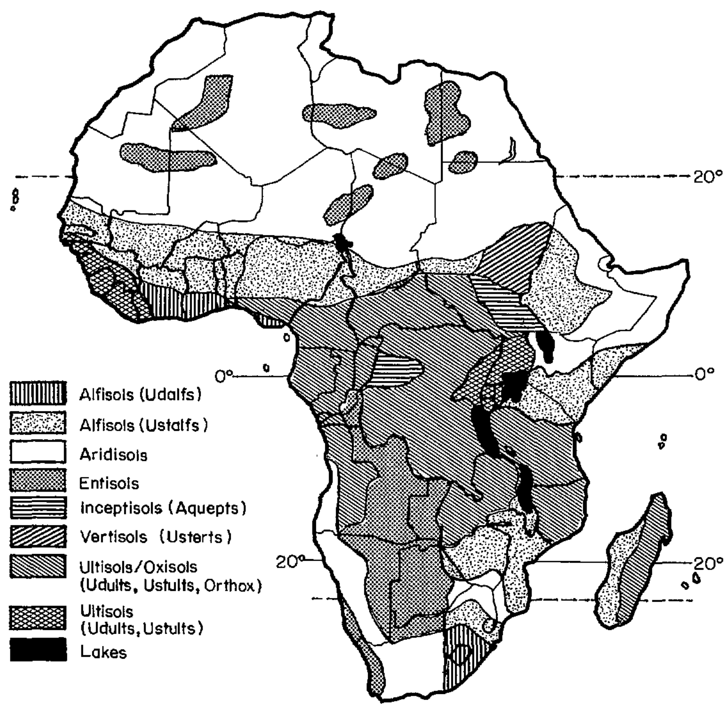


Figure 4.5: Soils of tropical Africa (adapted from Aubert and Tavernier, 1972, by Kang and Osiname, 1985)

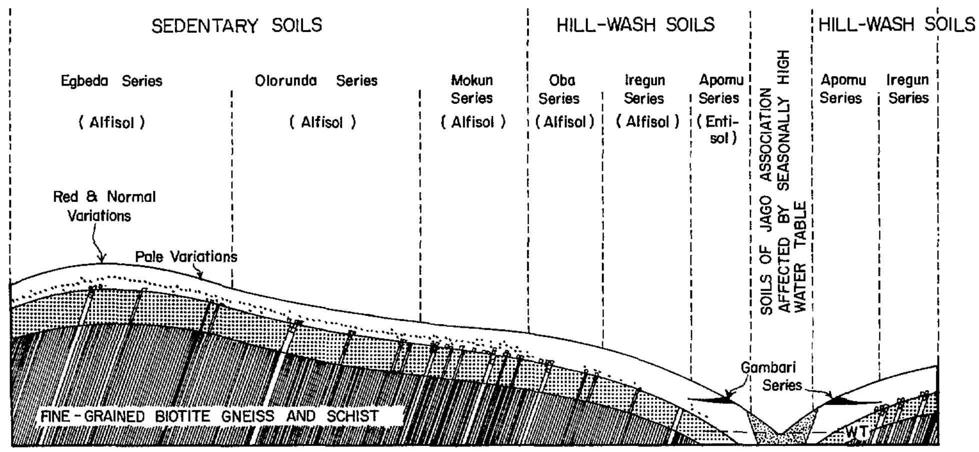


Figure 4.6: Topographical sequence of soil series in an Alfisol landscape ("Egbeda association"). Adapted from Smyth and Montgomery, 1962

- a characterization of topsoil (0–20 cm) and subsoil (20–50 cm) texture
- condition modifiers that indicate limitations, mainly in fertility

The system has been adapted to conditions in tropical Africa by Juo (1979) (Table 4.4). In FCC, the textural class of topsoil (0–20 cm) and subsoil (20–50 cm) are each represented by a capital letter, as follows:

S = sandy soil (> 85% sand)
L = loamy soil (< 35% clay)
C = clayey soil (> 35% clay)

The presence of quartz or ironstone gravel or other root-restricting layers in the top 20–50 cm is indicated by capital R.

Table 4.4: 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; slope >5%
Available water content	w	(Low available water reserve): <50 mm/50cm 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
NH4 OAc 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

Thus, SLR means a "sandy" topsoil overlying a "loamy" subsoil and a root-restricting layer within 20–50 cm. Indicative ranges of available water content (AWC) in mm/50 cm for these crude texture classes (Table 4.5) were derived from data 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.

Soils with a low organic matter content (< 1%OC) will be at the low end of the AWC range for their class and those with a high content (> 1.5%OC) at the higher end. Coarse materials (gravel, concretions) will reduce AWC in 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.

Table 4.5: 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	

With this information, a rough estimate can be made of the water storage capacity of the soil, which, together with the rainfall analysis, allows a good first approximation of drought risk to be made.

Consider, for example, a shallow soil in Nyankpala, northern Ghana, with loamy texture in top- and subsoil, medium organic matter content in the topsoil, a gravel percentage of 15% in both and a root impediment at 40 cm. This is not uncommon in the West African Guinea savannah. The top 20 cm of soil can store about 20 mm of water, and the next 20 cm about 16 mm (Table 4.5), totalling 36 mm. Gravel reduces AWC by the same percentage, and the total storage capacity thus equals about 30 mm. This is sufficient for about 6–7 days of full evapotranspiration (Steiner, 1984) (Fig. 4.7). The rainfall distribution for the area (Fig. 4.7) shows that for practically every 10-day period, less than 25 mm was recorded in one out of four years, which is sufficient for less than six 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 shallow soil.

Chemical soil properties

Most soils in Africa are deficient in nitrogen, especially for cereals, except in newly cleared forest fields. After 2–3 years

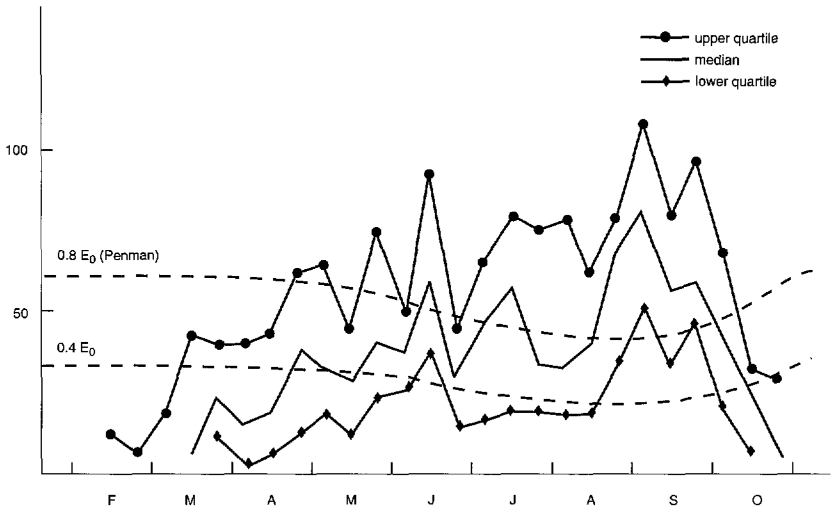


Figure 4.7: Rainfall and potential evapotranspiration at Nyankpala, Ghana, 1953-1982 (Steiner, 1984)

of cropping, nitrogen deficiency may appear in forest soils, too, and will continue to increase.

Phosphorus deficiency is also common, particularly in the savannah, but it can be corrected by low to moderate doses of P fertilizer (e.g., 30–60 kg P_2O_5/ha). IITA soil analyses give the available P by Bray-1 extractant. According to this method, 12 ppm is considered critical for maize, cowpeas and soybeans in most Alfisols in the forest and savannah regions. The critical level is 5–7 ppm for most other crops.

Most soils in Africa 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 considers an exchangeable K content of less than 0.15 meq/100g as critical (Table 4.4).

Secondary and micronutrient deficiencies may occur under certain soil conditions (Figs. 4.8 and 4.9) and may develop with high-intensity cropping. Magnesium, sulphur and zinc deficiencies often occur in sandy savannah soils. The critical level for

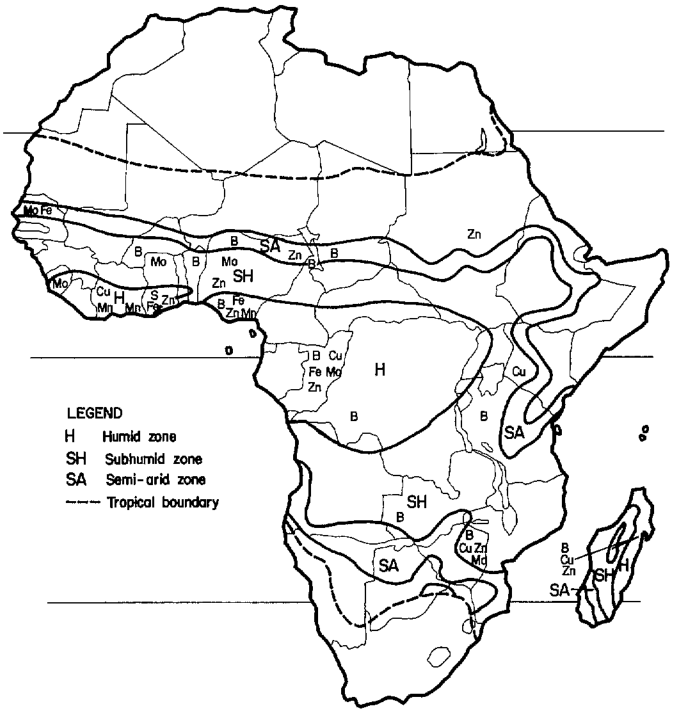


Figure 4.8: Nutrient deficiencies in tropical Africa. From Kang and Osiname, 1985

exchangeable Mg is 0.20 meq/100g (Kang, 1980). Boron deficiency has been reported both for forest (in oil palm and cocoa) and savannah 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 the applications of major nutrients.

Interpretation of soil data: an example

Information on soils can be used for two purposes: (i) explaining current cropping practices and identifying soil-related limitations, and (ii) assessing the potential for new crops or cropping patterns. We will first look at an example of the first kind of analysis.

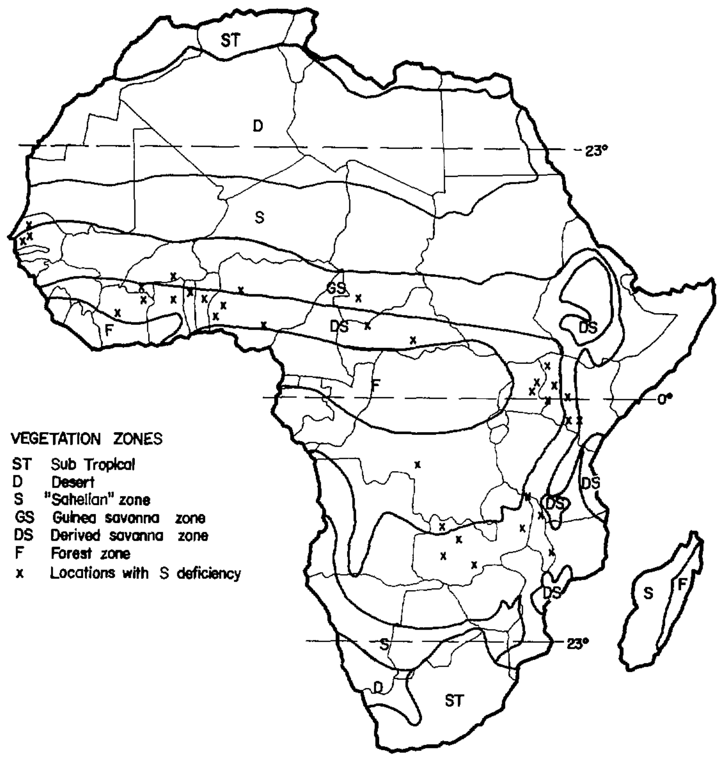


Figure 4.9: Sulphur deficiencies in tropical Africa (Kang 1980)

In the forest-savannah transition zone of south-western Nigeria, Alfisols (Ustalfs) are 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 and another zone of heavier soils. In the former area, although forest patches occurred, the development of savannah from human intervention was more pronounced than in the latter.

In the 'savannah zone', practically all food crop fields had sandy surface soils with medium 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, Fig. 4.2), 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 very 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 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.

Soils from a few 'representative' fields were examined in some detail (Tables 4.6 and 4.7). The savannah fields (1-3) 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) were on excellent soil that would probably support good yields for a number of years even without fertilizer.

In addition to assessing soil limitations for current land use, an OFR team may also want to consider possible new crops or cropping patterns. Their suitability depends on many factors, including soil conditions. The types of analysis given so far also apply here, but additional information is needed on soil requirements of new crop species. Table 4.8 gives indicative tolerances of different crops for important soil limitations which may be used for a first screening.

Cropping patterns and land use

We define a cropping pattern as the set of crops—mixed or in sequence—planted in a particular field over a complete cycle, for example from fallow to fallow. Information to be reported should include the planting and harvest dates of each component, their temporal and spatial relationships, and the minor crops.

Table 4.6: Preliminary Soil Classification and Present Land Use of Five Fields Sampled in an OFR Pilot Area, Ijaiye/Imini, Southwest Nigeria

Field	Position, slope %	Surrounding vegetation	Tentative soil series	Tentative ST[1] Classification (Great Group)	FCC notation	Present use, comments
1	Hill crest, 1%	Grass savannah	Ekiti	Oxic Ustropept	SSet (?)w	Maize+cassava crops-fallow
2	Lower slope, 10%	Grass savannah	Apomu	Typic Ustorthent	LSew	Cassava, sequence unknown
3[a]	Upper slope, 4%	Shrub savannah	Ekiti/Ibada?	Typic Ustorthent	SSew	Early maize-maize+cassava-yams -fallow, "good yam field"
3[b]	Middle slope, 7%	Shrub savannah	Iregun	Oxic Haplustalf	LLekw	Same field as 3[a]
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	maize+cassava crops, plantain borders, no foreseeable fallow

[1]ST = Soil Taxonomy

Table 4.7: Results of Soil Analyses in Five Fields Sampled in an OFR Pilot Area, Ijaiye/Imini, Southwest Nigeria (Kosaki and Mutsaers, Unpublished Results; Same Fields as Table 4.6)

								Exchangable cations (meg/100g)			
Sample	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH	C (%)	P Bray–1 (ppm)	Ca	Mg	K	ECEC meg/100g
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

Table 4.8: Tentative Classification of some Crops According to their Sensitivity to Adverse Soil Conditions[1]

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	+	+	–
Oil palm	+	o	o

[1] –, –– = sensitive, very sensitive; o = average; +, ++ = tolerant, very tolerant.

Zandstra et al. (1981) suggest a useful convention for the description of cropping patterns 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' (Fig. 4.10) indicates a mixture with millet and sorghum with cowpea intersown later but before the millet harvest. '(Maize-cowpea)+cassava' indicates that maize and cowpea are in sequence and cassava is mixed with both. Supplement descriptions with a diagram (Fig. 4.10) using the same time scale as for the rainfall diagram, which can be used as an overlay for the cropping pattern diagrams. The spatial relationships in a field can also be described by means of a diagram (Fig. 4.11).

Describe the minor crops associated with each major cropping pattern. State which minor crops were observed, and the approximate frequencies and densities. For example: "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."

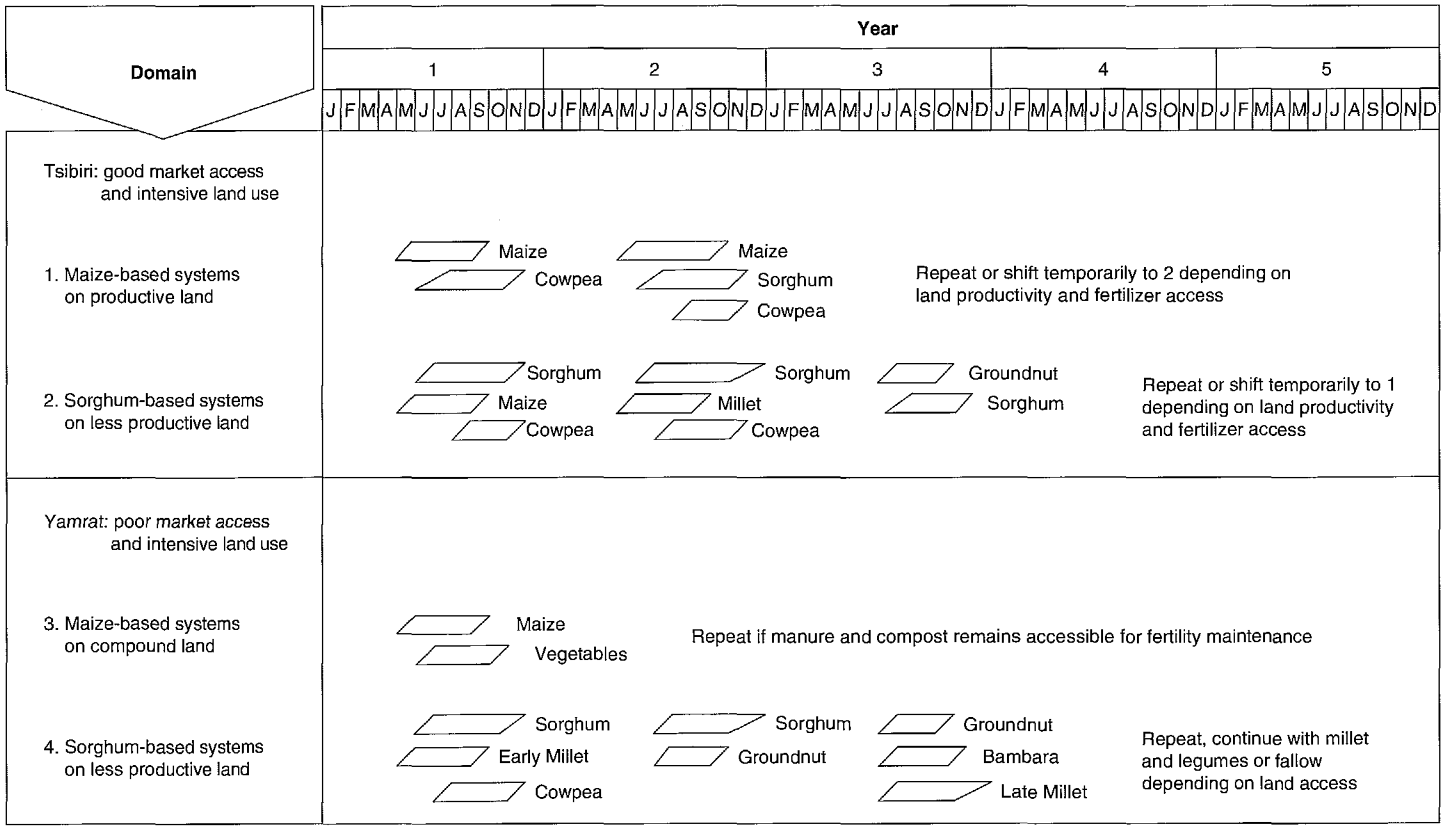


Figure 4.10: Major cropping patterns in northern Nigeria

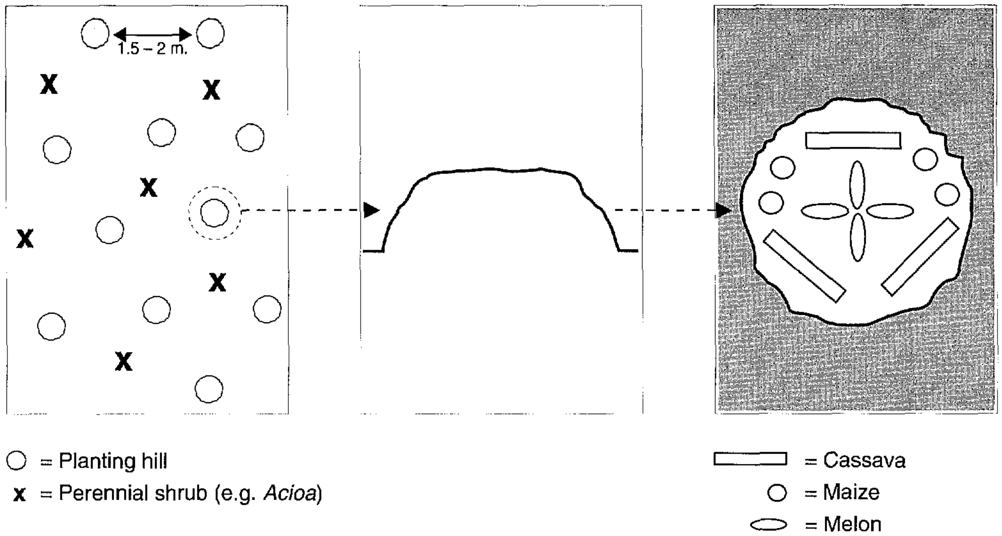


Figure 4.11: Planting arrangements of crops in a foodcrop field in Umudike, southeast Nigeria

Distinguish between different land types and their typical cropping patterns. The set of all cropping patterns and the fallow constitute the cropping system.

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

Try to estimate crop yields from interviews or field observations. Reliable estimates are hard to obtain from an exploratory survey alone, and you should not pretend that they are more than intelligent guesses.

Assess 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 cereals.

Analyze the cropping system with a view to possible limitations and opportunities for improvements or the identification of a 'niche' for a new crop or pattern. Speculate whether the present cropping intensity can be sustained with the technologies currently being used and, if not, what innovations might be brought in to assist in maintaining fertility?

Examine each cropping pattern and sequence in relation to the rainfall diagram in order 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?

Cropping operations and crop calendar

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

Draw up a crop calendar for each important cropping pattern (Table 4.9a). If this is too ambitious for the exploratory survey, ensure that you obtain the dates of operations. With the crop calendars for each cropping pattern, do a simple whole-farm labor profile, combining the calendars for each pattern (Table 4.9b). Transfer the estimated labor data into a figure and visually assess the occurrence of labor bottlenecks and slack periods. At Samaru, labor bottlenecks on a farm might occur in June (first weeding), July/August (weeding, sowing, remolding, harvesting) and in late November (sorghum and cowpea harvest). Opportunities for additional activities are in late August, late September and in early October.

Validate the analysis with 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? Develop a simple year-round labor profile together with the farmers, using, for example, barcharts with higher bars indicating greater labor use.

Table 4.9a: Development of a Labor Profile for a Hypothetical Farm at Tsibiri, Near Samaru, Northern Nigeria (See Fig. 4.10); (a) Crop Calendar for the Millet + Sorghum/Cowpea Cropping Pattern

Approximate period	Operation	Approximate labor for 1 ha		Tools used	Notes
		Adult days	Child days		
1–20 May	Part of land prepared & millet sown	4	8	Large hoe	At least one major rain
20 May–15 June	Land prepared & sorghum sown	20	10	Large hoe or oxen ridger	Following rainfall
10 June–15 July	First weeding & fertilization	34	0	Small hoe	Depends on weeds
10 July–15 Aug.	Second weeding & cowpea planting	30	10	Small hoe or oxen ridger	Depends on weeds and rain
10–25 Aug.	Millet cut down	4	0	Cutlass	Early food
15–30 Aug.	Millet heads removed, carried home	4	8	Sickle, transport as headload or with bicycle	Field drying depends on rain
10 Aug.–15 Sept.	Millet threshing	6 women	4	Sticks	According to needs
20 Aug.–15 Sept.	Weeding by remolding ridges	30	0	Large hoe	After millet harvest
10–30 Oct.	First cowpea harvest	8	20	Hand	Dry pods only
1–25 Nov.	Sorghum cut down	4	0	Small hoe	Depending on variety
5–30 Nov.	Sorghum heads removed, carried home	4	12	Sickle, transport as headload or with bycicle	Seed may be contaminated with pests e.g. Striga
10–30 Nov.	Second cowpea harvest; haulm carried home	12	20	Hand/cutlass, transport as headload	Clean before general livestock roaming
Dec.–Jan.	Sorghum threshing	22 women	10	Sticks	Postharvest processing

Note: Dates and labor requirements are approximate. Labor days are for hoe farming, not for ox-drawn implements. Men generally do farm work in Hausa land while women do processing; an additional column to differentiate labor by gender would be required in societies where both do similar work.

Table 4.9b: Development of a Labor Profile for a Hypothetical Farm of Tsibiri, Near Samaru, Northern Nigeria (See Fig. 4.10); (b) Simplified Labor Profile for the Whole Farm

Dates	Sorghum + millet/cowpea 0.3 ha	Sorghum + groundnut 0.2 ha	Maize/cowpea (50 % with cowpea relay cropped) 0.8 ha	Labor demand in work days for farm
1–10 May	Land prepared & millet sown (2)		Land prepared (5)	7
11–20 May			Land prepared & maize sown (12)	12
21–31 May	Land prepared & sorghum sown (8)		Land prepared & maize sown (10)	18
1–10 June		Land prepared & crops sown (7)		7
11–20 June			Weeding & fertilization (18)	18
21–30 June	First weeding (11)		Weeding & fertilization (9)	20
1–10 July		First weeding (7)		7
11–20 July			Weeding & fertilization (18)	18
21–31 July	Weeding, cowpea sown (11)	Second weeding (7)		18
1–10 Aug.			Remolding, cowpea sown (15)	15
11–20 Aug.	Millet harvest (3)		Remolding (15)	18
21–31 Aug.				
1–10 Sept.			Harvest maize (10)	10
11–20 Sept.	Remolding (10)		Harvest maize (5)	15
21–30 Sept.				
1–10 Oct.		Groundnut harvest (8)		8
11–20 Oct.	Cowpea harvest (5)		Cowpea harvest (7)	12
21–31 Oct.				
1–10 Nov.	Sorghum harvest (4)			4
11–20 Nov.	Cowpea harvest (7)		Cowpea harvest (10)	17

Note: Only farm work without postharvest processing. Labor demand is for hoe farming; farmers in the area hire some labor for maize during peak times.

The data can now be analyzed to answer questions such as

- when do labor bottlenecks occur on a whole-farm basis? Can any innovations be suggested to help?
- when are the slack periods, and can any new activity or crop be suggested for which the labor requirements would mainly fall in these slack periods?

Analysis of farmers' conditions

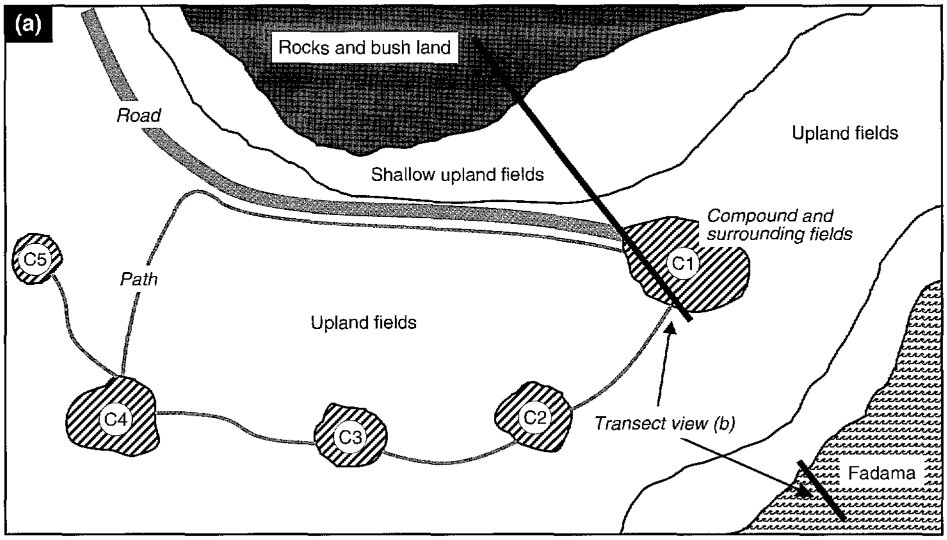
The purpose of the analysis of the system is to lay the foundation for a sensible experimental program. The information should result in the design of trials that are consistent with the physical and socioeconomic environment and which have some chance of improving the existing farming system. As a first step, the more detailed analyses of the previous sections should be synthesized into a general 'typology' of the farming system. Next, it has to be decided whether different target groups can be defined, that is, groups of farmers facing similar physical and socioeconomic conditions. Finally, those major constraints and opportunities in the farming system have to be identified which can be addressed by innovations to be tested under farmers' conditions.

Typology of farms and fields

As a basis for a synthetic summary of the findings, we recommend using the village maps and the description of the transects prepared during the village discussions (see Chapter 3), showing major aspects of the farming system (Lightfoot et al., 1988). An example is shown in Fig. 4.12 for a pilot location in Bauchi State, northern Nigeria.

Next, describe the criteria by which farms or farming households can be grouped. Some commonly used criteria are

- access to land, labor or credit
- degree of mechanization
- market orientation
- part-time versus full-time farming



(b)

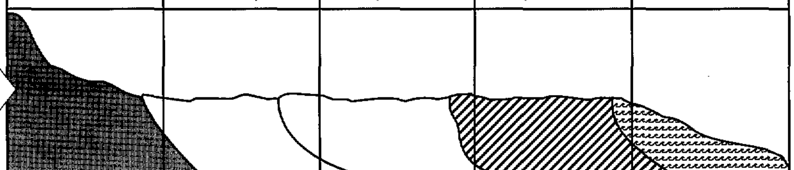
	Bush lands	Shallow uplands	Uplands	Compound fields	Fadamas
Land type					
Level of intensification	Firewood and hunting	Low, shifting cultivation	High, crop rotations	Very high, intercrops	Variable, depending on upland
Soil constraint	Very shallow	Low water-holding capacity	Fertitlity	Limited availability	Variable water levels
Major crops or livestock		Sorghum, millet, cattle	Sorghum, groundnut, millet	Maize, vegetables, livestock	Rice, cassava
Crop constraint		Drought, striga, fertility	Fertility, striga	Pests on vegetables, nematodes	Weeds, birds on rice
Promising innovations for on-farm testing		Improved fallow systems with fodder legumes	Striga control, legume integration, cassava	Pest-resistant varieties, N-use efficient maize	Rice varieties, cassava varieties

Figure 4.12: Sketch of compound and agricultural areas in Yamrat, Bauchi State, Nigeria (a) and a description of land use, constraints and opportunities for interventions along a transect (b)

Additional criteria may emerge from the exploratory survey. An individual farming family will often have access to different land types, such as plateau, sloping land, valley bottom land, which may be utilized in different ways. 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. They were grouped into those with rice-based, yam-based, cassava-based or cereal-based systems, according to whichever system was dominant on their farm.

Do not attempt overelaborate groupings based on the exploratory survey alone, as the quantitative data required will not be produced by surveys of this type. In fact, the groupings made in the Niger State project came out of additional studies, and the exploratory survey only distinguished 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. In all cases, such information helps to define recommendation domains for the choice of technology and for on-farm experimentation.

Constraints and opportunities

Examine carefully those factors you feel to be constraints—those elements in the farming system and its environment that limit the system's productivity. Also attempt to focus on opportunities—those features of the system that may be better exploited to increase productivity.

In the forest-savannah 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 decline of cocoa growing seriously limited cash-earning opportunities 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 review the lists prepared and ranked with the farmers during the village visits (Chapter 3). Next, expand these into a fairly comprehensive 'long list' as perceived by the team, using the checklist (Table 3.1 in Chapter 3) as a guideline. The long list, resulting from brainstorming by the team, is usually a shopping list at first, without much structure. The list should be sorted and reduced to a manageable set of priority constraints and opportunities in a methodical way.

A first distinction can be made between constraints which, in principle, can be addressed directly by the research team ('addressable') and those which cannot ('non-addressable'). A constraint may be non-addressable because it is related to factors outside the farming community, e.g., the non-availability of fertilizers. It may, however, also be non-addressable because of the composition, capabilities or the mandate of the team. Furthermore, the team will feel certain about the importance of some of the constraints but less so about others. The addressable constraints and opportunities should therefore be further subdivided into 'certain' and 'less certain' categories (Palada et al., 1985; Tripp and Woolley, 1989). The latter set would require additional diagnostic studies, which may, however, sometimes be combined with the testing of some simple technologies in the form of diagnostic trials (Chapter 6).

In the next step, each group is ranked in order of importance. More or less objective weighting criteria are therefore needed, which reflect the importance of a constraint or the potential of an unexploited opportunity, in terms of

- the number of farmers affected
- the relative importance of the 'enterprise' (crop, pattern, livestock, etc.) affected by the constraints or the potential

contribution of an opportunity which could be better exploited

- the effect of the constraint on the enterprise(s) it affects
- the risk of the constraint increasing in the future

Weighting constraints is highly speculative at this stage, but it forces the team to arrive at a preliminary consensus.

The ranking should be compared with that obtained from the farmers themselves (Chapter 3), using a simple matrix ranking technique. Both the researchers' final ranking and that of the farmers should then be discussed with farmers' groups. In some cases, farmers' opinions may lead to a change of priority; in others, farmers may be less aware or even totally unaware of a problem which the researchers feel strongly about. Farmers' awareness will affect the research approach as discussed in the next chapter.

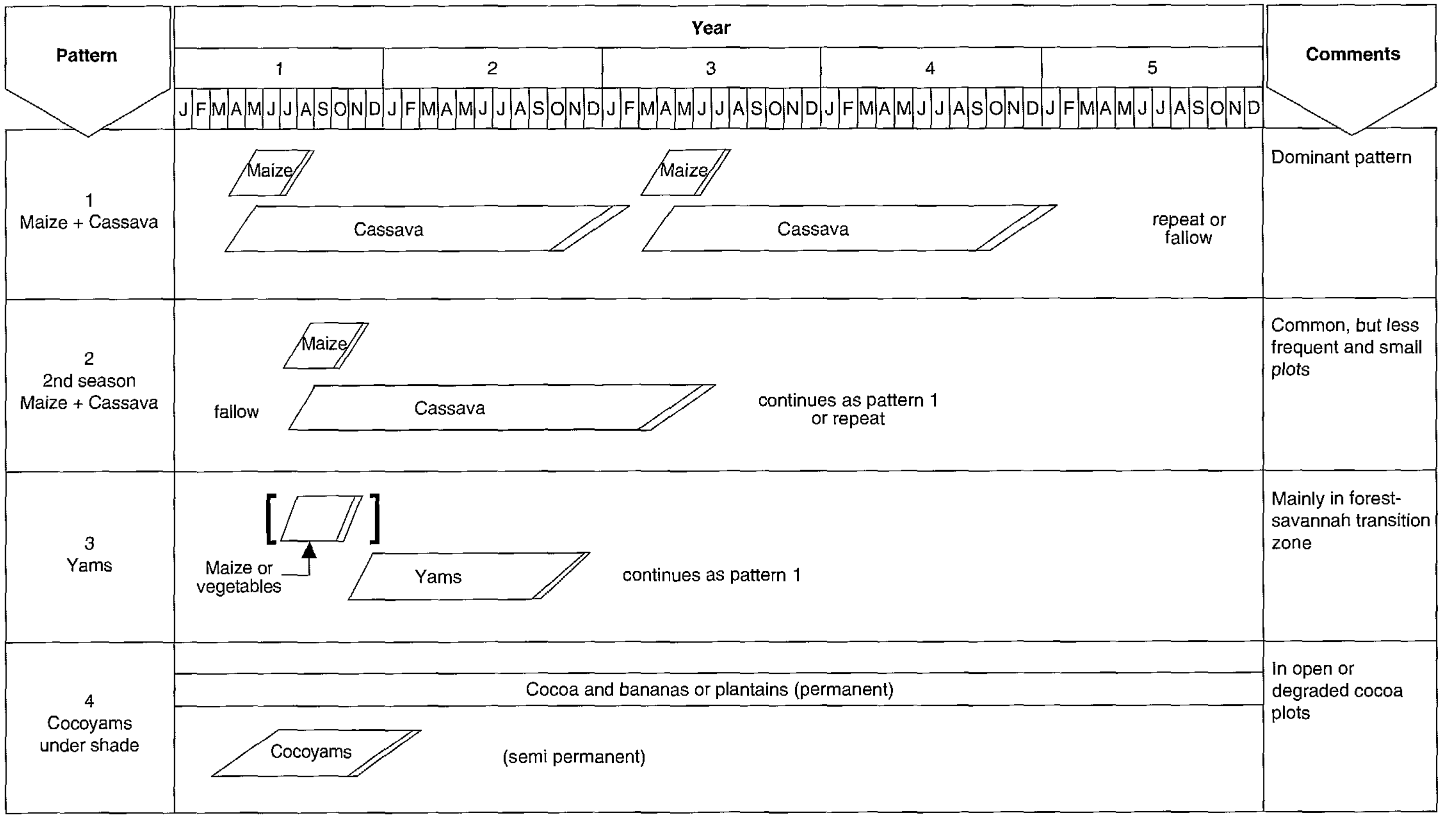
A priority list of constraints, developed early on in an OFR program, is no more than tentative, and the research program based on it should be viewed by the team as preliminary. The original views may have to be drastically modified as more is learned by close co-operation with farmers.

We will illustrate the procedures with two examples, from northern and southwestern Nigeria.

Examples of prioritization of constraints and opportunities

Southwest Nigeria

The research area (Palada et al., 1985) is in the forest-savannah transition zone with (pseudo) bimodal rainfall. 'Savannah fields' and 'forest fields' form a patchwork. Cocoa as a cash crop is in decline. Major food crops are maize and cassava, grown in association, yams and vegetables (Fig. 4.13). Oil palms form a naturally regenerated component of food crop fields, but they are disappearing. There is increasing incidence of *Imperata cylindrica* as a major weed in savannah fields. Male and female farmers often operate food crop fields independently and may be considered as different farmer categories. At the field level, a distinction was made between 'forest' and 'savannah' fields.

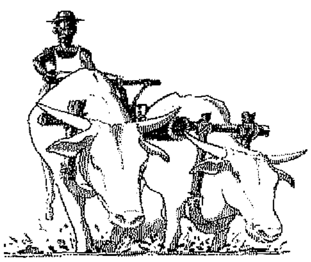


Note: Oil palms at varying densities (up to 75 palms ha^{-1}) form a natural overstorey in all food crop fields.

Figure 4.13: Major cropping patterns in southwest Nigeria

A long list of constraints and opportunities was developed, grouped into "addressable" and "non-addressable" categories, analyzed for relative importance and compared with farmers' own perceptions (Table 4.10). The highest ranking categories will be further examined in the next chapter.

Northern Nigeria



Access to input and output markets in the research area has led to the development of a highly intensified maize-based system without fallow periods. Fertilizer use is common and increasing use is made of animal traction. Sorghum is still widely grown, often intercropped with maize. Cowpeas are relay cropped into maize or sorghum, and cotton is planted in areas close to ginneries as a second market crop after maize. Soil erosion increased dramatically during the last decade with the increasing intensity of land use, although farmers still see it as a minor problem. Farmers pointed out other problems like pest problems on cereals and cowpeas as well as their difficulties in acquiring access to fertilizer and insecticides on the market, even if they have the money available. The soil scientist pointed out the risk of soil acidification on the sandy soils in the area, especially with the use of nitrogenous fertilizers. The long list of diverse constraints (Table 4.11) obviously requires further prioritization and focusing. Note the difference between farmers' and researchers' perceptions of the importance of erosion.

Table 4.10: Structured and Ranked Long List of Constraints and Opportunities, Alabata, Forest-Savannah Transition Zone, Southwest Nigeria

	Current importance					
Constraints/opportunities	Number of farmers affected (incidence)	(potential) importance of affected activity	Effect on productivity of affected activity (severity)	Risk of increase in the future	Rank according to current and future importance	Farmers' awareness of importance
Addressable						
Certain						
Insufficient soil fertility	xxx	xx	xx	xx	1	xxx
Weed pressure; Imperata in savannah fields	xx	xx	xx	xx	3	xx
Underutilized 2nd season	xx	xx	–	–	5	x
Severe stemborers in 2nd season maize	x	x	xxx	x		x
Failure of cowpeas due to pest complex	xxx	xx	xx	x	2	xxx
Decline of oil palm	xx	xx	xx	xx	4	x
Maize storage pests	xxx	xxx	x	x		xx
Lack of cassava-processing equipment	x	xxx	x	x		x
Underexploited small livestock	xx	xx	–	–		x
Less certain						
Under-utilized valley bottoms	x	xx	–	–		
Low yield potential of local crop varieties	xxx	xxx	xx	x	1	
Cassava grasshopper	xx	xxx	x	x	2	xx
Cassava root rot	xx	xxx	x	x	3	x
Non-addressable						
Lack of credit for crop production	xx	?	?	?		
Decline of cocoa	x	xx	xx	xxx		
Unavailability of agrochemicals	xxx	xx	xxx	?		
Unavailability of farm implements	xx	xx	xx	?		

Table 4.11: Structured and Ranked Long List of Constraints for a Market-Driven Maize-Based Farming System in the Northern Guinea Savannah of Nigeria

Constraints/opportunities	Current importance: Number of farmers affected (incidence)	Current importance: (potential) importance of affected activity	Current importance: Effect on productivity of affected activity (severity)	Risk of increase in the future	Rank according to current and future importance	Farmers' awareness of importance
Addressable						
Certain						
Striga on cereals	xx	xxx	xx	x	2	xxx
Zinc deficiency	xxx	xxx	x	xx	3	x
Cowpea storage losses	xxx	x	xx	x	4	xxx
Soil erosion	xx	xxx	xx	xxx	1	x
Shortage of livestock fodder	xx	x	xx	x	5	xx
Labor/equipment for groundnut harvest + processing	x	xx	xx	x		xxx
Less certain						
Nematodes on maize	?	xxx	xx	xxx(?)	3	x
Drought in cereals	xx	xxx	xx	?	1	xxx
Downey mildew in maize	x	xxx	?	?		x
Insect pests of cowpea	xxx	x	xxx	x		xxx
Soil acidification	xxx	xxx	?	xxx	2	x
Non-addressable						
Fertilizer availability	xxx	xxx	xxx	?		
Access to cotton insecticide	xx	xx	xxx	?		

Chapter

5

Choice of Innovations

Introduction

In the previous chapter, we introduced an informal method of ranking constraints and opportunities in order of their presumed importance. We will now discuss the process of choosing innovations to address some of the priority constraints and opportunities. The whole team should participate in this process in a number of brainstorming and design sessions, alternating with consultations with groups of farmers.

Farmers themselves are usually strongly aware of some constraints, while other constraints are for the most part only perceived by the team members as important. The decision on which constraints to tackle first may be influenced by this difference in perception. In the example of the northern Guinea savannah in Nigeria (Table 4.11 in Chapter 4), the researchers considered the erosion hazard as the number-one problem, while farmers did not regard it as being quite as serious. Erosion hazard may be seen as a 'strategic' problem, i.e., one which is likely to increase in the future unless measures are taken immediately to prevent it from developing.

In order to build up credibility, the team may decide to first address those constraints which farmers consider urgent, even if they are not the most important in the eyes of the researchers. Sometimes, however, an urgent problem may have underlying causes in common with a more strategic problem, and both may then be addressed by the same technology.

From constraints to solutions

In the following analysis we used several ideas and techniques from Tripp and Woolley (1989) and from GTZ's goal-oriented project planning (GTZ, 1987). The analysis consists of a series of steps (Fig. 5.1):

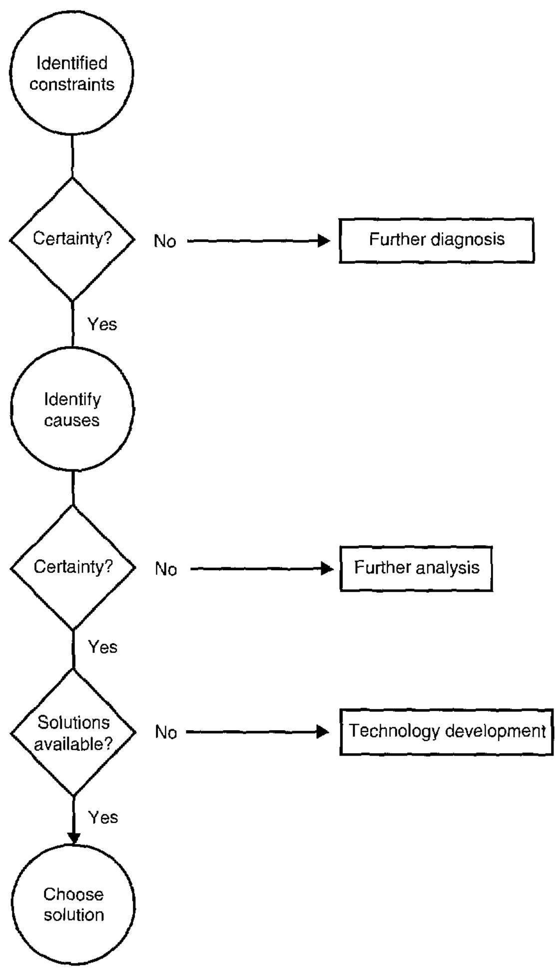


Figure 5.1: Analytical steps leading from the identification of a constraint to the choice of innovation

1. First, we will analyze the causes underlying the major constraints.
2. We will then examine whether there is sufficient evidence for these causes. If not, further diagnostic research will be needed.
3. Next, we will decide whether a constraint or its cause can be tackled directly by on-farm testing with the available technology or whether technology must be developed.
4. Finally, we choose specific, well-defined technologies for on-farm testing.

Constraints, their causes and potential solutions

Constraints can often be addressed directly, ignoring their causes. Weeds, for example, may be removed manually or chemically, but it is sometimes better to look at the weed problem as a symptom of a more basic underlying cause. Excessive weed accumulation may be the result of an imbalance in the production system. Some crops or cropping practices may stimulate weed build-up and cause a shift in species composition. Herbicides could be proposed, but they are often unavailable to farmers, or unaffordable. Looking for the underlying causes of problems may suggest solutions which are more environmentally friendly, less costly and even more productive than the use of herbicides.

We will look again at the two examples given in Chapter 4 for the analysis of the causes of some major problems and their potential solutions.

Examples

The Nigerian northern Guinea savannah

The area is intensively cultivated, and farmers use fertilizer for cereal production. Several constraints (Table 4.11 in Chapter 4) are closely linked with the intensity of land use and frequent cereal cropping.

The causes for each major constraint can be identified as shown in the example for soil erosion in Fig. 5.2a. First, the agroecological conditions which favor the constraint are assessed, then the effect of existing control options is analyzed. The more conducive the overall environment is to a constraint, the greater will be the need for a systems approach to tackle the causes of the

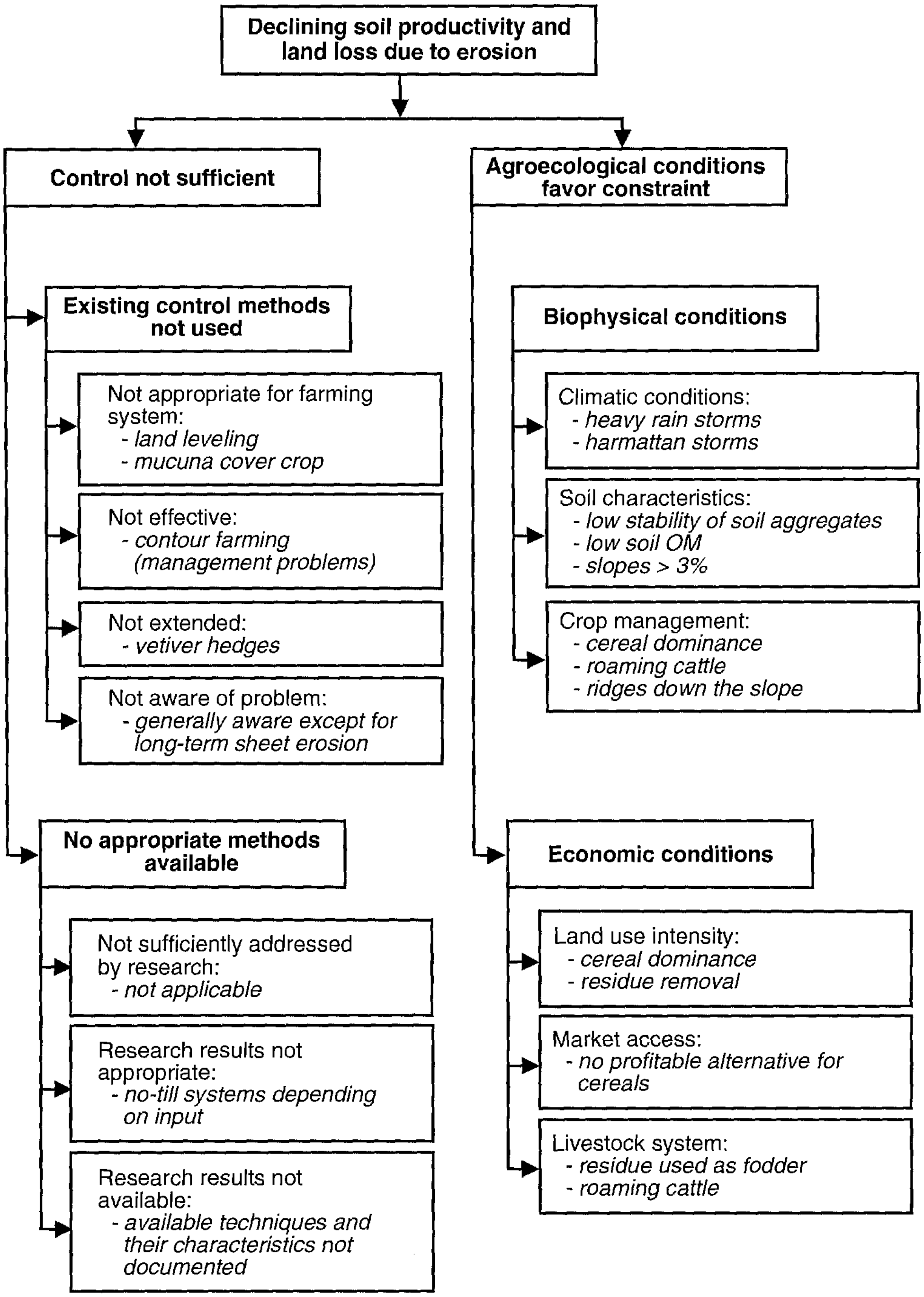


Figure 5.2a: A goal-oriented approach to identification of solutions for production problems: identification of underlying causes of the problems

problem. Fig. 5.2a indicates that the biophysical and socio-economic conditions in the area, such as heavy seasonal rain storms, the low stability of soil aggregates and the overdominance of cereals in the production system, are highly conducive to soil erosion. The analysis of the available control options shows that most of them are not appropriate, for example land leveling, as soils are very shallow, or mucuna cover crops, which interfere with the livestock system in the area. Furthermore, farmers are not really aware of the seriousness of the problem. The diagram of causes can easily be converted into a search for solutions. Each cause mentioned under Fig. 5.2a is examined for available solutions, and a new diagram of solutions emerges (Fig. 5.2b) The integration of cover crops into the farming system would improve erosion control directly through soil cover, as well as making the soil less prone to erosion by improving soil aggregate stability and by diversifying the cereal-dominated cropping system. One drawback is the possible interference with the livestock system—non-palatable cover crops are needed for dry-season survival, whereas fodder legumes may be more acceptable for farmers. Thus, after choosing 'cover crops' as a possible solution, the available cover-crop technologies must be evaluated in order to select the most appropriate one for a specific system. Planting vetiver hedges on the contours is another well-known technology for erosion control. As both technologies—cover crops and vetiver grass—require the integration of new components into the farming system, the participation of farmers and extension personnel in the design and testing of the technology is essential.

The other priority constraints of Table 4.11 were analyzed in the same way, and this resulted in a planning table for on-station, on-farm and diagnostic research (Table 5.1).

The forest-savannah transition zone, southwestern Nigeria

The area is in transition from a forest to a savannah environment. Secondary forest still exists, often in association with former cocoa fields. Farmers continue to clear remaining secondary forest for food crops and soil fertility is moderate in newly-cleared fields.

In many older fields, however, grassy vegetation has established itself and the fallow is dominated by gramineous species such

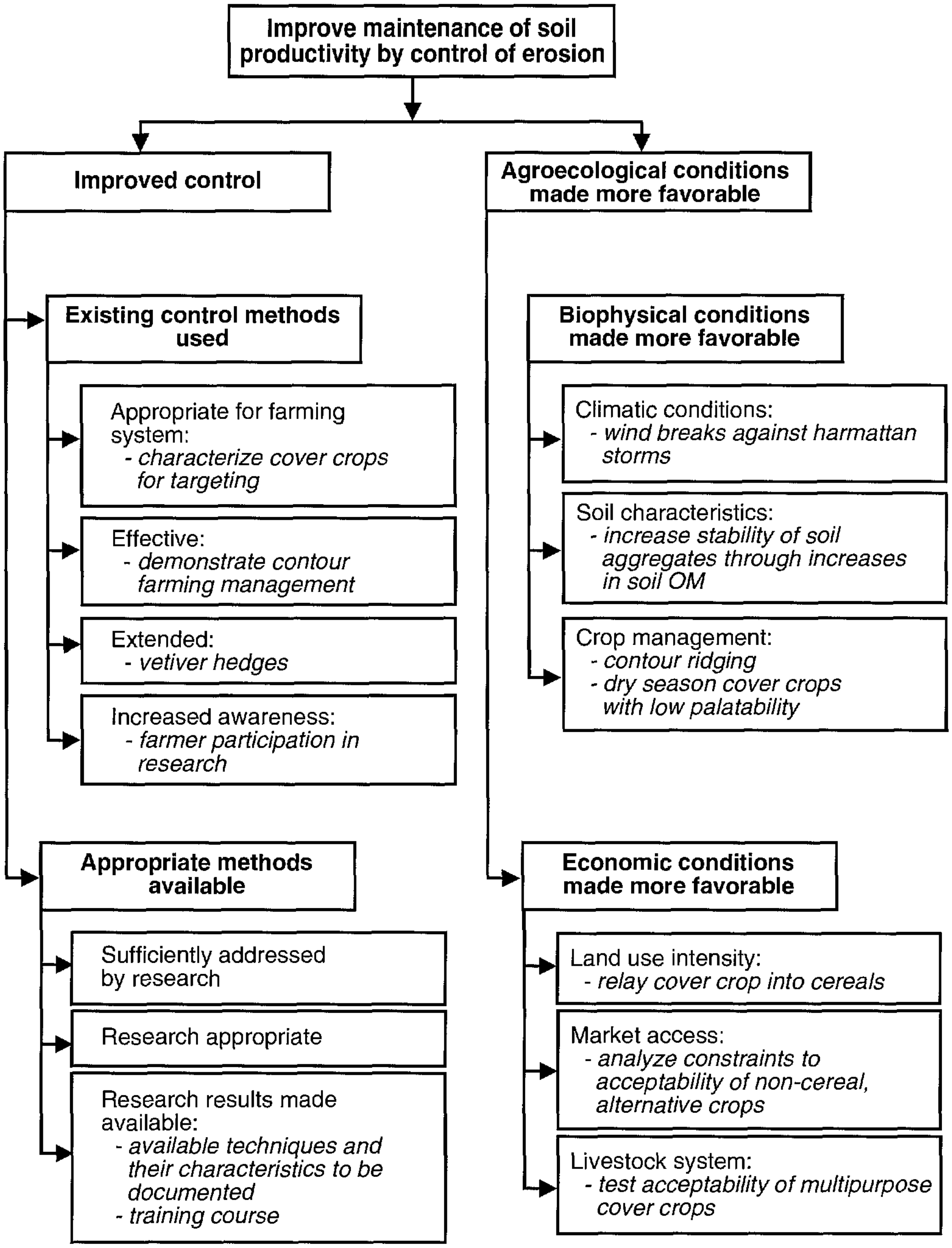


Figure 5.2b: A goal-oriented approach to identification of solutions for production problems: identification of solutions to remove the causes

Table 5.1: Priority Constraints, their Likely Causes, and Research Activities by the On-farm Team to Address them; Zaria Area, Northern Guinea Savannah, Nigeria

		Technology testing			
Constraints	Causes	On-farm	On-station	Additional diagnostic studies	Farmers' own solution
Certain					
Striga on cereals	shortening fallows, frequent sorghum intercropping, seed contamination	– resistant varieties – harvest and seed cleaning to avoid contamination – crop rotations	research for trap crops		fallow
Soil erosion	climate and soil conditions favorable, unprotected soil surface	– participatory research to increase farmers' awareness – vetiver grass – leguminous cover crops – contour ridging	assemble information on available technologies		
Zinc deficiency	inherently low Zn, intensive maize cropping + residue removal	– compound fertilizer with zinc			wood ashes
Cowpea storage losses	high pest pressure	– test pest control with solar drier			ashes, pepper, pesticides
Less certain					
Drought in cereals	to be analyzed: early planting, unreliable rain and soil insects	– diagnostic trial on seed treatment to control insects		compile long-term weather data to analyze risk	repeated planting
Soil acidification	inherent soil parent material, high use of acidifying fertilizers	– participatory research in affected fields to increase farmers' awareness		analyze severity across mandate area	

as *Rottboellia, Panicum* and *Imperata*. This vegetation is fire-sensitive, and perennial species, including oil palms, are disappearing. Nitrogen deficiency in savannah maize is obvious.

Fig. 5.3 shows an alternative method of analyzing the underlying causes (Tripp and Woolley, 1989) for the example of the low-fertility constraint in savannah fields and the relationship of these causes to other constraints. The chart leads to the hypothesis that the intrusion of grassy species is involved in three of the constraints mentioned in Table 4.10, namely (i) low fertility (grassy species are less effective in fertility restoration than the original broad-leaved forest species), (ii) weed pressure (grasses are also more competitive with arable crops), and (iii) the decline of oil palm (grasses are fire-sensitive).

The introduction of broad-leaved species into the system, those fixing atmospheric nitrogen in particular, could push back the grassy fallow, add mineral nitrogen to the soil and create a more

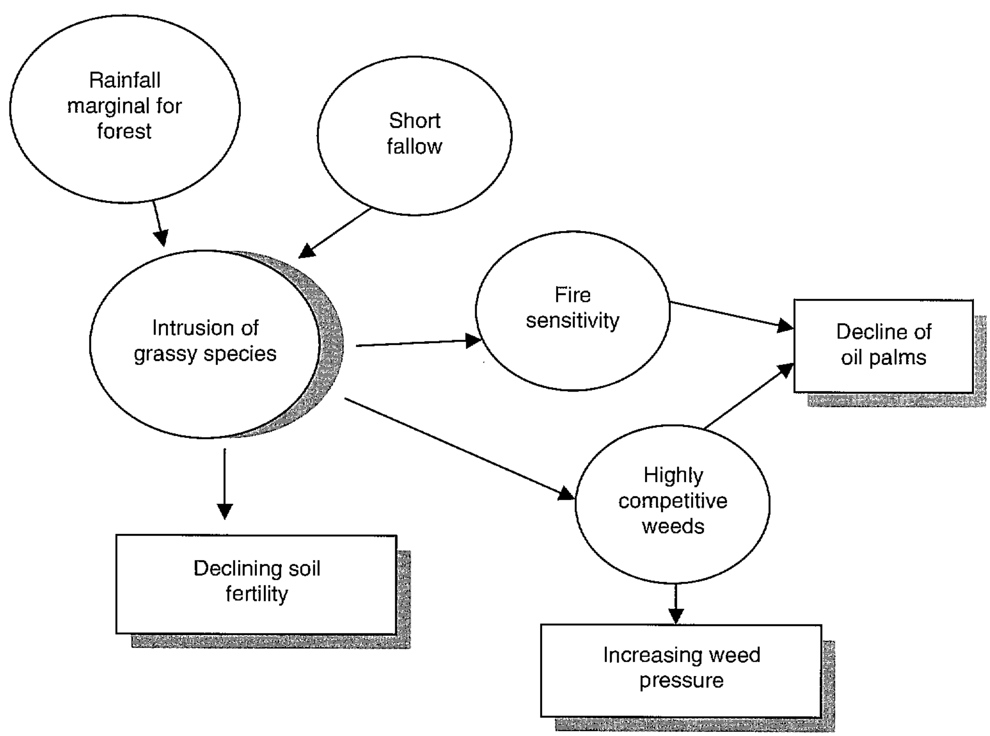


Figure 5.3: A graphic approach to the analysis of causes for problems: example of low fertility in savannah fields in Alabata, southwest Nigeria

favorable environment for oil palm. The introduction of a leguminous cover crop or planted fallow could be an option, as well as alley cropping with crops grown between widely spaced hedgerows of (leguminous) tree or shrub species (Kang et al., 1990). As in the previous example, the choice of an appropriate cover crop or planted-fallow species requires a careful analysis, both of the available species and their potential contribution to the system.

A similar analysis was carried out for the other priority constraints, resulting in proposals for on-farm and on-station testing and additional diagnostic studies (Table 5.2).

Choosing specific technologies

Choosing the most appropriate technology always requires a good knowledge of both the target system and the range of available technological options. Knowledge of the target system and the farming environment should be available from the diagnostic survey and from subsequent experience and the collection of information. Knowledge about the technology can be obtained by means of a systematic search for information from experts, literature or existing databases. The requirements of the target system are then compared with the characteristics of the technologies in a matching procedure in order to select the most appropriate technologies for the target area.

For relatively simple technology such as an improved variety, it is enough to compare the characteristics of the new variety with those of the old one in terms of their contributions to pest resistance, yield, quality, etc. For more complex or novel technological options, the following questions must be answered:

1. Has the target system been clearly defined in terms of location, cropping system and the type of farmer?
2. Is the specific technology adapted to the ecological conditions of the target area?
3. Will the technology contribute effectively to the solution of the problem?
4. Does the technology make other contributions to the farm as a whole?

Table 5.2: Priority Constraints, their Likely Causes, and Research Activities by the On-Farm Team to Address them; Alabata, Forest-Savannah Transition Zone, Southwestern Nigeria

		Technology testing			
Constraints	Causes	On-farm	On-station	Additional diagnostic studies	Farmers' own solution
Certain					
Insufficient soil fertility	shortening fallow, degradation of fallow vegetation, intrusion of grassy species	- integration of legumes, - improved fallow - alley cropping - fertilizer application	screening of potential legumes; seed multiplication	characterization of the soil resource	fertilizer application *when available*
Failure of cowpeas due to pest complex	high pest pressure	- early maturing, determinate cowpeas with pest control			
Weed pressure; Imperata in savannah field	high pest pressure insufficient soil fertility	-integration of legumes for soil cover	screening, seed multiplication of potential legumes		abandon Imperata-infested fields
Decline of oil palm	fire-sensitive fallow weed competition	- plant broad-leaf fallow or alley cropping -reintroduce oil palms			clear vegetation around palms
Less certain					
Low yield potential of crop varieties		test improved varieties of maize and cassava			exchange of varieties, especially cassava

5. Does it increase risks?
6. What does the technology require in terms of land, labor, cash or material investment from the farmer?
7. Does it require special extension efforts?
8. How does the technology fit into the farmers' system, i.e., where is the 'niche' for integrating it? Does it interfere with other parts of the system, for instance, livestock?
9. Are there other social, cultural or policy issues which may affect farmer adoption?

re 1: The matching procedure is an iterative process, as is any optimization. Even the definition of the target system may have to be reconsidered; the initial definition may have been too broad, and more specific targeting may be needed, for example, to non-acid soils or to farms with cattle.

re 2: The evaluation of the ecological adaptation of a technology may be easy for general criteria such as climate and soil (acidity, fertility, water-logging) and this will often be sufficient. Technologies must be adapted to the predominant conditions in the target area. However, the on-farm researcher may want to focus on the specific problems of degraded soils or acid soils, i.e., on a subset of the total target zone where adoption is more likely.

Weather risks can be quantified using the daily or 10-day rainfall totals (see Chapter 4) and mean temperatures for the study area. First, find out from an expert or from the literature which 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 pollination), 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 pearl millet at anthesis (pollination minimal) or by sorghum at head formation (grain is molded). Cold weather when sorghum is flowering hinders pollination, and hot weather or low humidity at maize silking can dehydrate the pollen or silks. Translate a weather hazard into a simple 'event', which can be searched for in the weather data. Examples of such 'events' are

- the occurrence of two consecutive 10-day periods with a total of less than 30 mm rainfall between 50 and 80 days after the anticipated date of sowing maize
- three consecutive days with recorded rainfall after the anticipated flowering date of sorghum

Scan the rainfall data to assess the frequency of the event occurring. On the basis of this, decide whether to go ahead with testing the innovation.

We will give here an example for Samaru in northern Nigeria. A simple weather hazard analysis (Table 5.3) showed the frequency of occurrence of periods of three or more consecutive days of rain at the time when sorghum might be in head. Such a wet spell might lead to fungal spoilage of the grain. Wet spells beginning 21–30 September were rather frequent, but there was 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 finish early. Fisher (1984) gives a full discussion of this problem. (Note that the rainfall record used extended to 1982. Conditions have changed in the last decade.)

Table 5.3: 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 September	16	0.29
1–10 October	4	0.07
11–20 October	1	0.02

re 3: The innovation must, of course, effectively address constraints or exploit opportunities that actually exist in the localities in which it is to be tested. It must be simple enough for ordinary extension personnel to be trained to demonstrate it and for ordinary farmers to operate it.

re 4: The integration of new component technologies may be easier if several objectives can be met at the same time. Leguminous cover crops may, for example, contribute not only to a reduction in soil erosion, but also to soil-nitrogen increase and to grain for food or residues for fodder.

re 5: All farmers, even in areas with cash-crop production for marketing, try first to arrange sufficient food production for their families. Any new technology should reduce rather than increase the risks. Climatic events, biological events (such as the susceptibility of a new variety to a pest) or economic events (the dependence of the technology on government-supported input supply or subsidies) may increase the risks. Sometimes, however, researchers tend to be 'paternalistic' in their concern about risk avoidance, whereas farmers may be ready to integrate a 'risky' technology on an enterprise which does not immediately affect their food security. It is most important that farmers should be made aware of the risks of a new technology.

re 6: Technologies have different input requirements in terms of labor, land, cash or materials from the farmer. Although most African farmers experience shortages of cash or material inputs, and many face a shortage of labor during some periods of the cropping season, the relative importance of one against the other has to be compared with the requirements of the technologies. Labor-intensive technologies are likely to be rejected in an area where labor is scarce, while they may be adoptable in other areas where farmers are short of land and can invest more labor-days per unit of land.

re 7: The simple farm-scale labor profile (Chapter 4) is the basis with which the labor requirement of the proposed innovation should be compared. Ideally, the innovation will require labor at slack labor periods or reduce the labor requirement at one of the peak times. Farmers will rarely accept an innovation that demands priority for labor allocation over their staple food crops. The same holds true for other inputs such as land or materials.

re 8: The information assembled to answer questions 1–6 can be summarized in point 8, where the 'niche' for integrating the new technology into the farming system is defined in detail. This step is of special importance where new component technologies are being suggested to the farmer. The temporal dimension of the niche is the time during the cropping season or off-season when the technology will not interfere with the current farming practices in terms of resource utilization (land, water, soil nutrient, labor). The spatial dimension of the niche is the non-utilized or underutilized land area which is available for the technology. Sole-cropped cassava, for example, has an early season niche, as the crop is widely spaced and grows slowly during the first two months. Sole-maize in the moist savannahs often provides a late season niche, whereas sorghum + groundnut or cassava + maize intercrops are close to a full use of available resources.

re 9: Additional criteria relating to land tenure systems, cultural traditions or policy issues may modify the choice. Long-term investment into land quality, for example through fallow management, requires land ownership. Some technologies may be adoptable at the present time, but changes in policy, like the removal of fertilizer subsidies, may render the technology unprofitable.

The application of these criteria in narrowing down the technological options requires detailed information on the technologies themselves. Sometimes the information is readily available from a research station where the technology may have been extensively tested. For other types of technology, a wider search for information may be needed. There are, for instance, many herbaceous legumes which can be considered as a cover crop, but only a few may satisfy all the requirements outlined above. In order to facilitate the screening of a large number of legumes for specific characteristics, a computerized search system has been developed (COMBS, 1993; see Annex I). Similar 'expert systems' may become available in future for other types of technology.

Examples

The Nigerian northern Guinea savannah

The target area has a season length of about 150 days. Soils are shallow and low in nutrient content, but farmers use fertilizers on maize and cotton. Fallow periods have almost disappeared and the land is cropped permanently. Maize and sorghum dominate more than 80% of the fields, while cotton, cowpea, yam and groundnuts are additional crops grown in rotation or intercropped with cereals. Many farmers use animal traction for land preparation and ridging, and they keep cattle, small ruminants and chickens as livestock. Fodder reserves run short around March–April, at the end of the dry season and the beginning of the new rainy season.

Four technologies were selected from Fig. 5.2b as promising solutions to the problem of soil erosion in the area. The LEXSYS expert system was used for prescreening potential herbaceous legumes to be used as undersown or dry-season cover crops. Characteristics of these technologies are analyzed in Table 5.4.

Contour ridging. Most farmers do not respect the slope direction when ridging the land. The technology is known to be effective, at least on light to moderate slopes, and it can be implemented without any major changes in the common farming practices. The technology does need intensive demonstration to farmers.

Vetiver hedges. Planting vetiver hedges is an effective erosion control measure even on moderate to steep slopes. It is a permanent investment into land improvement which will be fully established only after a few years and will therefore only be adoptable by those farmers who have permanent land ownership.

Lablab as undersown legume. Farmers plant maize early in the season with the first rains, and harvest the maize crop 3–4 weeks before rains terminate. *Lablab purpureus,* a leguminous herb with edible seeds and excellent potential for hay production, can be relay cropped into maize 4–6 weeks after planting. It will have 3–4 weeks additional rainfall after the maize harvest and is known to exploit residual soil moisture efficiently. It will contribute to the reduction of soil erosion and nutrient leaching towards the second half of the season. The labor requirements are minimal for planting, as this can be combined with the second maize weeding, but additional labor is required for the maize harvest, as the crop makes moving in the field more difficult. The contribution of the crop to fodder production and to soil nitrogen will be valued, especially by farmers who have a shortage of fodder for their livestock.

Canavalia dry-season cover. The leguminous, drought-tolerant species *C. ensiformis* can be relay cropped into cereals at 3–4 weeks before the end of the rains. It has the ability to extract residual soil moisture effectively and to survive the dry season. The plant is not palatable to cattle, and it will therefore provide

Table 5.4: Decision Table for Possible Innovations to Address the Soil Erosion Constraint around Zaria, Nigeria[1]

Technology	Target system	Efficiency of control	Requirements of technology				Additonal contributions
			Land	Labor	Materials	Extension	
Contour ridging	Slightly sloping lands	+	0	0/–	0	–/0	0
Vetiver hedges	Moderate slopes and farmers with land ownership	++	–	–	–/0	–	0
Lablab as undersown cover crop	Maize crops and farmers with fodder requirements	+	–	0/+	–/0	–/0	Fodder and soil N
Canavalia cover crop for dry season	Cereal crops on moderate slope, no or minor fodder shortage	++	0	–	–/0	–/0	Soil N

[1] + = favorable; – = unfavorable; 0 = neutral

N.B. An innovation that increases labor or material requirements is unfavorable (–). An innovation that requires more extension is unfavorable (–).

a soil cover after slashing for the next season. It provides effective erosion control, but the slashing of the woody residues is a labor-intensive task.

A comparison of these different technologies (Table 5.4) indicates the need to subdivide the target area into more specific target systems. Most areas are slightly sloping and livestock is a major element of the farming system in the area. Additionally, land preparation is a time of labor shortage. Thus, the Canavalia dry-season cover was dropped as a promising technology. The other three technologies are not mutually exclusive, and farmers can integrate them according to land slope, land ownership and fodder shortage. Thus, all three are viable options.

Nyankpala, northern Ghana (Steiner, 1984)

This is a typical southern Guinea savannah area with a practically monomodal rainy season from mid-April to early October. Rains are erratic from April to June (Fig. 4.7 in Chapter 4). Soils are Alfisols, sometimes quite shallow because of ironstone hard-pans. The typical cropping system is (i) yams relayed with millet and minor crops as the first crop after fallow, followed by one or two crops of (ii) maize + groundnuts, relayed with sorghum, sometimes followed by one year of (iii) cassava with some maize and cowpea or by fallow (Fig. 5.4). Population density in the area (1984) was moderate at some 60 inhabitants/km^2.

Decline in soil fertility due to reduced fallows was identified as a major constraint, particularly for yams and maize. On the assumption that increased fertilizer use would be difficult, three innovations were proposed for improving the fertility status of the fields (Table 5.5).

Sole groundnut. Farmers grow groundnuts mixed with maize and sorghum. If this mixture were grown only once, then it would probably be an efficient land use practice. Due to intensification, however, farmers now grow two or more successive groundnut + maize/sorghum crops. Station experiments had shown that cereal yields were poor in the year following the mixture, while sole cropping of groundnuts gave good maize yields in the next year. Sole groundnuts followed by cereals may therefore be an option for farmers. If adopted, the sole groundnut field would be expected to replace a field normally planted to

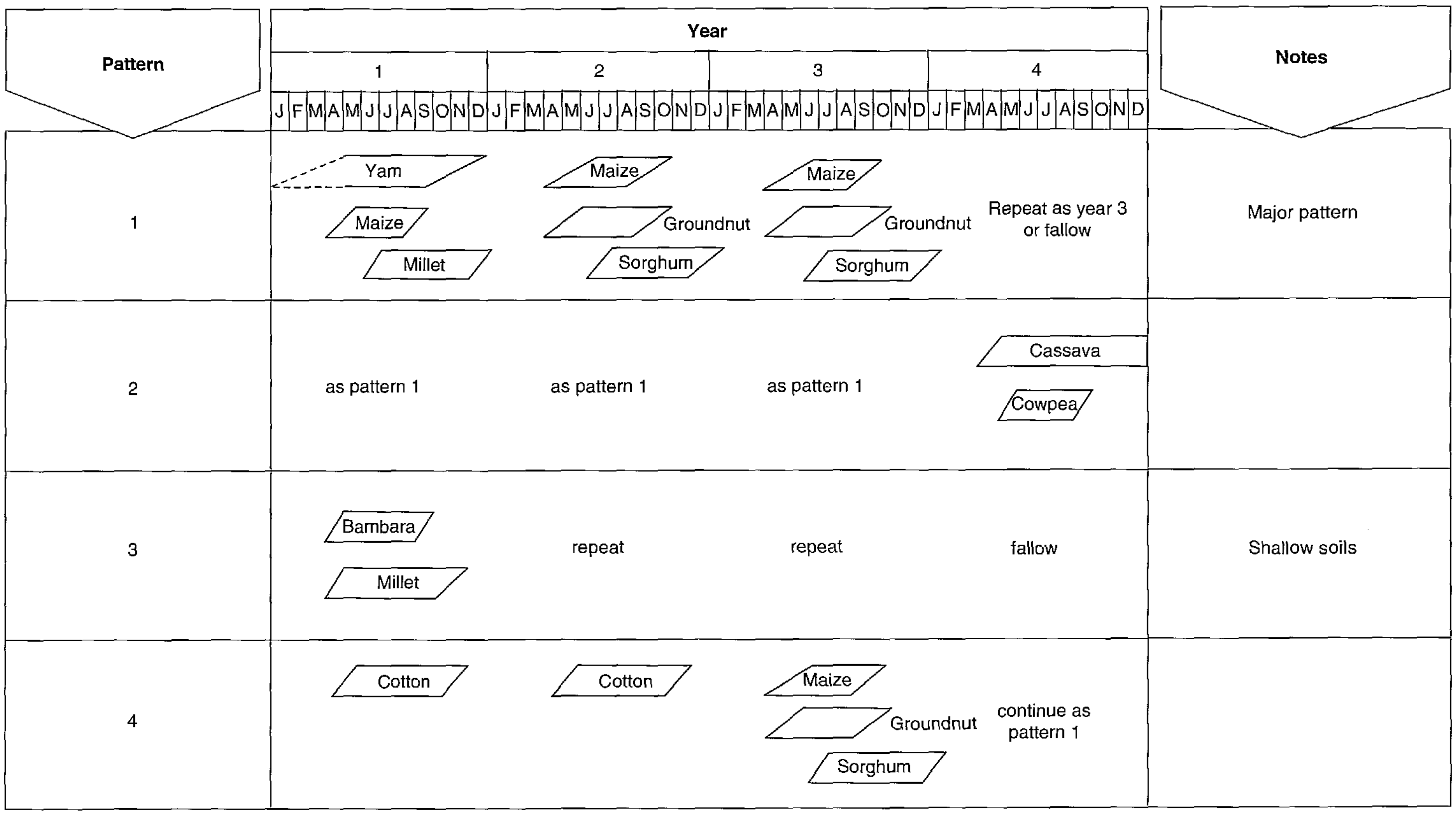


Figure 5.4: Major cropping patterns in the Nyankpala area of Ghana

Table 5.5: Decision Table for Possible Innovations to Address the Soil Erosion Constraint around Nyankpala, Ghana[1]

			Requirements of technology							
Technology	Target system	Efficiency	Risk	Land	Labor	Materials	Extension	Economic?	Interaction with livestock	Additonal contributions
Sole groundnut	land-poor farmers using several cycles of cereal crop combinations	+	–?	–	0	0/–	0	–?	++	Striga control
Cassava + groundnut 'break' crop	same	0	++	0	0	0	0	+	0	Striga control
Pigeon pea cover crop	degraded soil	+	+?	0	–	0/–	–	+?	–	Weed control

[1] + = favorable; – = unfavorable; 0 = neutral.
N.B. An innovation that increases labor or material requirements is unfavorable (–). An innovation that requires more extension is unfavorable (–).

the mixture, followed in the next year by maize (+ groundnut?)/sorghum.

Pigeon pea cover crop. Rows of pigeon peas may be relayed into maize at the same time as, or even better after, planting the sorghum, and in the latter case, at the time of weeding. After the harvest of the crops, the pigeon pea would be conducted as a full-season fallow.

Cassava (+ groundnut) break crop. Farmers believed that cassava gave good yields of cereals in a subsequent year but no information was available from trials. Cassava may be tested for its effect on a subsequent cereal in fields where the cereals performed poorly. Early cassava growth is slow, thus leaving a niche which could be occupied by groundnuts or another early-maturing crop such as cowpeas.

In the decision table (Table 5.5), sole groundnuts were rated poorly for risk. If the groundnuts fail, there is no other associated crop which would compensate for the loss. The other innovations were not expected to involve much risk, but pigeon peas might negatively affect sorghum yield.

The sole groundnuts would leave the land unoccupied for part of the season, and this was therefore rated negative from the point of view of land requirement.

None of the technologies required much in the way of material resources, but the legumes might require phosphate fertilizer.

Pigeon pea cover crop would require a special extension effort, because the crop was only used as a border by farmers.

Some economic analysis was undertaken for sole groundnuts with data from a 2-year groundnut-cereal rotation trial on the research station. The analysis took into account that it required giving up multiple cropping during the groundnut year. In the short term, the economics looked doubtful.

Interaction with livestock would be a problem with the pigeon pea fallow, which is palatable for roaming cattle.

Both technologies which excluded cereals for one season (sole groundnuts and cassava + groundnuts) were expected to reduce striga populations.

In summary, sole groundnut seems to be a somewhat doubtful innovation, but cassava + groundnut looks like a good option, especially if an early-bulking cassava variety is available.

Pigeon pea cover crop, relayed into maize and sorghum, may be tried on-farm, but it would probably be better to conduct some station research on the timing of pigeon pea interplanting and the effect on sorghum.

This example addresses only one of the constraints identified at Nyankpala. Separate decision tables should be made for other constraints.

Farmer involvement in the choice of innovations

Earlier on, we made a distinction between those problems which farmers are keenly aware of and those which are mainly perceived by the researchers. It is likely that farmers themselves experiment with methods to alleviate known constraints, and these 'farmer solutions' should be carefully examined (Tables 5.1 and 5.2). They will help in designing convincing experiments by addressing the questions farmers themselves ask and by comparing innovations with those which the farmers have tried (cf. Ashby, 1986). We recommend that the team, after carrying out a first ex ante analysis of possible innovations, meets with interested and knowledgeable farmers to discuss the proposed innovations and solicit farmers' inputs. Versteeg and Koudokpon (1993) in the Republic of Benin suggest 'problem-oriented groups' of farmers—i.e., groups who share an important problem—as the best medium to evaluate proposed technologies before trials are started.

Farmers should preferably be confronted with several possible options. In the case of Mono Province in the Republic of Benin, four options were proposed to address severe fertility problems. Two were for completely exhausted fields (planted fallow with *Acacia auriculiformis* and relay planting of *Mucuna pruriens* into maize), two for less exhausted fields (alley cropping and a short fallow with *Cajanus cajan*, interplanted into maize) (for details, see Versteeg and Koudokpon, 1993). Farmers visited each others' trials where different options were tested, and they compared results after the experiments.

Innovations for household activities other than cropping

We have tended in this manual to emphasize the improvement of cropping systems. However the most appropriate innovations in an area may not be directly related to cropping but, 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 the testing of innovations in these areas. If so, seek help from someone with experience in extending this type of innovation at village level. Although the next section of this manual assumes that the innovations to be tested will be applied to the cropping subsystem, we think most principles are applicable for other innovations.

Chapter

6 Design and Conduct of On-Farm Trials

Introduction

The objective of on-farm experiments is to test the performance of one or more improved technologies, usually in comparison with farmers' own practices, under real farm conditions and as much as possible under farmer management. The experimental plots should differ only in the innovation being tested, while all other conditions should be the same as if there were no trial. This applies not only to physical conditions such as climate, soil, pests and diseases, but also to farmer management.

On-farm researchers often shy away from leaving the management of a trial to the farmers, fearing that it introduces too much variability and thereby makes it impossible to analyze the results and draw solid conclusions. We maintain, however, that the way farmers manage their fields, with all the resulting variation among farmers, is an essential part of real farmer conditions. Trials conducted under maximum farmer management are the only valid way of testing technology, provided the farmers treat the trial fields in the same way as their other fields. Variability should be analyzed and explained, rather than artificially controlled by the researchers. This is the guiding principle of the next two chapters.

Types of on-farm trials

In many texts on on-farm experimentation, trials are classified into different types, according to the degree of farmer involvement. Examples are researcher-managed/researcher-implemented and researcher-managed/farmer implemented. We feel that such classifications are more confusing than useful. This book is based on the principle that in any on-farm trial the degree of farmer management should be maximized. This does not mean that everything will always be left entirely to the farmers. The researchers will have to assist farmers with technology they are not familiar with, but that does not mean that they should also interfere with those operations which farmers are perfectly capable of handling themselves and which they have sound reasons for using.

Whenever the team feels that a technology is not sufficiently mature to be exposed to farmer management, they should conduct trials under their own management. Such trials are no different from conventional station or multilocational trials, even if they are conducted in farmers' fields. The same applies to trials relating solely to physical conditions. If, for instance, nothing is known about crop response to fertilizer in the soils in the area, there is no point in conducting farmer-managed trials until the response curves have been established in researcher-managed trials. Such trials, sometimes called 'exploratory trials', may have to be conducted in farmers' fields if the soil conditions in the station or substations are not representative. We will assume that the researchers are familiar with the principles of such trials and will refer to standard textbooks (e.g., Snedecor and Cochran, 1967).

We will sometimes refer to a trial as a 'diagnostic' trial to emphasize that one major objective is to learn more about farmers' systems and practices. Such trials would consist of one or two very simple innovations, such as an improved variety, and are conducted entirely by farmers. The researchers take extensive measurements on all aspects of the farmers' practices and use the results to analyze production constraints. Such trials are not essentially different from other farmer-managed trials.

The only categorization we will use here is based on the class of innovations being tested, because it affects the way the trials are designed:

- *elementary technology.* We will call a technology 'elementary' if it cannot be broken down into separate elements. Examples are an improved variety or fertilizer applied to one of the crops in a mixture. Even elementary technology may be gradually adopted by farmers. A new variety, for example, may be adopted on a small area first, or mixed with local varieties, while fertilizer may be adopted at a lower rate.

- *technology packages.* This is a combination of several technologies, where the total effect on yield of the package is expected to be greater than the sum of the effects of the individual elements' 'synergy'.

- *composite technology.* We will call a technology 'composite' if it is composed of several elements which cannot be applied separately, or if it requires changes in the farmers' cropping pattern. One example is alley cropping, which means planting hedgerows, maintaining them and growing crops continuously in the alleys.

How are on-farm trials different from station trials?

Most agronomists are trained in experimental techniques developed for research stations. In station trials, the treatment factors are the only variables while everything else is kept constant. In variety trials, for example, land preparation, time of planting, planting density, fertilizer rate, weeding frequency, etc., are all standardized and uniformly applied to all varieties and to all replicates. The effect of soil differences in the experimental fields is usually controlled by grouping the treatments in more or less homogeneous blocks. Therefore, the most important principle of controlled field trials is that 'the non-treatment variables' are applied as uniformly as possible, thereby giving maximum expression to differences due to the treatments.

This principle cannot be applied to the same extent in farmer-managed trials. Imposing uniformity would require the choice of uniform trial fields, planting the crops at a fixed time and at a prescribed density, applying recommended maintenance, etc.

In this way, researchers would interfere with the farmers' usual practices to an unacceptable extent. The farmers would invariably lose interest, consider the trial as the researchers' business and insist that labor be provided. Under these conditions, the technology is certainly not being tested under farmers' conditions and farmer management. In fact, it is being tested under artificial conditions with the farmer as a reluctant laborer or a passive observer. Whereas station trials are meant to measure the treatment effect only, on-farm trials should focus on the fact that the treatment effect depends on the differences in farmers' management practices.

For farmer-managed on-farm trials, we therefore propose that the condition of uniformity should largely be abandoned and that the trial should be embedded ('superimposed') in a field chosen by the farmer, planted at his convenience and managed entirely in his own way. Control over non-treatment variables is then replaced by the observation of farmers' actual practices. Statistical techniques are available to account for the effect of variable management practices between farmers, but we would point out the desirability of treating all plots in a given field in the same way. The gains from this non-interference approach are (i) a realistic assessment of technology performance under real farmers' conditions and (ii) a reduction in the need for supervision, because the farmers will take full responsibility for their own fields. The price paid for these advantages are (i) the need for frequent observation of the farmers' management, (ii) a larger number of participating farmers to capture the entire range of variation in management practices and (iii) the need for more sophisticated statistical analysis.

Defining the target population: choice of farmers and fields

Choice of farmers

On-farm trials should measure the performance of the technology under the conditions of the real farm, that is under *'representative farmer conditions and management'*. The first question to be asked is: representative for which farmers?

There may be considerable differences among farmers in physical and socioeconomic conditions as well as in management practices, and the researchers must decide whether the technology is intended for all farmers or for a specific group. In other words, they must define the target population for the technology and select a sample of trial farmers which is representative of the target population. This may seem obvious, but in many on-farm trials the target population is not explicitly defined. The information needed to group farmers into meaningful categories was collected earlier by means of the informal survey (Chapter 4) and subsequent experiences. Identifying the target population for a specific technology now means matching the technology to the appropriate farmer category or 'recommendation domain'.

In the case of improved varieties, the target population will usually be 'all farmers in the area': the researchers want to know the varieties' performance across the range of farmers' conditions and management practices.

In the example from the forest-savannah transition zone in southwest Nigeria (Chapters 4 and 5), legume cover crops were identified as a potential innovation for fertility improvement and Imperata control. The constraints addressed by the innovations were typical for 'savannah' fields, and these fields would therefore be the target for the technology.

To take another example, the on-farm team in southwest Benin differentiated between Imperata-infested fields, low-fertility fields and totally degraded fields within the same zone. Different technological options were chosen for these targets (mucuna, pigeon pea and *Acacia auriculiformis*, respectively) for on-farm testing (Versteeg and Koudopon, 1993).

Within a target population of farmers or fields, there will always be considerable variation, both in physical conditions and in farmers' management practices. Technologies will perform differently according to which farmer is using them. Average yields are therefore not sufficient, and the trials should provide information on the effect that farmer-related factors have on the technology's performance. To achieve that, the range of each important factor should be represented in the sample of trial farmers as it occurs in the target population. For example, if farmers usually plant the target crop over a period of, say, 2–3 months, then the trial should also cover this period.

Choosing a sample from the target population for participation in the trials is similar to the problem of sampling in surveys. In surveys, stratified sampling is carried out if it is expected that some groups will have a systematically different score. For instance, people with a university education are expected to have higher incomes than those without. The accuracy of information on income distribution will be enhanced by including representatives of each group, according to their frequency in the total population.

When choosing trial farmers, stratified sampling could in theory be used, but, when pushed too far, this leads to major theoretical and practical problems. There are many factors which influence the performance of a technology. Some of them are physical—such as soil types, differences in hydrology and shadiness of the field—and some are farmer-related—such as management practices, time of planting and weeding frequency. It is practically impossible to ensure the equal or proportional representation of all these characteristics in the sample. Some of the physical factors may be assessed before the trial, but farmers' management practices mostly become apparent after planting.

We therefore only recommend systematic sampling for at most one or two clear-cut factors. Possible examples are

- different villages
- clearly differing soil types, if they occur and can easily be distinguished
- gender, if both men and women farm individually, as in southwest Nigeria

Deciding for which factors to stratify is only part of the problem. In surveys, the researchers can set up the sampling frame before the survey is carried out. In on-farm trials, however, it is often very difficult to get firm commitment for participation from farmers ahead of the season. A predetermined sampling scheme is therefore practically impossible and even self-defeating. Much time may be wasted by visiting farmers who are on the sample list but who may not really be interested in participating. Rather than identifying individuals in each category ahead of the season, we suggest that participants be recruited as the planting season progresses, while taking precautions to see that each important category is adequately represented.

For date of planting, we recommend more or less systematic sampling, i.e., distributing the trial plantings over the farmer's usual planting season. For gender, caution should be taken to ensure that both men and women farmers are adequately represented, if this is appropriate. Otherwise the sampling should be done randomly. The sample is thus selected using a mixture of a fixed (categories) and random approach.

In practical terms, the team could proceed as follows:

1. Decide on the categories of farmers and fields which need to be represented in the sample. Use only a small number of categories (probably not more than two) which can be easily identified.

2. Hold village meetings to discuss and explain the purpose of the experiments and explain how the experiments are conducted. Emphasize that the experiments will be superimposed on the farmers' normal fields.

3. During the meeting, ask farmers to sign up for the trials. Treat this list as very preliminary. Only part of the initial list may eventually participate.

4. When farmers start planting their fields, approach the farmers on the list, but make it known that any farmer, whether on the list or not, is welcome to participate.

5. In any given week, try to obtain the desired participation from the predetermined categories.

6. Continue adding new participants until the end of the planting season.

This procedure should result in participation by a cross-section of farmers, while care is taken that important categories (e.g., females) and planting dates are adequately represented. The resulting sample would be less biased than by including only 'contact farmers'. It is more easily implemented than drawing up a final list before the season.

A condition for the success of this approach is that the field team resides permanently in the research villages and keeps in constant touch with the farming community.

Choice of fields

Our sampling method is based on farmer interest, while bias is avoided as much as possible by favoring the inclusion of certain categories. A farmer will choose a field for a certain crop on the basis of his or her own criteria, but the researcher has the choice of accepting that field for the trial or rejecting it if it does not qualify for reasons of representativeness. There may be two reasons for rejecting a field:

- if it is not representative for the 'target population'. For example, a field cleared from forest fallow would not be acceptable for a technology intended for fields with a savannah vegetation.
- if this type of field is already adequately represented in the sample. For instance when the researchers have decided to stratify fields according to soil class, and enough fields have already been planted in this particular class during this week. This option only applies when there are abundant candidates for participation. Otherwise, it may be better to accept fields, even if one in a different category would have been preferable.

Design of trials

We use the word 'design' in a broad sense, including the following elements:

- the choice of treatments to be compared in the trial
- the choice of 'non-treatment variables'
- the choice of the most appropriate experimental design
- the choice of the number of replicates
- the size of plot (in the statistical sense)

Choice of treatments

As with any experimental design, the choice of treatment must follow from the objectives of the trial. We recommend that the team explicitly formulates hypotheses for each trial and then designs specific treatments to test the hypotheses. Farmers should be closely associated with this process, and they may bring in unexpected insights which can alter the choice of treatments.

Consider the simple example of testing streak-resistant maize varieties. Streak disease can be devastating, especially when maize is planted late in the season. The hypotheses could be:

H_1 Growing a streak-resistant variety instead of a traditional one will improve the yield of farmers' maize planted late in the season.

H_2 Farmers will accept the variety if H_1 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), planted in the farmers' usual cropping pattern(s).

Plant breeders often insist that their varieties be tested with a package of recommended practices, such as sole cropping and fertilizer rate. However, this does not follow from the above hypotheses. Hypothesis H_1 implies that the varieties should be grown by farmers using their own management practices. If the researchers want to include other components in the trial, such as fertilizer application, this should be explicitly stated in the hypotheses.

Another consequence of H_1 is that the improved varieties should be tested late in the season when streak pressure is high. It is likely that the researchers will also want to know how the improved variety will perform early in the season when disease pressure is less. In that case, the hypothesis would be different:

H_1 A streak-resistant variety will improve farmers' maize yield when planted late in the season and will not produce less than the local variety when planted early.

H_2 as before

For a more complex example, consider two of the innovations for Nyankpala in the previous chapter, aimed at alleviating a soil-fertility constraint. The hypotheses would be:

Sole groundnut (innovation 1):

H_1 The benefits of sole groundnut for next year's cereal crop as found on the research station will also be obtained on farmers' fields.

H_2 Farmers will be prepared to grow sole groundnut if hypothesis H_1 is demonstrated to be true.

Cassava + groundnut break crop (innovation 2):

H_1 Yields of cereals (next year) after cassava, grown with groundnuts (this year), will be better than yields after cropping patterns that include cereals.

H_2 Farmers will accept the practice of growing cassava without cereals admixed if H_1 is demonstrated to be true.

To these primary hypotheses, subsidiary ones may be added to narrow down the choice of treatments. For instance, in the sole groundnut innovation:

H_3 Phosphate fertilizer will improve the yield and subsequent benefits of sole groundnut.

H_4 Farmers will use phosphate fertilizer if H_3 is demonstrated to be true.

In each case, the hypotheses were divided into those that concern technical questions and those that concern adoption by farmers. Adoption will be discussed separately in the next chapter.

Next, the hypotheses are translated into experimental treatments. This involves a precise definition of the innovation and the way it is to be fitted into the farmers' cropping patterns, based on the trial's hypotheses. We recommend the following four steps:

1. Describe the *innovations* in sufficient detail.
2. Define *the target cropping pattern* into which the innovations are to be introduced.
3. If necessary, describe *the niche* for the innovations in the target pattern and describe how the innovations are to be integrated into the pattern.

4. Define *the control treatment* with which the innovations will be compared.

We will give examples of the three categories of technologies defined earlier on.

Elementary technology. For elementary innovations such as an improved variety, choosing treatments is straightforward, but the four steps should nevertheless be carefully followed.

Consider, for example, the cropping pattern with maize in Nyankpala, northern Ghana (Fig. 5.4 in Chapter 5). Planting is staggered over a long period to reduce risks associated with dry spells during the first few months of the rainy season (Fig. 4.7, Chapter 4). Improved streak-resistant varieties of maize were proposed in order to improve maize yield. The hypotheses given at the beginning of this section would apply in this case. We will describe the four steps necessary to define the innovation and the way it is integrated in the farmers' pattern.

1. *The technology.* One or more streak-resistant varieties will be tested with approximately the same growing cycle as the local variety and a similar grain quality. Farmers should participate in choosing the desirable varietal characteristics.

2. *The target cropping pattern.* Farmers' (maize + groundnut)/sorghum pattern. Planting densities and planting time may vary considerably from field to field, according to choices made by farmers.

3. *The niche.* Because of their resistance to streak, the improved varieties are particularly useful for late-planted fields. Such fields must therefore be well represented in the sample.

4. *The control.* The local variety. Different farmers may grow different local varieties. This should be carefully recorded.

Technology packages. Assume that a team wants to test a simple technology package consisting of an improved variety and fertilizer to improve maize yield in an area where the major cropping pattern is maize + cassava (see for example Fig. 4.14, chapter 4). The hypotheses are as follows:

H_1 An improved maize variety recommended for the area will significantly increase maize yield.

H_2 A moderate fertilizer rate with about 45 kg N ha-1 will significantly increase maize yield, particularly in degraded fields.

H_3 Farmers will keep seed of the improved variety for later planting if the yield advantage is convincing to them.

H_4 Farmers will apply fertilizer if (i) maize yield increase is sufficient and stable, (ii) cassava yield is either not affected or increased and (iii) fertilizer can be purchased locally.

Note that we now explicitly mention fertilizer as a possible yield-increasing factor in the hypotheses. In the first example in this section this was not the case.

If we want to test only two varieties (improved and local) and two fertilizer levels, then this will result in four treatments arranged as a factorial. H_2 implies that the sample of trial farms should include a considerable number of degraded fields, say, at least half. In the example of Alabata in southwest Nigeria, these would be the fields with a savannah vegetation.

H_3 states as a criterion for adoption that if farmers take the trouble to keep the seed of the improved variety, that is convincing evidence that they are ready to adopt the variety. The researchers, therefore, have to monitor this. H_4 says that (i) the yield of cassava should also be measured, (ii) an economic analysis is needed for the effect of the treatments on both maize and cassava yields and (iii) the researchers must monitor whether farmers will continue to apply fertilizer on maize after the trial is completed. If fertilizer is not purchased in spite of its profitability, the researchers must find out why.

This example illustrates how a careful definition of hypotheses helps in developing a complete research program around some simple technologies.

A more complicated situation arises when the maize production package also includes an increased maize density. Experience shows that farmers usually plant at densities which are adequate for their management and input levels (Kang and Wilson, 1981; Mutsaers et al., 1981). Higher densities will only make sense at higher fertilizer rates than farmers usually apply. We will, therefore, add an additional hypothesis to the previous set:

H_{2a} Iincreased maize density will increase maize yield if combined with a moderate fertilizer rate.

And change H_4 by adding 'and increase maize density'

Even if these three factors (variety, fertilizer and maize density) are applied at only two levels each, a full factorial would require 8 plots. Instead of a full factorial, we therefore suggest a stepwise trial design, which will be further discussed in the next section. A possible set of treatments is shown in Table 6.1. The sequence of the treatments is based on the expectation that increased density will only affect maize yield if combined with fertilizer.

Table 6.1: Treatments in a Stepwise Design for Maize Variety, Fertilizer and Maize Planting Density

Treatment	Maize variety	Fertilizer	Maize density	Note
1	local	farmers'	farmers'	baseline
2	improved	farmers'	farmers'	step 1
3	improved	increased	farmers'	step 2
4	improved	increased	increased	package

Composite technology. Such technology cannot be broken down into components and must therefore be tested as a whole. A fairly simple example was the introduction of a cassava + groundnut intercrop in Nyankpala to 'break' the continuous cereal sequence in the farmers' system. The hypotheses have already been given. We will develop the experimental treatments using the four steps highlighted above.

1. *The technology.* An intercrop of cassava + groundnuts, cassava grown at about 10,000 plants ha-1 and groundnuts at 40,000 ha-1 with one cassava and four groundnuts planted to a heap. Cassava is planted early in the season and groundnuts about 2 weeks after the cassava. Cassava will be harvested after 8 months (December).

2. *The target cropping pattern.* The cassava + groundnut mixture is meant to break the continuous cereal sequence where farmers grow several successive cycles of the (maize + groundnuts)/sorghum pattern (Fig. 6.1).

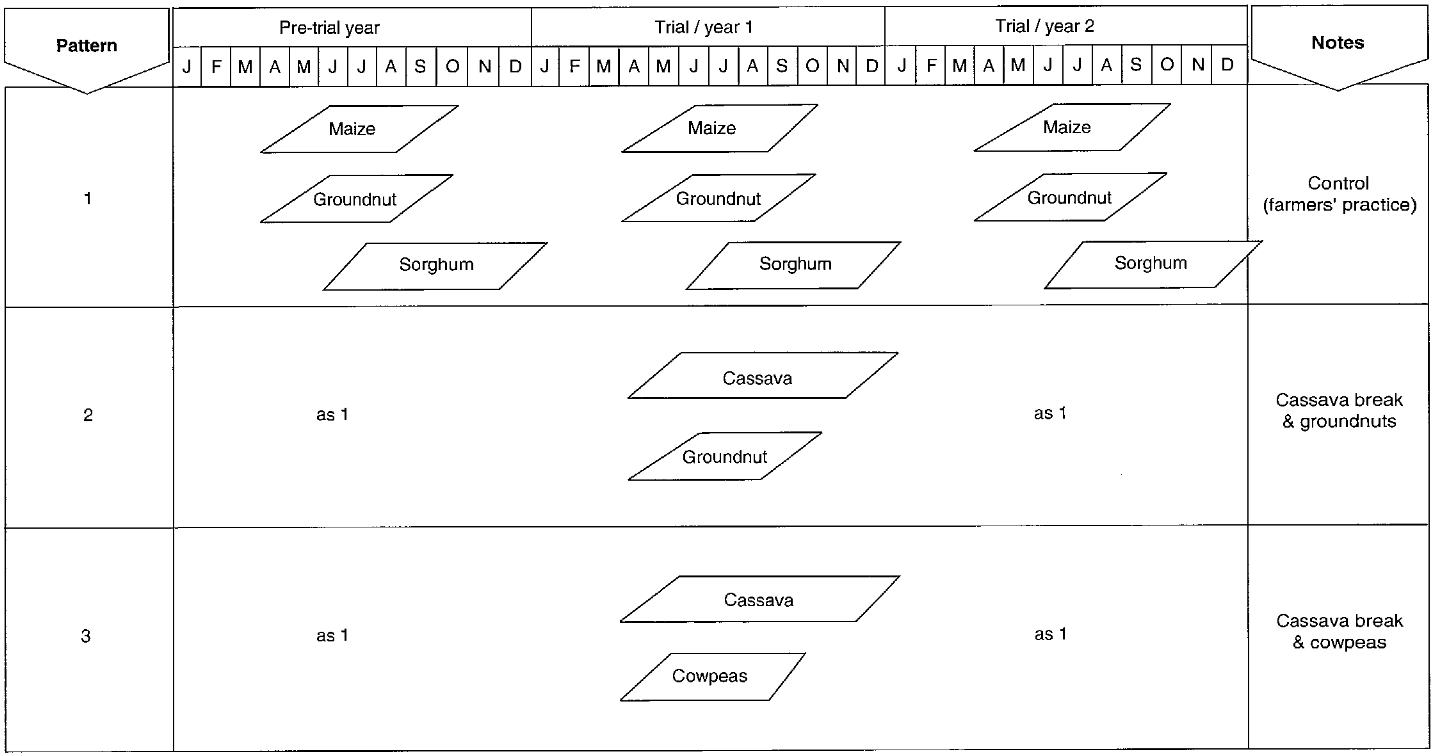


Figure 6.1: Experimental treatments and control treatment for the 'cassava break crop' intervention, extending over a period of 2 years, Nyankpala, northern Ghana

3. *The niche.* One cassava + groundnut mixture will be grown between two (maize + groundnut)/sorghum crops (previous and subsequent cropping year).
4. *The control.* In the control, a crop of (maize + groundnut)/ sorghum will be grown both in the trial year and in the subsequent year.

Fields which were cropped with (maize + groundnut)/sorghum in the previous year will be selected for the trial. Only two treatments—the cassava + groundnut 'break' crop and the control (Fig. 6.1)—will be planted in the trial year, followed by farmers' (maize + groundnut)/sorghum in the subsequent year. There would be no objection to expanding the trial by including one or two extra treatments if the team or the farmers would consider that useful. An obvious choice would be two cassava varieties, the farmers' usual variety and an early-bulking type from the research station, resulting in three treatments. Another option would be to include sole cassava or cassava associated with another legume such as cowpeas, so as to break continuous groundnut- as well as maize-cropping.

We strongly recommend the use of charts such as Fig 6.1 to visualize the trial set-up.

Farmer participation in the choice of treatments

In the past, farmer participation in the choice of treatments has often been weak, but there are many examples which show that it is essential. Ashby (1986) gives examples of the design of fertilizer treatments which incorporated farmers' views and experiences, thereby greatly increasing their sense of ownership of the trials.

In a series of on-farm trials with second season cropping in southwest Nigeria (Mutsaers, 1991), farmers expressed reservations about the researchers' proposal of growing groundnuts and (streak-resistant) maize, because, in their experience, neither crop produced well in the second season. They were, however, interested in testing new genetic material on a small scale, especially for groundnuts. The farmers proved right in both cases, and many of them largely abandoned the maize plots halfway through the season when the damage due to stemborers made it uneconomical to devote any more time to the crop.

In Mono Province (Republic of Benin), the OFR team offered a range of possible innovations for fertility improvement and discussed these with farmer groups. They explained the characteristics of each innovation and invited the farmers to choose one or more, depending on the severity of the fertility problem in the individual farmer's field (Versteeg and Koudokpon, 1993).

In Lake-Zone, Tanzania, the OFR team organizes 'Farmer Technology Markets' before each season, where researchers display and explain innovations, allowing farmers to make a well-reasoned choice, according to their own circumstances (Budelman, pers. comm.).

Non-treatment variables

In controlled trials, all conditions and practices which do not form part of the treatments are kept constant as far as possible, both within and across replicates. This allows the researcher to measure the effect of the treatments under otherwise constant conditions. Performance across environments is measured by conducting parallel replicated trials in different environments.

In on-farm trials, however, the situation is completely different. Differences among farmers are important, and the performance of the technology as a function of farmers' conditions is often more important than average performance. While treatment effects in controlled trials are measured under basically one or a few sets of conditions, in on-farm trials they are tested under as many different conditions as there are farmers. All the operations and management practices which are not part of the treatments should be left entirely to the farmers. Differences among farmers, if properly monitored, can be used to analyze in how far the performance of a technology depends on farmers' conditions.

Complete farmer management will not only result in important differences between farmers, but also in differences between plots within fields. When farmers are fully in charge, there is no way to ensure that all the plots are treated equally. A farmer may, for example, weed part of the plots on a given day and the rest a week later. It will usually also be impossible to ensure uniform physical conditions within a replicate because of soil variability, differences in shade due to trees, etc. Researchers trained in experimental techniques for research stations may find this objectionable; uniformity within replicates is one of the cast-iron rules in field experimentation. It is obviously true that farmer-related variations inflate the error term in the analysis if they are not accounted for, but analytical techniques are available for capturing a large part of this variation, provided the trials are properly monitored. The price paid in increased variability is more than compensated for by a large gain in representativeness and the understanding of factors affecting the performance of a technology on farmers' fields. The relevant analytical techniques will be discussed in the next chapter.

Statistical design

Statistical design *sensu stricto* is concerned with:

(I) how treatments are put together, i.e., whether they consist of variations within a single factor or of combinations of several factors, perhaps at different levels

(ii) how the treatments are laid out in the field, i.e., assigned to the experimental units ('plots') within a replicate

(iii) how many times the treatments are replicated within and across fields

Treatment composition. The simplest cases are single factor trials where the treatments are variations or levels of the same qualitative or quantitative factor (variety, nitrogen rate). In the case of variety trials, each variety stands on its own and is compared with all the other varieties. With nitrogen rates, the different levels are related through an underlying response curve to nitrogen, which is estimated from all levels jointly.

When two or more factors are tested simultaneously, the different treatments (factor combinations) are always interconnected. In the case of a factorial trial with two varieties and two fertilizer levels, for example, the main effects (variety, fertilizer) and interactions (variety x fertilizer) are calculated from all four treatments simultaneously. Another example is a stepwise trial where each factor is introduced in a predetermined order. We will discuss stepwise trials in more detail later on.

Sometimes treatments may not be related at all in a statistical sense, as, for example, in the experiment to test the cassava + groundnut break crop of the previous chapter (Fig. 6.1). The treatments are the farmers' usual sequence (control) and the alternative pattern (cassava + groundnut break crop).

Treatment lay-out. The simplest case is the randomized complete block (RCB) design, where each treatment or factor combination occurs exactly once per replicate and is assigned randomly to the experimental plots. Treatments may be different levels of a single factor, completely unrelated treatments, factorial combinations or stepwise treatments as discussed above. When testing combinations of two or more factors, we will sometimes want to use split-plot or criss-cross designs, instead of a randomized factorial. We will discuss this later in some detail. More complex designs such as confounded factorials and partially replicated designs are not recommended for on-farm trials.

Replication. In controlled trials, the experimental field is usually subdivided into several more or less homogeneous blocks and, with complete blocks, each treatment combination occurs once per block. In on-farm trials, there are many fields, each with its own conditions and management practices. Obviously, the trial will be replicated across farmers' fields, but the question is, should the trial also be replicated *within* each farmer's field?

There are strong practical arguments for a one-farmer, one-replicate approach (e.g., Mutsaers and Walker, 1990) and recent analysis (Stroup et al., 1991) has provided statistical justification for a single replicate per farm. We therefore recommend a single replicate in each farmer's field.

This allows the number of plots to be kept to a minimum and ensures that the demonstration effect of the trial is maximized. In Chapter 7 we will discuss statistical techniques for drawing inferences about technology performance across farmers' conditions from single replicate trials.

The number of farmer replicates needed to get the desired answers from a trial will be discussed later on in this chapter.

Choice of appropriate design. Which design is best for a particular trial depends on a number of factors, but the overriding condition is that farmers should understand exactly what is being tested and be able to evaluate the treatments using their own criteria.

This implies that

- the number of differently-treated plots should be limited and not exceed five or six. Three to four would be better.
- all treatments should occur in every field, which excludes fractional replication
- the trial should be laid out in such a way that the differences between the treatments are obvious to farmers

We will consider several statistical designs which are suitable for farmer-managed on-farm trials, keeping these restrictions in mind.

Single factor trials

When testing a single elementary technology, such as improved varieties or fertilizer levels, or composite technology such as alternative cropping patterns, the different treatments are arranged in an RCB. We recommend restricting this kind of trial to four treatments, e.g., not more than three improved varieties and a local variety or at most two alternative cropping patterns.

Randomizing the treatments in each field is advisable. Otherwise, a particular treatment which is always in the first position may be disadvantaged, for example, by always being closer to the surrounding forest and therefore more exposed to shade or other types of competition.

Simple factorials (2^2)

The simplest factorial consists of two factors at two levels each, e.g., two varieties and two fertilizer levels, resulting in four treatments. Two examples are shown in Fig. 6.2. Whatever the arrangement, the two varieties or fertilizer rates will always be in adjacent plots (row, column or diagonal). Since there is no *a priori* choice of orientation of the trial in a particular field, gradients of fertility or shade may occur in any direction. It is therefore acceptable to use a systematic arrangement with varieties in a vertical and fertilizer in a horizontal direction or vice versa and still analyze this as a randomized factorial. Such

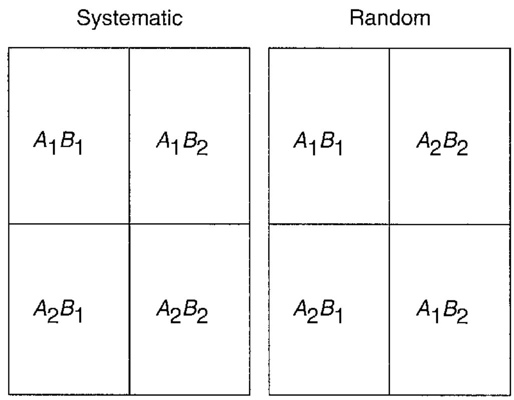


Figure 6.2: Two options for field layout of a 2^2 factorial trial

systematic arrangements have an advantage for their demonstration effect.

The restriction of no more than six treatments means that the number of factors that can be tested in a factorial trial cannot be more than two (e.g., variety and fertilizer), with one of them at two and the other at three levels, if necessary (for example, farmers' variety + two improved varieties, each at two fertilizer rates).

Factorial trials with several factors at two or more levels are not appropriate for farmer-managed trials. If a team thinks such trials are needed, it probably means that they do not have enough information to narrow it down to a smaller number of treatments or that the target system has not been sufficiently well defined.

In the first case, they should carry out researcher-managed experiments to decide on the most appropriate combinations of factor and levels for subsequent on-farm work. In the second case, the target system should be redefined in order to make the choice of treatments more specific. For example, if farmers grow early cassava varieties in some fields and late varieties in others, the research team may choose different sets of varieties for the two field types. The example of erosion control technology in northern Nigeria also indicated the need to differentiate two separate target systems, thus reducing the number of treatments.

Split-plot and criss-cross trials

Consider a trial with three varieties at two fertilizer levels. The six combinations could be completely randomized, but then the farmers may lose sight of the differences between treatments. One alternative would be a split-plot design with one factor, e.g., variety, on the main plots and fertilizer on the sub-plots. This ensures the adequate visibility of the effect of the two factors.

Sometimes it may be desirable to use an even more systematic layout and a 'criss-cross' design may then be useful. In a criss-cross (or 'strip-plot') design, one factor is arranged in one direction and one in another. Limited randomization is possible in criss-cross designs and should be carried out. For example, a team in the Republic of Benin wanted to test the effect of pigeon peas interplanted into sole-cropped maize on the subsequent maize crop. They decided to combine this test with the evaluation of three maize varieties. They wanted to keep all the plots of a particular variety together for demonstration purposes, as well as plots with pigeon peas, so that farmers could clearly observe the effect on the next maize crop. They therefore chose a criss-cross design as shown in Fig. 6.3 (Versteeg and Huijsman, 1991). The analysis, which is discussed in detail in Chapter 7, treats the trial as two separate split-plot trials for the main treatments, while using the sub-plot variance for testing interactions.

	Variety$_1$	*Variety$_2$*	*Variety$_3$*
without pigeon peas	P_0V_1	P_0V_2	P_0V_3
with pigeon peas	P_1V_1	P_1V_2	P_1V_3

Figure 6.3: Field layout of a criss-cross trial with three maize varieties, with and without pigeon pea, Mono Province, Republic of Benin

Stepwise trials

Recommended production packages for a crop usually consist of several factors, such as improved varieties, a recommended fertilizer rate and recommended density, at levels determined in researcher-managed trials. An on-farm team may wish to evaluate the contribution of each of the components of a package under full farmer management. Conducting a full factorial, even for three factors at two levels, would result in an unacceptably large number of treatments. Besides, a full factorial does not make use of previous knowledge, for instance, that increasing maize density makes no sense unless more fertilizer is applied.

A stepwise trial design is an alternative which allows the testing (and demonstration!) of the contribution of several factors with a limited number of treatments. It requires a judgement to be made about the likely order of importance and the contribution of the factors.

For example, in an experiment in southwest Nigeria, the team wanted to test several simple improvements for maize in the maize + cassava pattern. The factors were maize variety, fertilizer and increased maize density. It was decided to use a stepwise design, with each following step including an additional improvement. The team reasoned that the improved maize variety would be the single most profitable innovation, requiring no cash outlays nor other additional inputs. Improved variety was therefore introduced as the first 'step'. Increasing the density of maize was thought to be meaningless without fertilizer. Fertilizer was therefore the second step and increased density the third (Table 6.1). For demonstration purposes, it would have been ideal to lay out the treatments in the order of the different steps. This could introduce a systematic bias, however, and it was therefore decided to randomize in each field in an RCB design.

In the analysis, the effects of treatments on both maize and cassava had to be combined. We will discuss the analysis of stepwise trials in Chapter 7.

Plot size

In controlled experiments, the size of all plots is the same and depends on the species or type of technology to be tested, as well as on the measurements to be taken.

In farmer-managed on-farm trials, the minimum plot size will always be larger than in controlled trials:

- The microvariability of the fields is usually much greater than in research stations.
- Farmers must be able to assess the technology at a 'real life' scale.
- The information on management and labor which sometimes needs to be collected requires larger plots than would be acceptable for purely physical and biological measurements.

Furthermore, the larger the experimental plots, the more likely farmers will be to accept the trial as a significant part of their cropping operations and to apply their usual management practices.

We recommend a minimum plot size of about 200 m^2, larger if this is required by the experimental treatments (e.g., alley cropping!), or if labor measurements are important (Spencer, 1993). It is not essential for plot sizes to be identical across fields. Some farmers may be able or willing to devote a greater area to a trial than others. As a rule of thumb, however, the difference between the largest and the smallest plots should not be more than 50%, to ensure approximately equal variance across fields.

Number of replicates

We will see later on that the analysis of on-farm trials will usually consist of (i) an ANOVA which tests for treatment effects and their interaction with mean site yield and (ii) a regression analysis of mean site yield for a number of farmer categories against variables measured in the fields. The number of replicates of a trial must be adequate for both types of analysis.

Remember that we usually have a single replicate per farmer, so number of replicates means here number of different sites or farmer fields.

For the *regression analysis,* we need to have at least 15 degrees of freedom (df) for the residual variance. The number of replicates then depends on how many categories and variables we will use as independent variables in the analysis. Assuming that the latter will rarely exceed 10, the minimum number of replicates would be 26 (15+1+10).

For the *analysis of variance* the number of replicates depends on

- the expected within-field variability
- the desired precision of the conclusions

Let us assume that we want to be reasonably (say 80%) sure that the trial will detect a significant difference between treatments if the *real* difference is f% of the treatments average. The number of replicates (k) needed to detect such a difference in an analysis with tests at a probability level of 95% depends on f and on the coefficient of variation (CV) of the trial according to the following expression (see Cochran and Cox, 1957):

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

with k = number of replicates

CV = coefficient of variation

f = difference between treatment means which the researcher wants to detect, expressed as a percentage of the trial mean

Both f and CV are expressed as a percentage.

If we want to be 90% sure of detecting such a difference, k must equal

$$k = 23\ (CV/f)^2$$

This relationship is plotted for 80% certainty in the nomogram of Fig. 6.4. The number of replicates can be read from Fig. 6.4 for any combination of CV and f or calculated with the formulas. If you want to be 90% sure of detecting a difference at the desired level, instead of 80%, multiply the number of replicates read from Fig. 6.4 by 1.3 (= 23/17.5).

Note that the number of replicates increases as the square of the detectable difference decreases.

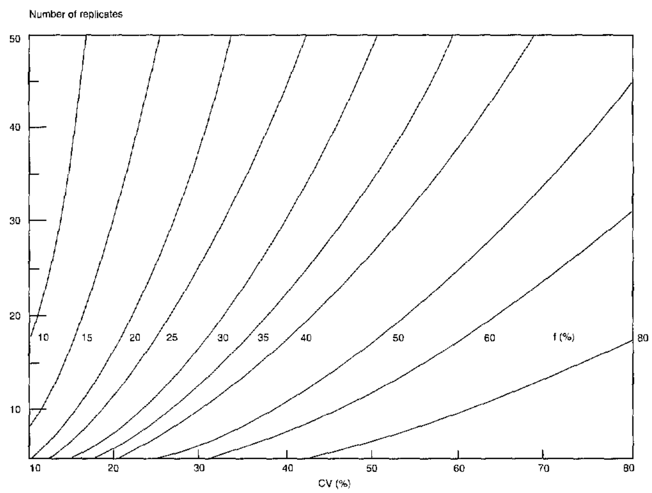


Figure 6.4: Nomogram for the number of replicates needed to detect a given percentual yield difference at a given CV of the trial

As an example, consider a trial that is expected, on the basis of earlier experience, to have a CV of 25% (not unreasonable). If researchers want to be 80% sure of detecting treatment differences that exceed 25% of the trial mean, they will need a minimum of 18 replicates (verify this with Fig. 6.4!). To be 90% sure, the number of replicates has to be 23 or more.

Thus, we have two *statistical* criteria for the minimum number of replicates, one based on the ANOVA, one on the regression analysis. Both criteria will usually carry the same weight and we will therefore choose the larger of the two.

Observations and measurements

Every farmer's field is a different environment. There are differences in soil conditions, weed flora, shadiness. Fields differ in previous cropping history, farmers plant their crops at different times, they may or may not weed thoroughly. These differences will affect crop production in general and the performance of new technology in particular. We may term this 'desirable variation' because it helps to explain differences between farmers.

Also, there is usually considerable variation between plots within each field in soil conditions, the amount of shade, and the incidence of pests and weeds. Farmers may weed part of a field at one time and the rest later, etc. These differences will inflate the within-field variation which affects the precision of the trial, but, if properly recorded, they will also contribute insights into the causes of yield-depressing factors.

We have stressed the need for minimum interference with farmers' cropping practices, and we should exploit the observed differences to explain yield variation among farmers and to help diagnose production constraints. Statistical techniques for interpreting farmer differences and for explaining the effect of within-field variation will be discussed in the next chapter. Here, we will review the type of information useful for those purposes.

Collecting good information in farmer-managed trials is the key to quality results and solid conclusions, while collecting unnecessary information is a waste of time and energy. It is quite common for laborious plant measurements to be carried out which are never used, while other observations, which could explain differences, are not recorded. The former category includes details of plant growth—such as height, leaf area, girth, number of tillers, number of grains per panicle or cob—which may be useful in controlled trials but hardly ever in farmer-managed trials.

It is better to spend limited resources and time on the collection of data that characterize the environment and farmers' practices, such as shade—if appropriate—soil texture and depth of profile, cropping history and weed incidence. Another pitfall is an overemphasis on accuracy of measurement. Shade or weediness, for example, can be measured with sophisticated methods, but this will rarely be possible or even useful in on-farm trials.

Before the start of the trial, the team should carefully spell out in the trial protocol which data should be collected and how this will be used in the analysis:

- Some variables must be recorded at the level of the individual plots, such as stand density and shadiness. They will later be used as 'regressors' (or as covariates) in the statistical analysis to reduce the residual variance of the trial, thereby increasing its precision.

- Other variables need only be recorded at the field level, such as crop varieties and time of planting. These variables will be needed to explain differences between farmers and fields. Average values of the 'plot variables' will also be useful. For example, the average shadiness of a field will affect the overall (average) yield in that field.

Every area and every type of trial has its own specific conditions which will determine what kind of data should be collected. Here we will only look at that information which will almost

Table 6.2: Minimum Data Set for Farmer-Managed On-Farm Trials

Plot level	
1.	Stand counts at establishment, midseason and harvest
2.	Density of secondary crops
3.	Pest and disease scores (ordinal)
4.	Weed scores (ordinal), repeated a few times, or number and times of weedings
5.	Shade scores (if applicable)
6.	Crop yields
7.	Variable inputs (i.e., inputs which differ between treatments), including labor if appropriate
8.	Farmer assessment of treatments
Field level	
1.	Depth of soil profile
2.	Soil texture (sandy, medium, heavy) at two depths (0–15 and 15–30 cm)
3.	Soil pH at 0–15 and 15–30 cm
4.	Slope and position on slope
5.	Crop management information which is not part of the treatments (date of planting, field history, land preparation, varieties, plant arrangement)
6.	Age and sex of farmer and origin (indigene or immigrant)
Village level	
1.	Rainfall (daily, mm)
2.	Prices of inputs
3.	Wage rate during the season
4.	Output prices, end of season

always be needed, in any area or for any type of trial—in other words the 'minimum data set' (Table 6.2). Most of the data in the table is self-evident, but we will discuss some types of information that may need further clarification.

The information to be collected before and during the trial should be discussed with prospective trial farmers, who may have valuable suggestions about factors which could influence trial results. It will also increase farmers' awareness of the objectives of the work and their role as co-researchers.

For all the observations during the growing season and for the final harvest, we recommend using a limited number of sample rows or strips, rather than the entire plot. The location of the rows should be clearly indicated on the field maps.

For recording all the relevant information on the trial and the trial fields as well as all the measurements and observations, a field book should be designed and kept for each trial field with a layout of the trial field and pre-printed data sheets.

Soil analysis

There is much confusion and disagreement about the need for and the value of soil analysis in on-farm trials. Many field workers do not have access to laboratory facilities, and if they do, the costs for routine analyses are often prohibitive. It is our experience that the value of detailed chemical analysis in explaining differences among farmers in most cases does not justify the efforts and costs. We therefore do not recommend analysis at the level of each trial field. Detailed soil analysis for a sample of fields may be useful for a general characterization of soils in the pilot area and may already be available from secondary sources, but it is rarely useful for explaining yield differences between individual fields.

Three easily measured parameters may, however, be considered at the field level, namely profile depth, textural class and pH. Experienced agronomists should be able to estimate textural class manually in the field. Simple field testing kits or hand-held meters are commercially available, and these can give reliable data on soil pH.

An interesting alternative to chemical soil analysis for the measurement of initial soil fertility is the use of maize as an indicator plant (Osiname et al., 1991; Eilittä et al., 1991). Early growth of maize, expressed as the plants' girth, was found to relate better with yield than any of the chemical soil parameters (Eilittä et al., 1991). If maize is not part of the target cropping pattern, maize plants may be sown at low density to serve as indicators for initial soil fertility. Their girth is then used as a covariate in the statistical analysis.

Technologies which are highly responsive to nitrogen availability in the soil perform differently according to the inherent nitrogen release in a field. Such soil processes cannot be measured with routine soil analysis, and total N or organic carbon are poor indicators of such differences. Recent work in the savannah of Nigeria indicates that extractable nitrogen-nitrate is a good indicator for inherent soil fertility and correlates highly with farmers' maize yields (Weber et al., 1993). Simple methods for analyzing extractable soil nitrate are under development at IITA.

Crop disorders (pests, diseases, weeds)

The simple scoring of crop disorders is as much as field workers should attempt, although for certain types of trials more quantitative measurements may be required (e.g., when studying new weed control techniques). The scoring of crop disorders is often conducted in such a way that the data is of no use in the analysis of trial results. The problems are (i) the lack of objectivity of the scores, (ii) the unknown relation between scores and expected crop losses and (iii) the timing of scoring.

Clear criteria must be agreed beforehand. If, for instance, an ordinal scale on insect infestation includes none, light, moderate and severe infestation, an entomologist should instruct the field staff which average number of insects per plant, averaged over how many plants, corresponds with each ordinal point. The criterion may be based on previous on-station research, relating infestation to yield depression, although most scoring systems developed on station are too laborious for on-farm work. In the absence of such data, research may be required. Purely subjective scores are often meaningless. An example of on-farm scoring methods for pest infestation of maize in the savannah and for on-farm assessment of yield loss from Striga is available in Weber et al (1992).

The timing and frequency of the scoring are also important factors. For weed scores in particular, a single visit is inadequate. The farmer may just have weeded the field. A few visits should be made at the growth stages which are most sensitive to weed competition. If this is not possible, it may as well be omitted altogether, and the team may simply record the number and times of weeding. A good sampling plan designed before the cropping season is therefore crucial.

Labor

Calculation of the profitability of a technology may require an estimate of labor cost. Measuring labor use is, however, difficult and costly. Sometimes secondary data from surveys in the area can be used to estimate labor requirements for standard operations. This cannot be done when new practices/inputs are being tested, e.g., new planting methods or new implements. In this case, labor data for those operations should be collected from the experimental plots. Spencer (1993) developed a simple method of collecting labor data by recall. He showed that farmers will accurately recall labor use for at least 28 days, provided the operation is made into a significant event in the farmer's memory. Farmers will remember the time spent on various operations if requested beforehand to do so. The minimum plot size for this purpose was found to be about 350 m2.

Yields

In station trials, measurement of yield is straightforward—the whole trial is harvested at a predetermined time. In on-farm trials, we recommend rather large plot sizes and, apart from the amount of labor needed, weighing the entire plot yield may meet with objections from the farmers. We therefore recommend the use of sample rows or strips, not just for observations but also for the final harvest. The researchers must, of course, know the size of the area their sample rows represent.

Even in station trials, losses may occur due to theft or accidents. In on-farm trials, there are many more possible causes of loss of information on crop yield, such as spot harvesting by farmers for early consumption (green maize!), theft, farmers harvesting all or part of the plots without advising the researchers and staggered harvesting of root crops such as cassava. Because of our principle of minimum interference, some of the causes of losses are unavoidable, and we should use a sampling and measurement scheme which allows us to extract the maximum of information anyway. Every on-farm trial and every situation will demand its own imaginative solution. Rather than trying to be comprehensive, we will give two examples of methods to correct for losses which were applied in the trials treated in this book.

The first example is for maize harvesting and accounting for missing cobs. Farmers in West Africa will go into their fields before the crop is fully mature and harvest fresh cobs for home consumption or sale. Sometimes the stalks are left standing, sometimes they are chopped down. In either case, it is fairly easy to count the number of cobs which were harvested. We corrected for these missing cobs by assuming that their weight equalled the average cob weight of the remaining stands. This may be a slight underestimate, because farmers may actually pick the largest cobs. After weighing, the remaining cobs in the sampling rows are left with the farmers. We therefore only measured wet weight and corrected for moisture content, based on a few samples taken at intervals in different fields, which were shelled, dried and weighed again. This introduces an error because different fields will be harvested with different moisture status. The differences among treatments within fields, however, will be much less affected by this source of error. The (probably rather small) error among fields is a small price to pay for greatly increased efficiency and minimum interference with farmers' operations.

The second example is for cassava. Farmers may do a few rounds of harvesting, each time harvesting only those stands they consider ready. First, we must count the number of stands present sometime before the farmers are likely to start harvesting. We would then ask the farmers to advise us when they would be going into the trial field, and we would request them to include in their harvest those stands in our sample rows which they consider ready for harvesting. Those stands are then weighed on the spot. If possible, the process is repeated as many times as the farmers harvest. At the end of the season, the average weight of all the harvested stands is calculated and multiplied by the number of stands counted before harvesting started. This also accounts for those stands that were harvested by the farmers in our absence. Although the resulting yield figures are not exact, we expect the error to remain within reasonable limits. Our justification for the procedure is that it faithfully mimics farmers' harvesting behavior and involves a minimum of interference. More systematic procedures will always involve a measure of pressure on farmers. If they resent this, they may refuse to co-operate, and this could result in a greater loss of information than the error involved in our method.

Farmer assessment

Farmer assessment of the performance of trial technology and the results of on-farm trials is crucial and arguably the most important part of technology evaluation. Farmers will only decide to adopt technology if they are convinced of its benefits and if the technology does not require unacceptable efforts on their part. No amount of statistical and economic analysis can replace farmer assessment and farmers' adoption behavior as the definitive test. The assessment of acceptability for farmers must therefore consist of two parts:

- eliciting farmers' opinion on the technology (passive evaluation)
- monitoring farmers' actual adoption behaviour (active evaluation)

Of these two, the second is the most important. Without actual adoption by farmers, a technology has not been proven!

An extensive body of literature has accumulated on these subjects and we will not treat the issues here. We urge the reader to consult specialized books for guidance, such as

1. a set of case studies on successful OFR projects published by CIMMYT (Tripp, 1991)
2. a book of methods on technology evaluation by farmers, published by CIAT (Ashby, 1990)
3. a manual for the design of surveys on technology adoption by CIMMYT (CIMMYT Economics Program, 1993)

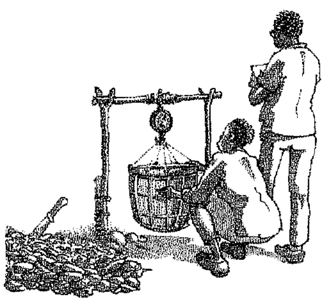
Managing a trial program

The selection and training of the field staff who supervise and monitor the trials is perhaps the most difficult and yet the most essential component of good on-farm experimentation. The field team should live in the pilot villages and must be prepared to be available whenever they are needed, rather than working office hours. They must be competent in both the official and the local languages, have a good knowledge of the locality and a sympathetic personality. Former extension staff 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 field team undergoes on-the-job training with the researchers. They must participate in all village and farmer meetings and become familiar with the concept of farmer-participatory research. First and foremost, they will have to develop the attitudes necessary for conducting real farmer-managed trials. Although the underlying ideas are quite simple once they have been accepted, experience shows that many scientists and field staff alike often have great difficulty in putting them into practice.

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 a questionnaire into the local language and another, independently, to translate it back. Then meet with both to discuss where the inaccuracies have arisen.

The field team should keep a file on each individual trial field containing the 'field book' with all the original data sheets and questionnaire forms. They should be copied into a second file for safekeeping by the researchers. The field staff should always carry a field note book to record occasional observations while visiting the fields or discussing with farmers.



The color-coding of the trial plots is advisable. 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 explains that the plots should differ only in the intended treatment. The enumerator should always be within reach to answer farmers' questions or refresh their memory.

Chapter

7 Statistical Analysis

Introduction

The aim of the statistical analysis of experiments is to examine to what extent observed effects, such as yield differences, are caused by experimental treatments. In station trials, treatment factors are chosen by the researcher, and all other (non-treatment) factors are kept constant. Uncontrolled variation is minimized to enhance the precision of the trial. In the previous chapters, we have seen that, in farmer-managed trials, it is impossible and even undesirable to keep non- treatment factors constant. Non-treatment variables are part of farmers' normal crop management practices, and on-farm trials need to reveal how such factors affect the performance of the treatments.

An overview of the chapter

We will distinguish two types of uncontrolled variation in farmer-managed trials:

- variation at the field level due to the differences between fields in soil, planting dates, management practices, pest incidence, etc., which affect all plots in a particular field in more or less the same way
- variation at the plot level which causes differences between plots within a field, because farmers do not treat the plots uniformly and because of local differences in soil, shade, pest incidence, etc.

Differences among fields are most interesting, because they are likely to influence the performance of the treatments. In fact, the way treatment effects vary among farmers is essential information which should be extracted from the trials. In order to quantify this variation, we need a simple indicator value which characterizes the overall conditions in a particular field. An obvious choice is the mean yield of all the experimental plots in a particular site (field). We will use this 'site index' to examine if and how treatment effects vary with farm conditions. This will be done by testing for *interaction between mean site yield and treatments* in the analysis of variance (ANOVA) (Morris, 1981) and by a graphical method called *adaptability analysis* (formerly *modified* stability analysis) developed by Hildebrand (Hildebrand, 1984; Hildebrand and Russell, 1994).

- Plot-level variation inflates the residual variance and reduces the accuracy of the trial, unless it can be reduced by statistical techniques. For this purpose, we will use measured ('concomitant') variables as *regressors* in the analysis (and sometimes as covariates).[1]
- Finally, we want to *explain* differences in average yield among farmers and fields, i.e., why certain fields produce better than others. For this analysis, we will mainly use

1. Covariance analysis of on-farm trials is rather complicated and will often not be needed. We have separated the treatment of covariance analysis as well as other more advanced topics from the rest of the text by using a smaller font size. These parts may be skipped.

multiple regression analysis of mean site yield on a number of variables, measured at either the field or plot level.

The four analytical techniques—(i) tests for 'treatment x site-mean' interaction, (ii) adaptability analysis, (iii) regressor (and covariance) analysis and (iv) multiple regression analysis—are the selected tools in the analysis of farmer-managed on-farm trials. Without them, such trials will often have an unacceptably high degree of variability, and important information about how technology performance varies from farmer to farmer will be lost. By using these techniques, the methodological arguments often heard against farmer management in on-farm trials lose any validity. On-farm trials will then become powerful tools for identifying factors affecting the performance of technology under farmers' conditions and for analyzing the causes of variability between farms.

Three trials will be used as examples to demonstrate the analytical techniques:

1. a 2^2 maize variety-fertilizer trial, conducted in Alabata, southwest Nigeria
2. a stepwise maize + cassava trial with fertilizer, improved weeding and increased density, carried out in the forest fringe ecology of Ayepe, southwest Nigeria
3. a criss-cross trial with maize varieties with or without pigeon pea interplanted into the maize, conducted in Mono Province, Republic of Benin (Versteeg and Huijsman, 1991)

African farmers, especially in the wetter areas, rarely grow a single crop in their fields. Mixed cropping is much more common, and researchers must take the yields of all major crops into consideration. We will consider the implications later on in this chapter, but first we shall discuss the analysis of trials where the dependent variable is the yield of one particular crop.

Analytical methods

We will demonstrate the basic analytical techniques with a simple 2^2 maize variety-fertilizer trial conducted in Alabata in the forest-savannah transition zone of southwest Nigeria in 1988, with 25 farmers and a single replicate per farmer/field. In

22 of the fields, yields could be measured. All farmers interplanted maize with cassava, but for the moment we will ignore the cassava yield.

In the analysis of on-farm trials, we will usually want to consider all the classifications, treatment factors, interactions, (covariates) and regressors simultaneously. For the sake of clarity, however, we will introduce the different analytical components one by one. This will also allow us to see what additional information is obtained with each increase in refinement of the analysis.

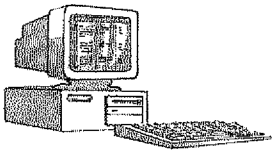
Before any statistical analyses are conducted, we strongly recommend that the data be carefully inspected to identify any anomalies. Extreme values or 'outliers' should be carefully examined, because they may distort the analysis. Some variables are best inspected graphically by plotting the data in scatter diagrams.

To demonstrate the statistical analyses, we first carry out a simple ANOVA, as we would if this were a station trial, and then examine the conclusions from this analysis. Next, we add the term for 'treatment x sitemean' interaction in order to account for differences between fields, and examine any additional information yielded by this technique. Adaptability analysis is then used to examine what this interaction means. This is followed by an ANOVA augmented with additional variables which were measured in each plot in the course of the trial and which we treat as regressors (or sometimes as covariates). Finally, we look at the average yield of each field (averaged over treatments) and try to explain differences among fields by regression analysis for several measured variables.

The ANOVA routines in most statistical software packages are not capable of performing all the calculations needed for a comprehensive analysis which exploits all the available information. Exceptions are large packages like GENSTAT and SAS, which have all the necessary capabilities, but these require fairly advanced hardware and are rather difficult to learn. We recommend the use of a computer package which has a general linear model (GLM) capability or a multiple regression routine with dummy variables for qualitative factors, classes and replicates.

We will give full details of the analytical concepts and calculations in Annex II, including notes on the use of software.

Data inspection and scatter plots



In the maize variety-fertilizer trial, we first verify that the shade figures are all in the range from 0 to 3. We then plot different scatter diagrams for the yield data, for shade and for plant stand at establishment, tasseling and harvest. Most statistical packages have a facility for generating such scatter plots; otherwise a spreadsheet package may be used.

One way is to plot the variables against field number to spot fields with exceptional values. Another way is plotting the dependent variable—in this case yield—against the independent ones, for different treatments. This will show whether treatment effects are influenced by the values of the concomitant variables. In this trial, there appeared to be a trend of this kind for the effect of fertilizer on maize in relation to date of planting (Fig. 7.1a, yields are averages for the two plots with the same fertilizer level). This will be further analyzed later on. A strong relationship was further observed between stand at harvest and yield for all treatments taken together (Fig. 7.1b).

Another useful plot is for the stand measurements at different times. Outliers could indicate measurement errors or serious pest attacks in a field. In this trial, the only anomaly observed was a single plot in field 16 with very high stand density (Fig. 7.1c). This as not due to a measurement error, because the fourth scatter plot (Fig. 7.1d) shows that the high stand persisted in later countings.

Analysis of variance

The standard analysis for station trials involves calculating mean yields for all the treatments and carrying out an ANOVA. The ANOVA tests which differences between treatments are significant. We will carry out the analysis for the 2^2 maize variety-fertilizer trial with two maize varieties and two fertilizer levels in all four combinations (Table 7.1). Since this is a factorial trial, we will distinguish the main effects of the treatment factors and their interactions, and all of them can be tested independently for significance (see Snedecor and Cochran, 1967 for details on

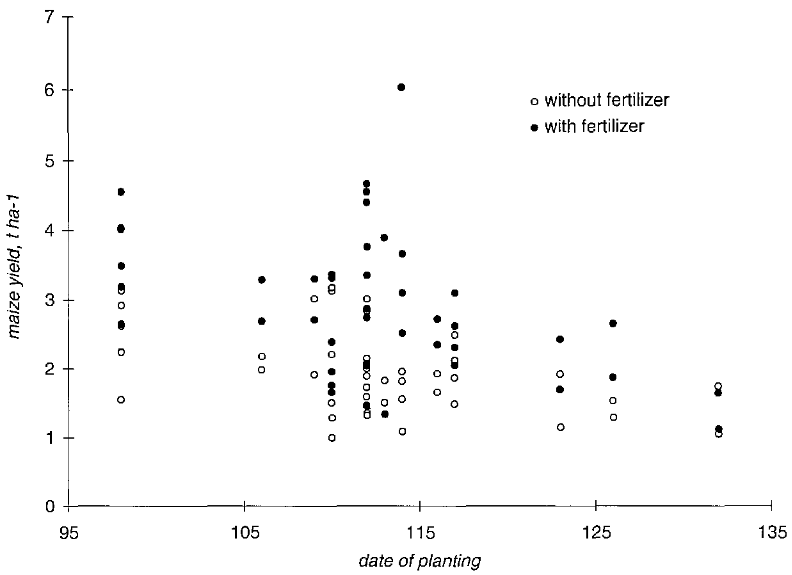


Figure 7.1a: Scatter diagram of maize yield with and without fertilizer, versus date of planting; 2^2 variety-fertilizer trial, Alabata, southwest Nigeria, 1988

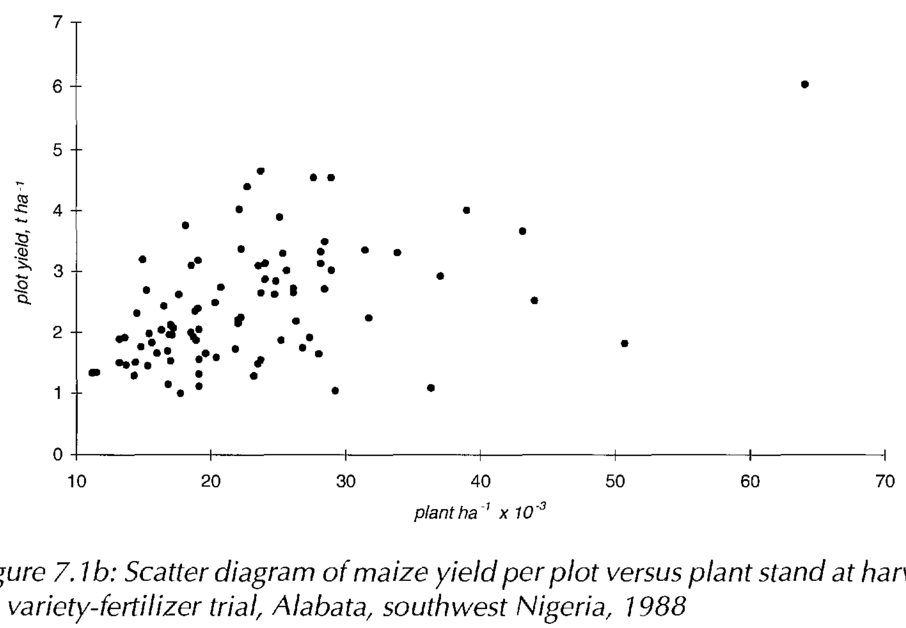


Figure 7.1b: Scatter diagram of maize yield per plot versus plant stand at harvest; 2^2 variety-fertilizer trial, Alabata, southwest Nigeria, 1988

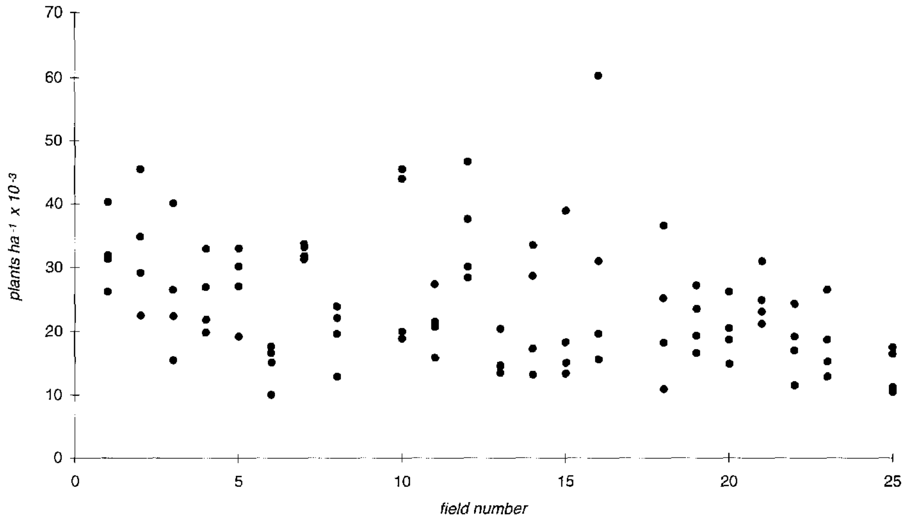


Figure 7.1c: Scatter diagram of plant stand at harvest versus field number; 2^2 variety-fertilizer trial, Alabata, southwest Nigeria, 1988

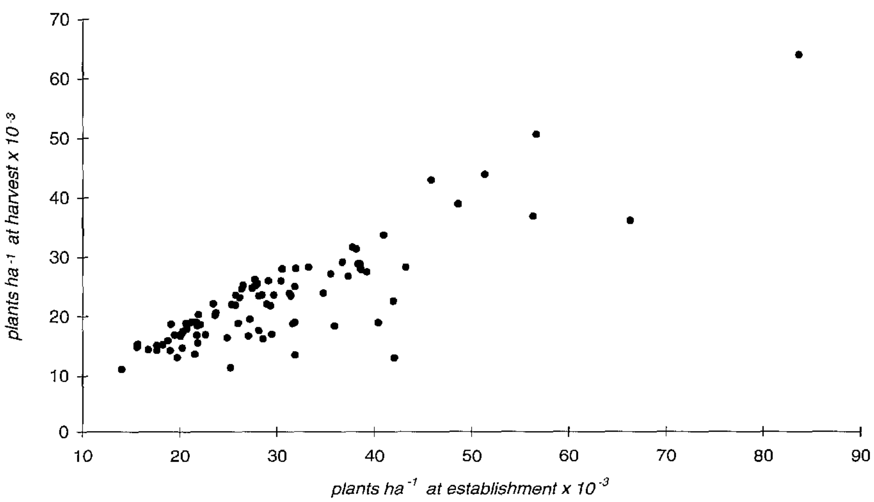


Figure 7.1d: Scatter diagram of plant stand at harvest versus stand at establishment; 2^2 variety-fertilizer trial, Alabata, southwest Nigeria, 1988

Table 7.1: Mean Treatment Yields and ANOVA, On-Farm Trial with 22 Farmers; 2 Maize Varieties and 2 Fertilizer Levels, Alabata, Southwest Nigeria, 1988

	Fertilizer, kg ha^{-1}		
Varieties	0	300 (15:15:15)	Mean
Local	1.85	2.73	2.29
TZSR-W	2.04	3.06	2.55
Mean	1.94	2.90	2.42

Source	Sum of squares	D.F.	Mean square	P-Value
Mean	514.93	1	514.93	<0.0001
Sites	35.20	21	1.68	<0.0001
Variety	1.44	1	1.44	0.0615
Fertilizer	19.96	1	19.96	<0.0001
Variety x fertilizer	0.10	1	0.10	0.6200
Residual	25.0875	63	0.3982	
	R-Square: 0.69		CV: 26.1%	

the analysis of factorial trials). What can be learned from this simple ANOVA applied to farmer-managed on-farm trials?

The ANOVA (Table 7.1) shows that only the fertilizer effect was significant, but we suspect that the non-significance of the variety effect could simply be due to the unacceptably high CV of 26.1%. Furthermore, the differences in mean yield between fields are large (line 2 in the ANOVA). The treatment effects could therefore vary substantially across fields, but that cannot be verified by this simple ANOVA. Variation of treatment effect with farmers, if it occurs, may also explain part of the high CV, because the 'treatment x field' interactions are included in the residual ('error') term of the ANOVA. We will first extend the ANOVA with a test for 'treatment x field' interaction.

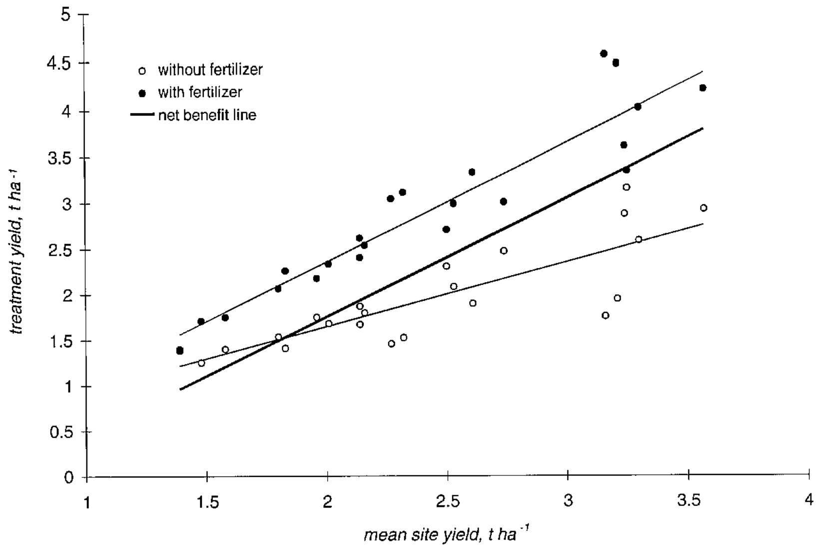
Treatment x sitemean interaction; adaptability analysis

We now want to examine whether the treatment effects vary significantly across fields. It is likely, for example, that fields with poor management will have a lower yield and would benefit less from fertilizer than those with good management. Also, a variety which performs better than the local varieties under good management may have less advantage under poor management. The varieties may even 'cross over', with the local variety doing better in low-yielding fields and the improved variety in higher-yielding ones, as was often the case with improved rice varieties released during the early stages of the green revolution in Asia. This could mean, in practical terms, that blanket recommendations given to all farmers, irrespective of their conditions, may not be appropriate.

Thus, the underlying conditions which affect fertilizer response need to be further analyzed. For this purpose we will use mean site yields (the average yield of all treatments in a given field) as a 'site index', which is assumed to reflect the overall growing conditions and the quality of management in a particular field. For each field we will plot the yield at each factor level (F_0, F_1 and V_1, V_2) against the sitemean for that field (Fig. 7.2). Since each fertilizer level comprises two plots in each field (one for each variety), the yield for a particular fertilizer level is the average for the two plots which received that fertilizer level. For each variety, there are also two plots one at each of the two fertilizer levels. The graph shows that the yield difference due to fertilizer was greater as the field's overall yield level was higher; the slope of the regression of yield on sitemean is steeper with fertilizer than without. The variety effect did not show any trend with mean site yield. This type of analysis has been used extensively in multilocational testing of varieties (e.g., Finlay and Wilkinson, 1963) and was generalized by Hildebrand (1984) for on-farm trials as 'adaptability analysis'. It may be used for any type of treatment, not just varieties or fertilizer.

Plots like Fig. 7.2 are often published without a test of significance for slope differences. We find this unacceptable, because apparent differences in slope of the calculated regression lines may not be significant. This may suggest an effect which is not substantiated by the data. A test for the significance of the differences in slopes is needed to complement adaptability analysis. A conventional test for 'treatment x site' interaction is not possible because there is only one replicate per farm. It is also inappropriate in on-farm trials for other reasons, discussed by Stroup et al. (1991). A test of significance for slope differences is equivalent to a test for interaction between 'site index' (average yield of all treatments in a given field) and treatments in the

(a)



(b)

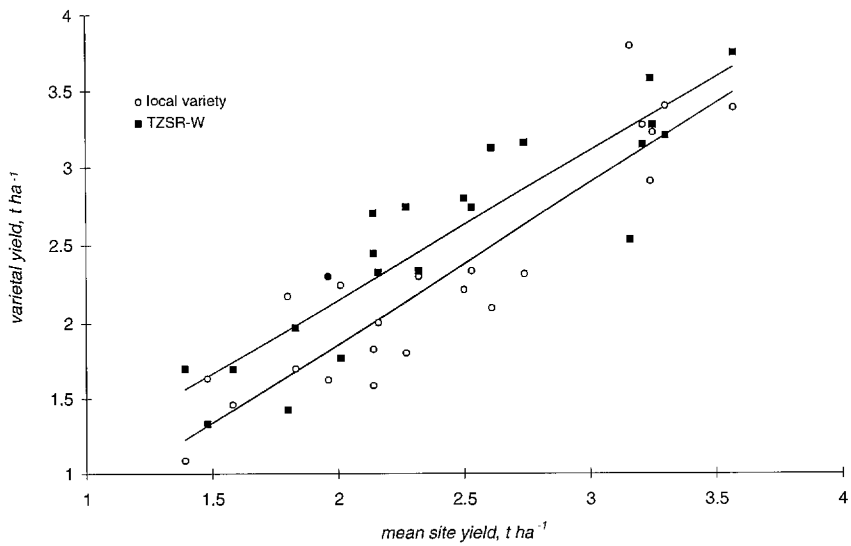


Figure 7.2: Relationship between mean site yield of maize and (a) mean yield with and without fertilizer, (b) mean yield of local and TZSR-W variety; 2^2 variety-fertilizer trial, Alabata, southwest Nigeria, 1988

ANOVA (Morris, 1981). We will call the site index 'sitemean' from now on. This analysis can be done with some general linear model (GLM) or with multiple regression (see Annex II) but not with most routine ANOVA packages. If the interaction is significant, this means that the yield response to treatments depends on field conditions and differs systematically across fields. Since, in our example, we are dealing with a factorial trial, we may calculate separate interactions for variety and fertilizer effect with sitemean. The results for this trial (Table 7.2) show that only the interaction of fertilizer with sitemean, in other words, the difference in slopes between the regression lines in Fig 7.2a was significant (more details on the calculations are given in Annex II).

Table 7.2: ANOVA of Treatment Yields of the Same Trial as Table 7.1, with Treatment x Sitemean Interaction

Source	Sum of squares	D.F.	Mean square	P-Value
Mean	514.93	1	514.93	<0.0001
Sites	35.20	21	1.68	<0.0001
Treatments				
Variety	1.44	1	1.44	0.0487
Fertilizer	19.96	1	19.96	<0.0001
Variety x Fertilizer	0.10	1	0.10	0.6003
Interactions with sitemean				
Variety x Sitemean	0.05	1	0.05	0.6971
Fertilizer x Sitemean	3.05	1	3.05	0.0048
Residual	21.9814	61	0.3604	
	R-Square: 0.7385		CV: 24.8%	

We conclude that the fertilizer effect was dependent significantly upon farmers' overall yield level, but not the variety effect. The error term and the CV (Table 7.2) have somewhat decreased because we isolated some meaningful variation in the interaction terms, which would otherwise inflate the error. As a result, the variety effect is now declared significant at the 5% probability level, and inspection of the table of means (Table 7.1) shows that this was due to a higher yield of the improved variety.

We will now look more closely at the 'fertilizer x sitemean' interaction. According the ANOVA of Table 7.2, the interaction was significant, in other words, the effect of fertilizer depended on the farmer's yield level. The yield increase due to fertilizer does not come free—the net benefit from fertilizer is the gross benefit minus the cost of fertilization. In order to obtain the net gain, we must shift the yield line with fertilizer in Fig. 7.2 downwards by an amount which is equivalent to the cost of applying fertilizer. Assume for simplicity's sake that the cost of the purchase and application of 1 kg of fertilizer is the same as the price of 1 kg of maize. It is often assumed that the net return to investment should be 100% in order to be attractive to farmers. At an application rate of 300 kg fertilizer per ha, the fertilizer line should therefore be shifted downwards by 600 kg (the thick line in Fig. 7.2). At this price ratio between fertilizer and maize, fertilizer is only expected to be profitable for those fields which had an average yield of 1800 kg/ha or more. For more complex technologies, partial budget analysis should be considered (CIMMYT, 1988).[2] We will further analyze the causes of differences in treatment effects among farmers and fields in a later section.

Regressors and covariates

The analysis of Table 7.2 still does not use any of the additional information which was collected in the trial plots. The CV remains rather high (24.8%) and we suspect that a lot of variation may be hidden in the error term, which could be explained by some of our measurements. For instance, some plots may be more shady than others, and there may be differences in planting density and in stand losses due to pest attacks. These unintended plot differences are usually the cause of a high CV. We will now introduce the use of regressors (and covariates) to account for such unscheduled variation. In most cases, unscheduled variation will not favor one treatment at the expense of another, and we can use a fairly simple extension of the ANOVA with regressors to reduce the residual variance.

2. For a thorough treatment of economic analysis of on-farm trials we refer to CIMMYT, 1988, From Agronomic Data to Farmer Recommendations: *An Economics Training Manual.* Completely revised edition. Mexico, D.F. The manual may be obtained from: CIMMYT, Lisboa 40, Apdo Postal 6-641, 06600 Mexico D.F., Mexico.

Sometimes, however, a variable *may* bias the treatment effects. For example, one particular treatment may have been assigned by farmers to a greater number of shady plots than another treatment, either by chance or even intentionally. The former would then be at a disadvantage. Or the seed of one variety may be of better quality than another. If the seed of an improved variety is provided by the researcher, for example, it may have a higher germination percentage than the local variety provided by the farmer. In that case, the variety with the better seed has an undue advantage and the difference in yield between varieties could be partly due to seed quality rather than yield potential. Analysis with regressors only reduces the error term, while covariance analysis also corrects the treatment effect for biases caused by covariates. An analysis by regressors leaves the treatment effect unaffected and will only remove that part of the residual variance which is caused by the concomitant variables. Covariance analysis is a rather complex subject. We will see that, in most experiments, the need for it may not even arise. We feel, however, that it is necessary to treat the subject in some depth for the benefit of readers with more advanced statistical training, because it will increase their insight into the potential complexity of on-farm trial analysis. We recommend that the reader consult a good text book on statistics (e.g., Snedecor and Cochran, 1967 or later) as an introduction to the subject.

Regressors

Unscheduled variation among plots will most often be more or less random. In other words, we would not expect the value of a variable such as shade to be consistently higher for some treatments and lower for others. Other examples of random variation are differences in planting density between plots or stand differences caused by random pest attacks. These random effects will inflate the error term in the analysis and reduce the precision of the trial unless we take them out. To account for such variation, we use the measured variables as 'regressors' which are included as the last terms in the analysis. This removes part of the residual sum of squares (SS) without correcting treatment SS.

Even variation with a *partially* causal relationship with the treatments can be handled in this way. Take, for example, stem borer damage in maize. Part of the difference in damage between plots may be caused by varietal differences or by differences in plant vigor due to fertilizer. A variable such as 'plant stand at harvest' will include these effects as well as random stand losses. If the variable is included as the last term in the ANOVA, however, it only accounts for the *random part* of the stand losses. Differences in stand losses which are associated with the treatments have already been absorbed by the treatment factors. The example later on in this section will further clarify the concept.

Covariates

Unintended variables should in some cases be treated as covariates if their values are systematically different for the different treatments. A classic example is the sizes of trees in a trial with a perennial crop (Snedecor and Cochran, 1967). Treatments are assigned randomly to the trees but the average tree size of one treatment may be different from that of another, purely by chance. If, as is likely, the size of a tree affects its yield, then the treatments with the larger trees would be unduly advantaged and a correction should be applied to remove this effect from the treatment SS and from the mean treatment yields. This is accomplished by covariance analysis, which also reduces the residual SS, thereby improving the accuracy of the trial. Before deciding to use covariance analysis, we should very carefully consider whether the conditions for its application have been met.

We recommend that the researchers very carefully consider for each measured variable whether there are arguments for considering its use as a covariate. Covariance analysis can become quite complex and laborious and should be used only when the researcher is convinced that there is an undesirable association with treatments. Before deciding in favor of covariance analysis, the researcher should then conduct a formal test to examine if an association between the candidate covariates and treatments has actually occurred. This is done by carrying out a simple ANOVA with the covariate as the *dependent* variable. If there are no obvious *treatment* effects on the covariate, then that variable should not be used as a covariate. Secondly, it should be verified that the variable does indeed have a *direct* effect on yield. If not, then covariance analysis need not be applied either. This will be demonstrated in the example further on.

We will examine the use of covariates and regressors for the 2^2 variety-fertilizer trial, but we refer the reader to Annex II for a more detailed treatment of the calculations. The four variables measured in each plot were (i) shade scored on a scale from 0–3, (ii) maize stand at establishment, (iii) at tasseling and (iv) at harvest.

The stand counts are not suitable as covariates. There may be differences in initial stand due to difference in seed quality among varieties, which in some cases may inflate the varietal effect. Differences in seed quality, however, cannot be separated from the overall variety effect. Later stand differences may be a direct result of treatments and should therefore in no case be used as covariates.

Shade is a possible candidate for covariance analysis. Before this can be decided, we must conduct a ANOVA with 'shade' as the *dependent* variables. Because of the inevitably high degree of variability, we suggest using a conservative criterion for significance, say P<10%. Table 7.3 shows that shade may be considered as independent and should therefore be treated as a regressor.

Table 7.3: ANOVA with 'Stand at Establishment' and 'Shade' as Dependent Variables

Source	Sum of squares	D.F.	Mean square	P–Value
Stand at establishment				
Mean	78488	1	78488	
Sites	6833.79	21	325.42	<0.0001
Variety	192.34	1	192.34	0.0966
Fertilizer	28.52	1	28.52	0.5183
Variety x Fertilizer	43.54	1	43.54	0.4253
Residual	4258.9026	63	67.6016	
Shade				
Mean	8.28	1	8.28	
Sites	8.47	21	0.40	0.0703
Variety	0.28	1	0.28	0.2879
Fertilizer	0.28	1	0.28	0.2879
Variety x Fertilizer	0.10	1	0.10	0.5225
Residual	15.5795	63	0.2473	

Association of the covariate with treatment is a *necessary, but not a sufficient* condition to justify its analysis as a covariate. It could happen, for example, that the covariate *in the range in which it occurs* in the trial does not really have a causal effect on yield. If that is the case, then covariance analysis is also not appropriate. We must therefore first test whether there is a 'pure' effect of the covariate on yield, i.e., independent of its association with treatment. This is done by running an ANOVA, with the covariate included as the last term after the classifications, treatments and interactions, but before regressors. This provides a test for the independent part of the covariate. If the pure covariate effect is significant, it suggests that covariance analysis is indicated.

Although stand at establishment is not suitable for covariance analysis, the above tests may still be useful to examine whether seed quality could have affected the varietal effect. Table 7.3 shows that stand was associated with variety and Table 7.4 suggests that there was a real independent effect of initial stand on yield. The conclusion would be that part of the varietal difference could have been due to seed quality, but there is no way to decide how much. The outlier which showed up in the scatter plot, however, should make us suspicious. We therefore run the ANOVA again, this time excluding the outlier and treating it as a 'missing value' (see below and Annex II). The effect of initial

Table 7.4: ANOVA of the Same Trial as Table 7.1 with Treatment x Sitemean Interaction, the Candidate for Covariance Analysis (Stand at Establishment) and Regressors; Each Term Sequentially Adjusted for the Preceeding Terms

Source	Sum of square	D.F.	Mean square	P-Value
Mean	514.93	1	517.93	
Sites	35.20	21	1.68	
Treatments				
Variety	1.44	1	1.44	
Fertilizer	19.96	1	19.96	
Variety x Fertilizer	0.10	1	0.10	
Interactions with sitemean				
Variety x Sitemean	0.05	1	0.05	
Fertilizer x Sitemean	3.05	1	3.05	
Candidate covariate				
Stand at establishment	7.63	1	7.63	<0.0001
Regressors				
Shade	1.24	1	1.24	
Stand at tasseling	0.24	1	0.24	
Stand at harvest	3.75	1	3.75	
Residual	9.1294	57	0.1602	

stand on yield is now not significant and we feel more confident that the measured varietal effect on yield is indeed due to variety and not to difference in seed quality.

Covariance analysis was *not appropriate* for this trial and we suspect that this will often be the case in carefully designed on-farm trials. In Annex II, we will nevertheless work an example of covariance analysis (corrected SS and means for the treatment) to demonstrate the technique.

The four measured variables are used as regressors to reduce residual variance, thereby increasing the sensitivity of the trial. They are inserted in the analysis as the final terms, after classifications (sites), treatments, interactions and 'treatment x site-mean' interaction (and, if appropriate, covariates). This is also called 'forward inclusion' or 'sequential adjustment', each following term being adjusted for the previous ones. This can be done with some GLMs or with a multiple regression package. By this arrangement, that part of the regressor effect which is associated with treatments is removed by the treatment SS, and what remains is the random part. This is essentially different from covariance analysis, because now we do not correct the treatment SS. That part of the stand differences which is *caused by* the treatments remains part of the treatment effect itself, as it should. The calculations are explained in detail in Annex II.

Table 7.5 shows the complete ANOVA with the SS of the model terms and the regressors. The contributions from 'treatment x sitemean' interaction and regressors to the overall analysis of the trial can be seen from a comparison of Tables 7.1, 7.2 and 7.5. The simple analysis of variance only took those treatment effects and interaction effects into account which were part of the trial design (Table 7.1). The inclusion of 'treatment x sitemean' interactions (Table 7.2) did not change the treatment SS but only the residual SS. As a result, the significance of the variety effect changed, and we obtained a test which showed that the fertilizer effect was significantly different at different sites (see the 'fertil-

Table 7.5: Complete ANOVA of the Same Trial as Table 7.1

Source	Sum of squares	D.F.	Mean square	P–Value
Mean	514.93	1	514.93	
Sites	35.20	21	1.68	<0.0001
Treatments				
Vartiety	1.44	1	1.44	0.0040
Fertilizer	19.96	1	19.96	<0.0001
Variety x Fertilizer	0.10	1	0.10	0.4353
Interactions with sitemean				
Variety x Sitemean	0.05	1	0.05	0.5619
Fertilizer x Sitemean	3.05	1	3.05	<0.0001
Regressors				
Shade	1.67	1	1.67	0.0020
Stand at establishment	7.19	1	7.19	<0.0001
Stand at tasseling	0.24	1	0.24	0.2241
Stand at harvest	3.75	1	3.75	<0.0001
Residual	9.1294	57	0.1602	
	R–Square: 0.8884			CV: 16.5%

izer x sitemean' term in Table 7.2). Combined with an adaptability analysis, it allowed a differentiation between sites with different responses to fertilizer. Finally, the use of regressors did not change treatment effects (their SS), but it changed their significance (P-value) through a reduction in the residual SS (Table 7.5). The preliminary conclusions for the example are as follows:

1. There was a very significant effect of fertilization on average maize yield. The effect of fertilizer was significantly higher in fields with an overall higher yield.
2. There was a significant yield difference between the two varieties, with TZSR-W on average yielding 270 kg/ha more than the local variety. The variety difference was consistent, i.e., did not vary from site to site.
3. There was a significant difference between the two varieties in early establishment, due to differences in seed quality, but this probably did not affect the final performance of the varieties.
4. There was considerable yield variability and variability of treatment effects across fields. Its causes will now be analyzed.

Further analysis of mean site yield and 'treatment x sitemean' interaction

The previous analysis showed a significant interaction between the effect of the fertilizer and the mean site yield. On-farm researchers must try to translate this effect into a recommendation domain, i.e. they need to understand why the response is less in fields with lower mean site yield, and then target fertilizer applications to those fields which are most responsive to fertilizer. Therefore, the factors determining mean site yield, and the interaction of treatment effects with mean site yield, have to be understood.

First, we use multiple regression analysis to relate mean yield recorded in a field to measured non-treatment variables (table 7.6). Some of the variables were measured at the field level only, others at the plot level (e.g., Table 6.2, Chapter 6). For the latter, we use mean values for the whole field.

Table 7.6: ANOVA for Regression of Mean Site Yield on Measured Variables; Same Trial as Table 7.1

Source	D.F.	Mean square	P-value
Mean	1	128.60	
Field type[1]	1	0.28	0.3016
Shade	1	1.18	0.0483
Clay content	1	0.03	0.7350
Date of planting	1	2.34	0.0093
Stand at establishment	1	0.06	0.6337
Stand at tasseling	1	0.18	0.4059
Stand at harvest	1	0.02	0.7940
Gender	1	1.07	0.0579
Age	1	0.71	0.1132
Residual	12	0.2443	
R-square: 0.83			

[1] Field in 'forest' or 'savannah' environment.

Most statistical software packages allow stepwise regression which orders the independent variables according to their relative contribution to the variance of the dependent variable. We prefer a *logical order of inclusion* in a forward regression procedure, as follows (see Table 7.6):

1. We first look at those physical factors which are beyond farmers' immediate control, such as soil type and shade.

2. We then include physical factors which farmers can modify through management, for example planting date, planting density, stand at establishment, weediness (not recorded in this trial).

3. Crop disorders are entered, if available.

4. We introduce plant stands later in the season, for example, at midseason and harvest. By introducing them at this point, they measure stand losses which are not explained by the other variables.

5. Finally, non-agronomic factors are entered, e.g., farmers' gender, age and origin (indigene or immigrant).

Table 7.6 shows the contribution in SS for each successive entry in the analysis. Each SS represents the effect of that particular variable after, i.e., independent of the preceding variables. The analysis shows that date of planting and shade had a significant effect on mean yield. Farmer's gender was just short of significance. The regression equation for date of planting was:

$$Y = 3.06 - 0.045X \qquad R^2 = 0.33$$

where

Y is yield in tons per ha
X are days after day 98 (day of planting in the first field)

The effect of gender is peculiar and shows the intricacy of multiple regression analysis, particularly with social factors. When gender is entered as the first variable in the analysis, it is not significant at all, with an SS of only 0.003. There were only four females in the sample and we calculated the average values of the measured variables for males and females. It turned out that all four fields owned by females were shadeless. In the regression equation, the coefficient for sex was negative (males were coded as 1 and females as 2). This suggests that the female fields performed worse than would have been expected from the shade conditions of their fields.

This example points to the need for caution with multiple regression analysis. Before carrying out the multiple regression, we therefore recommend the use of a correlation matrix to examine any collinearities among the variables. Highly correlated variables are exchangeable in a regression analysis. A careful assessment as to which factors are correlated is necessary for an interpretation of the regression analysis. For our example, Table 7.7 shows part of the correlation matrix obtained. The female farmers all planted in shadeless fields and also planted at a considerably higher density (41,600 plants/ha) than the males (27,200 plants/ha). This also explains the correlation between plant stand and shade. Correlations like those between gender and some explanatory variables in the example help in interpreting the multiple regression analysis. Although there was no correlation between gender and yield, we reached the tentative conclusion that the female fields underperformed consid-

Table 7.7: Correlation Matrix for some of the Field Level Variables and Field Averages of Plot Variables Measured in the Trial of Table 7.1

	Shade	Clay	Date of planting	Stand at establishment	Stand at harvest	Gender	Age
Clay	0.22						
Date of planting	-0.18	-0.18					
Stand at establishment	-0.47	-0.18	-0.04				
Stand at harvest	-0.53*	-0.20	-0.13	0.89**			
Gender	0.47*	0.21	0.11	0.63**	0.66*		
Age	0.00	0.11	-0.28	-0.11	-0.06	0.17	
Yield	-0.30	0.11	-0.57**	0.24	0.32	0.02	0.51*

ering their physical conditions. The data do not allow further conclusions as to why this is so.

Earlier on, we have shown that the fertilizer effect depended on the overall yield level of a field (sitemean), and we identified some of the causes of the variation in sitemean. Remember, however, that our aim is to formulate an appropriate fertilizer recommendation based on the outcome of the trial. A statement such as "Do not apply fertilizer if the yield is below a certain level" is not of much use, because yield is only known after the harvest. We must understand the underlying causes of the 'sitemean x fertilizer' interaction in order to arrive at a more specific recommendation. We therefore want to examine if part of the difference in fertilizer effect between sites is explained by the same factors which were shown to affect mean site yield itself, viz. planting date and shade. The ANOVA of Table 7.5 is therefore repeated, with the interaction terms 'shade x fertilizer' and 'planting date x fertilizer' *preceding* the original 'fertilizer x sitemean' interaction. For shade we use the *average* shade level of a field (i.e., averaged over all the plots) because this reflects the overall shade conditions of the field and distinguishes, for example, forest and savannah fields. The results were as follows (see Annex II):

interaction of fertilizer with		
shade	SS = 0.06	P = 0.5527
date of planting	SS = 0.67	P = 0.0483
sitemean (remainder)	SS = 2.51	P = 0.0002

By testing the three interaction terms in this order, the last term (interaction with sitemean) is what remains after accounting for the other two terms.

The 'shade x fertilizer' interaction was not significant, but the 'planting date x fertilizer' interaction explains part of the 'sitemean x fertilizer' interaction. We conclude that the fertilizer effect tended to decrease with later planting. A considerable part of the 'sitemean x fertilizer' interaction SS remains unexplained and must be related to unrecorded differences in management. The available data do not allow further conclusions.

The analysis of the role of planting date as a factor affecting yield and fertilizer effect confirms our initial tentative impressions based on the scatter plot of Fig. 7.1a. The plot is reproduced in Fig. 7.3 but now with the calculated regression lines and the 'net benefit line'. It shows a (weak) tendency for the fertilizer effect to decrease with planting date, but also that there is a lot of unexplained variation in the data. The conclusions on page 152 can now be supplemented with the following additions:

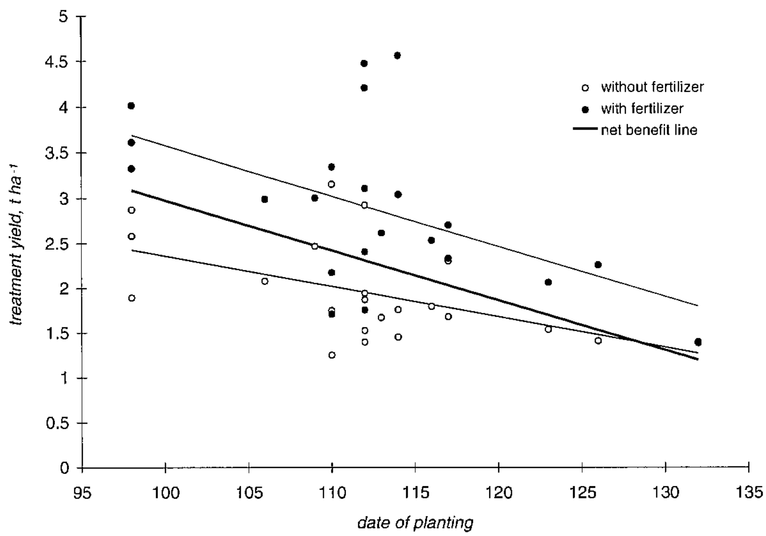


Figure 7.3: Relationship between maize planting date and mean yield without and with fertilizer; 2^2 variety-fertilizer trial, Alabata, southwest Nigeria, 1988

5. Planting time significantly affected the mean site yields. Delayed planting caused reduced yields.

6. The response to fertilizer was weakly but significantly associated with planting time and declined with delayed planting. *On average*, fertilizer application was not profitable for maize planted after the first week of May.

The conclusions from the trial, *if confirmed over two to three years,* can be translated into recommendations, which specify under which conditions fertilizer use is likely to give a good response under farmers' management conditions. The conclusions about the effect of planting data may, however, not be reproducible because of the variablity of rainfall from year to year.

Multivariate analysis

Multiple regression analysis is not the only technique for examining mean site yield. In trials (or surveys) where many variables are measured at the site level, multivariate analysis may be more appropriate, especially in order to organize a large amount of information. As these techniques require considerable amounts of calculations, their use has only recently been increasing with the availability of powerful personal computers. Most statistical problems can be solved with the techniques discussed so far, but multivariate techniques may be useful in the following cases:

1. When we are dealing with a characteristic which cannot be described by a single factor, such as soil conditions. Soil characterization requires the measurement of macronutrients (N, P, K, Ca, Mg), soil texture (sand, silt, clay) and possibly some micronutrients (Zn, Mn). The different factors contributing to the overall characteristic vary in their relative importance. The description of soils in trial fields or survey fields can be strengthened by using principal component analysis. It tests for collinearity between soil characteristics and indicates which soil factors contribute most to the overall variance in soil characteristics.

2. We may want to group together fields or locations with a similar response pattern to certain interventions or with similar combinations of measured characteristics. This is a common problem in multilocational variety trials. For example, the ANOVA of a trial with 6 varieties of a crop grown across 50 sites may show a strong 'variety x site' interaction, where none of the six varieties is the highest yielding in all sites. We want to group together those sites which have a similar response pattern to (or a similar ranking

of) varieties in order to select the best performing varieties for each group. Cluster analysis provides the possibility of grouping sites with similar response patterns. The same technique can also be used for survey data in order to group fields, farms or other items according to patterns of similarity for a number of measured variables.

3. We may distinguish different classes of fields or farmers and we want to examine whether each class shows a characteristic combination of measured variables. A simple example would be a distinction between "savannah" fields and "forest" fields in an area. The on-farm researchers may have a hypothesis as to which factors contribute most to the difference (for example soil texture, topography, land-use intensity and past crops grown). Discriminant analysis provides the possibility of testing and quantifying the contribution of factors to a given grouping. The technique can be used in combination with cluster analysis for diagnostic purposes. In that case, fields, farms or other entities are first grouped using cluster analysis, for instance, on the basis of the performance of different varieties. Next, that combination of different factors or variables is analyzed which best differentiates between the groups.

Examples of all three techniques are given in Annex II.

Analysis of variance for some special designs

We now turn to the analysis of two special designs discussed earlier on: the stepwise and the criss-cross designs. The difference from single factor or factorial designs lies in the way the treatments are grouped and laid out and in the way treatment effects and 'treatment x sitemean' interaction are analyzed.

Stepwise trials

We will analyze a stepwise trial carried out in the non-acid forest area of southwest Nigeria in 1988. The target cropping pattern was maize + cassava and three simple innovations were applied to the maize. The treatments are shown in Table 7.8. We only analyze maize yields here, but later on we will look at both maize and cassava yields obtained in this trial.

Table 7.8: Stepwise Trial in a Maize + Cassava Cropping Pattern, Ayepe, Southwest Nigeria, 1988

Fertilizer kg/ha (15:15:15)	Weeding	Maize density	Remarks
0	farmers'	farmers'	baseline
300	farmers'	farmers'	step 1
300	'timely'	farmers'	step 2
300	'timely'	increased	'package'

The full package consisted of a moderate fertilizer rate, timely weeding and increased maize planting density. Increased density was known to be ineffective in the absence of fertilizer, and timely weeding was expected to be most beneficial if the crop was fertilized. This resulted in the ordering of Table 7.8. The logic for the order of inclusion was as follows:

- The first 'step' was the improved variety. The variety was expected to perform better than the local one, irrespective of management, and involved low cost because farmers would be able to multiply the seed.
- Increased density was expected to increase yield only in combination with fertilizer. Fertilizer was therefore included as the second step and density as the third.
- The effect of timely weeding was uncertain but thought to be most beneficial in combination with the other improvements. It was therefore included last.

Forty farmers participated in the trial, but in two of them no yield data could be collected. In four other fields, some of the plots were harvested by the farmers before sample taking. In two out of these four fields, three plots out of four were missing. We also discarded these fields. Of the other two fields, one plot was missing in one and two plots were missing in the other and we estimated the missing values. The technique for estimating missing values is explained later on. The data set, completed with estimated values for the missing cells, is used to calculate treatment mean yields and sitemean. The ANOVA may also be carried out with the completed data set, but the use of measured yields only is preferable (see Annex II).

We first carry out a complete ANOVA without paying attention to the special order of the treatments, lumping them together as 'treatments' with four degrees of freedom. Table 7.9 shows that there was a highly significant 'treatment' effect. We now want to have more specific information about the contributions of the successive technological components. This can be obtained by carrying out a multiple range test. The multiple range test technique is described in all standard statistical text books. We use the Newman-Keuls test (Snedecor and Cochran, 1967) and find that both fertilizer and increased density (combined with fertilizer) had a significant effect on maize yield, while there was no effect from timely weeding (Table 7.9).

Another way of looking at differences between treatments is by defining some interesting 'contrasts'. Contrasts are linear combinations of the treatments chosen in such a way that they have

Table 7.9: Mean Maize Yields and ANOVA, Stepwise On-Farm Trial, Ayepe, 1988; 36 Farmers

A. Mean maize yields and multiple range tests

Treatment	Fertilizer (15:15:15)	Weeding	Maize density	Maize yield t ha[1]	Multiple range test
1	0	farmers'	farmers'	1.78	a
2	300	farmers'	farmers'	2.45	b
3	300	'timely'	farmers'	2.50	b
4	300	'timely'	increased	2.74	c

[1] Mean yields followed by the same letter are not significantly different at the 5% probability level.

B. ANOVA for treatment yields

Source	Sum of squares	D.F.	Mean square	P-value
Mean	795.83	1	795.83	
Sites	99.16	35	2.83	< 0.0001
Treatments	18.11	3	6.04	< 0.0001
Treatments x Sitemean	2.94	3	0.98	0.0022
Regressors				
Shade	0.18	1	0.18	0.3283
Weeds	0.03	1	0.03	0.6946
Stand at establishment	3.88	1	3.88	< 0.0001
Stand at tasseling	2.63	1	2.63	0.0003
Stand at harvest	8.04	1	8.04	< 0.0001
Residual	17.6653	94	0.1879	
	R-square: 0.88		CV: 18.2%	

a logical interpretation. They will be needed for the further analysis of the 'treatment x sitemean' interaction. The concept of contrasts is most easily explained for a full factorial trial. Take a 2^2 factorial for maize variety and fertilizer. The two most interesting contrasts are usually called the main effects of variety and fertilizer, i.e.,

- the difference between variety 1 and 2
- the difference between fertilizer levels 1 and 2

The varietal contrast may be represented by a variable whose value is –1 for plots with variety 1 and +1 for those with variety 2. The same is done, *mutatis mutandis*, for the fertilizer contrast. The sum of the coefficients of a contrast variable equals zero. A GLM computer package creates the contrast variables automatically when analyzing a factorial trial.

In the case of a stepwise trial, we must define contrasts explicitly. Table 7.10 shows examples for the trial of Table 7.9. Contrasts 1, 2 and 3 respectively represent the effects of fertilizer, increased density and improved weeding (contrasts 4 and 5 will be used in a later section). Note that contrasts 1 and 2 are orthogonal (independent), but 3 is not. Instead of the multiple range test (Table 7.9a), we may carry out tests of significance for each contrast (for more details see Annex II):

contrast 1 (fertilizer)	SS = 8.08 (1df)	P = 0.0001
contrast 2 (density)	SS = 1.12 (1df)	P = 0.0017
contrast 3 (weeding)	SS = 0.03 (1df)	P = 0.6904

Table 7.10: Coefficients of Various Contrasts in the Stepwise Trial of Table 7.8 (not all contrasts are orthogonal)

	Treatments				
Contrast	1	2	3	4	Comments
1	–1	+1	0	0	fertilizer effect
2	0	0	–1	+1	density effect
3	0	–1	+1	0	weeding effect
4	–2	1	1	0	1 versus 2 and 3
5	–1	0	1	0	1 versus 3

Note that the SS do not add up to the SS for treatments of Table 7.9 because contrast 3 is not independent of the other two. These tests are identical to LSD tests. This is justified because the three contrasts were *a priori* chosen in the trial design. The conclusions are the same as for the multiple range tests.

We would now like to know more precisely what caused the significant 'treatment x sitemean' interaction, in particular, whether the fertilizer effect and the effect of increased density showed interaction with mean site yield. We repeat the ANOVA, now with two interaction terms: that between contrast 1 and sitemean, and that between contrast 2 and sitemean. The results are:

interaction with sitemean:		
contrast 1	SS = 0.81 (1df)	P = 0.0406
contrast 2	SS = 0.09 (1df)	P = 0.4906
contrast 3	SS = 0.18 (1df)	P = 0.3302

Only the first one is significant and we conclude that the fertilizer effect varied significantly with the farmers' overall yield level, but the density effect did not.

We now plot the fertilizer contrast against mean site yield (Fig. 7.4) and interpret this graph in the same way as for the Alabata 'variety x fertilizer' trial (Fig. 7.2). We will return to the analysis of this trial in a later section.

Criss-cross trials

A criss-cross (or strip plot) is a systematic design with two factors, whereby one factor is arranged as strips in one direction and the other factor in the other direction. An example was given in Fig. 6.3 (Chapter 6) where three maize varieties were tested with and without interplanted pigeon peas. We will use this example to explain the analysis.

A criss-cross trial is in essence a combination of two split-plot designs. In the example of Fig. 6.3 (Versteeg and Huijsman, 1991) the experimental units for varietal effects are the strips of the three maize varieties, while for pigeon pea intercropping the units are the strips with and without pigeon peas. The effect of each factor has to be tested against its own error term. The interactions between treatments and mean site yield are tested

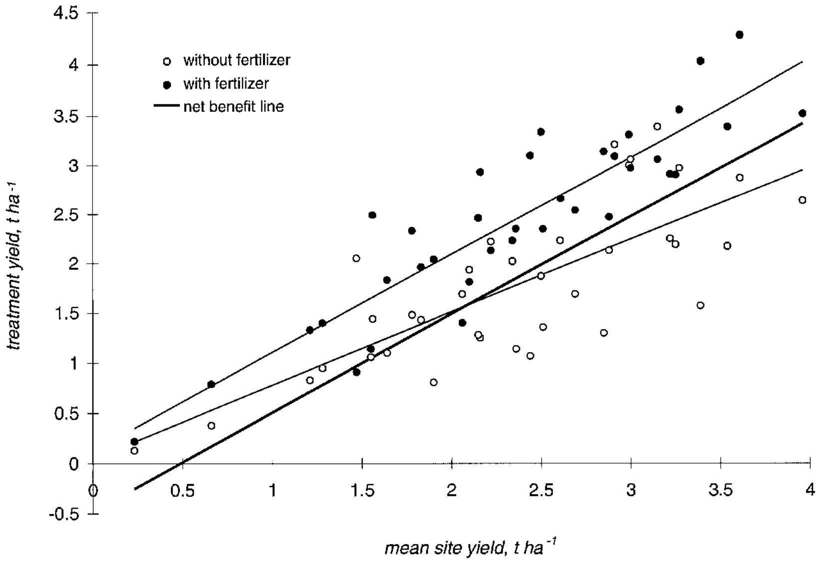


Figure 7.4: Relationship between mean site yield of maize and yield without and with fertilizer, stepwise trial, Ayepe, southwest Nigeria, 1988

against the error terms corresponding to maize varieties and to pigeon pea intercropping. For the 'pigeon pea x maize variety' interaction, however, the sub-plots (i.e., plots with and without pigeon pea for each variety) are the experimental units, and the error for the test of significance is calculated from the sub-plot yields. The ANOVA is shown in Table 7.1,1 and details on the calculations are given in Annex II. No additional measured variables were reported, so regressors (or covariance analysis) could not be considered.

The analysis shows a significant effect for varieties but not for pigeon pea intercropping on maize yield. Pigeon pea growth is initially suppressed by the maize and develops after the maize harvest, so an effect from pigeon pea is only expected on the *following* maize crop. A multiple range test for average yields of the varieties showed that the two improved varieties yielded significantly better than the local, but the difference between TZSR and Hybrid was not significant (Table 7.11b).

The ANOVA also shows that varietal differences varied significantly with mean site yield. The yield of the three varieties was

Table 7.11: Mean Maize Yields and Analysis of Variance of a Criss-Cross Trial with 3 Maize Varieties, with or without Pigeon Peas, Mono Province, Republic of Benin (Versteeg and Huijsman, 1991)

A. Mean maize yields for varieties and pigeon pea intercropping and multiple range tests

	Pigeon pea		
Variety	–	+	Mean [1]
Local	1.62	1.45	1.54a
TZSR	1.88	1.94	1.91b
Hybrid	2.18	2.06	2.12b
Mean[1]	1.89a	1.82a	1.86

[1]Mean yields followed by the same letter were not significantly different (5% probability)

B. ANOVA of treatment yield

Source	Sum of squares	D.F.	Mean square	P–value
Mean	516.27	1	516.27	
Sites	83.75	24	3.49	
Factor 1				
Varieties	8.76	2	4.38	< 0.0001
Varieties x Sitemean	3.83	2	1.92	0.0022
$Residual_1$	12.56	46	0.2730	
Factor 2				
Pigeon pea	0.21	1	0.21	0.3908
Pigeon pea x Sitemean	0.01	1	0.01	0.8503
$Residual_2$	6.30	23	0.2743	
Variety x Pigeon pea	0.33	2	0.17	0.2892
$Residual_3$	6.41	48	0.1335	

therefore plotted against mean site yield (Fig. 7.5) showing that, at very low yield levels, the differences between the varieties were negligible, but that the differences increased as the growing conditions were better. We may also test which of the three regression lines are significantly different in slope. We can therefore define meaningful contrasts between varieties, for instance the difference between the local and the average of the two improved varieties. We can examine whether this contrast varies with overall yield level by testing for interaction between

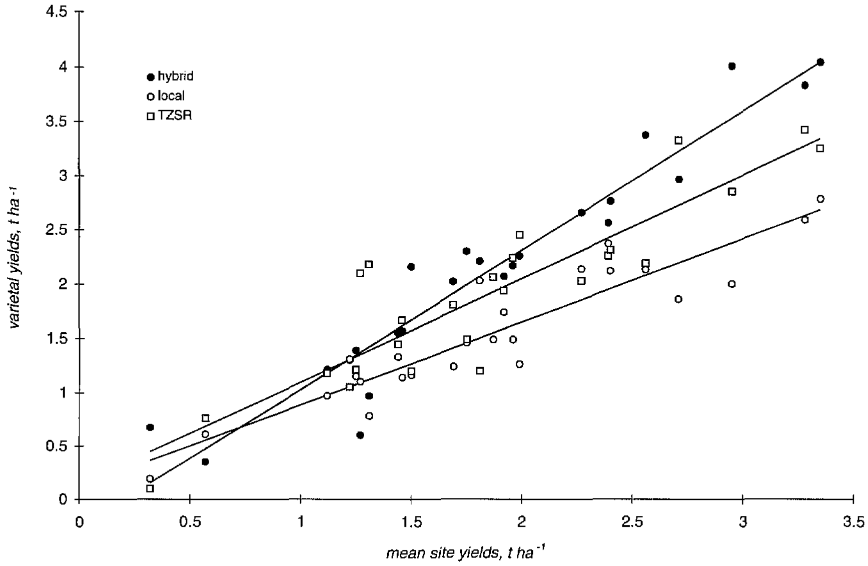


Figure 7.5: Relationship between mean site yield of maize and yield of three varieties, Mono Province, Benin

the contrast variable and mean site yield. The results were as follows:

interaction with sitemean:		
contrast (varieties)	SS = 2.31 (1 df)	P = 0.0013
remainder	SS = 1.52 (1 df)	P = 0.0087

The interaction with the contrast variable and with the remainder were both highly significant. This means that both improved varieties performed better in a good environment and that the response was stronger for one of the varieties (the hybrid) than for the other (open pollinated variety).

In Annex II we carry out an analysis for this criss-cross trial with an imaginary regressor for demonstration purposes.

Missing values

Accidents and errors will occur in any research, leading to loss of information. On-farm researchers should increase the number of replicates at the planning stage in order to allow for an expected 10–15% loss. The most regrettable is loss of a complete replicate when, for instance, farmers harvest the field before the field team can come and take yield measurements. This is also the easiest to handle in the analysis as the complete replicate is discarded.

Loss of individual plots is less serious but also a little more difficult to allow for in the analysis. First of all, we recommend that any site where more than half of the plots are missing be completely excluded from the analysis. For the remaining replicates, we need methods to calculate the correct estimate for the treatment means in spite of empty cells and to carry out the correct ANOVA.

Estimating missing values

We want to fill the empty cells with the best possible estimated values. Since regressors are only meant to reduce the residual SS, we do not use them when estimating missing values. Also, sitemean cannot be calculated for the fields with missing plots. We therefore use the 'minimal' model with only sites and treatment factors as elements to estimate missing values. The easiest way to obtain the estimates is to run the ANOVA without the missing values and obtain the 'estimated values' for the empty cells directly through the GLM. If the GLM package does not include the facility for generating estimated (or 'fitted') values for empty cells, or if multiple regression is used, we recommend a method proposed by Rubin (1972). It requires two special operations:

1. obtaining a matrix of residuals after fitting a model
2. finding the inverse of a symmetric m x m matrix with m being the number of missing values

Most GLM packages include an option for calculating residuals, but inverting a matrix must be done separately. The technique for inverting a matrix is straightforward and can be found in any textbook on linear algebra or matrix algebra. As the m x m matrix is usually rather small, it may be done by hand fairly easily. It can also be done with some sophisticated hand calculators (such as the HP48 series) or by a computer package. Details of the calculations are given in Annex II. After filling the empty cells with the best estimated values, we can calculate the correct treatment means and the sitemean from all plot values, including the estimated values for the missing plots.

Analysis of variance

As long as the number of missing values is less than 5%, we may still safely carry out a standard ANOVA on the data set, completed with estimates for missing values but with the error degrees of freedom diminished by the number of estimated values. The treatment SS will be somewhat inflated, but this only becomes serious when the number of estimated values is larger. We prefer to conduct the ANOVA without the missing values in the usual 'forward inclusion' manner. The estimated values are only used to calculate treatment means and sitemeans. The latter are needed for the 'treatment x sitemean' term in the ANOVA.

Because of the imbalance resulting from the empty cells, this ANOVA also does not give the exact treatment SS, but the difference will be small as long as the percentage of missing values is small. In order to find the correct treatment SS when the number of missing values is greater than 5%, we can analyze the trial as an unbalanced design. Details of the calculations are given in Annex II.

Redefining the target population and making recommendations

In this chapter, we started the discussion on the experimental design process by defining the target population for our test technology. With the results obtained in the trials, we sometimes have to redefine the target population or target conditions or make further refinements before arriving at recommendations to farmers.

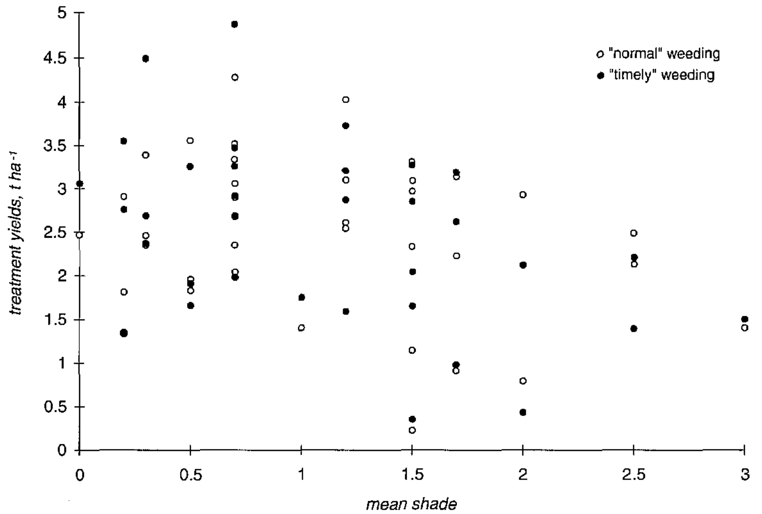
In the Alabata trial, we were only able to conclude that the response to fertilizer was significantly associated with planting time and shade and declined with delayed planting (see Table 7.6 and Fig. 7.3). To further illustrate how on-farm trials can lead to specific recommendations, we will look again at the stepwise trial with fertilizer, timely weeding and increased density in the forest zone of SW Nigeria (Tables 7.8 and 7.9). It was found that the fertilizer effect varied significantly with the overall yield level in a field (see the interactions between contrast and sitemean).

Thus, the response of maize to fertilizer depended on the overall performance of maize in the field, and we want to identify the factors that affect the performance of the technology at the farm level. This requires, as in the Alabata trial earlier, an understanding of the factors affecting mean site yield and of the factors causing the 'fertilizer x sitemean' interaction.

In this trial, several observations were recorded for diagnostic purposes. First, we plotted the yields of different treatments against the measured variables in order to explore possible trends in treatment effects with these variables. This turned up a peculiar trend in the weeding effect with shade (mean value for each field) and plant stand at establishment (Fig. 7.6). The two treatments 'crossed over': timely weeding had a positive effect in plots with low shade levels and high initial maize stand, but had no effect, or even a negative effect, in the opposite case. This sheds a new light on the absence of any overall effect from weeding in this trial. A positive effect under some conditions may have been canceled out by a negative effect under other conditions. The variation of treatment effect with field conditions must now be examined in a more formal way.

We first analyzed the mean site yield of this trial (including the two replicates with missing values) by multiple regression analysis (Table 7.12). Shade, initial plant stand and stand losses (grasscutter, termites and other causes) together explained 77% of the yield variations. Scatter plots showed that grasscutter and termite damage were severe in some fields but moderate in the majority of fields. There was no correlation between termite and grasscutter damage, they occurred in different fields. Secondly, we re-examined the 'treatment x sitemean' interaction in the ANOVA (Table 7.9) by replacing it by the interaction of the fertilizer effect with shade and with initial and final plant stand, which were the most important factors affecting mean site yield (stand at harvest taken on its own includes the effects of termite and grasscutter damage). Note that in the ANOVA of Table 7.9, we used *plot values* for shade and plant stands as regressors in order to correct for difference in shade between plots. For the interaction with the fertilizer contrast, we use *average field values* for shade,m because they reflect the overall shade conditions in the fields.

(a)



(b)

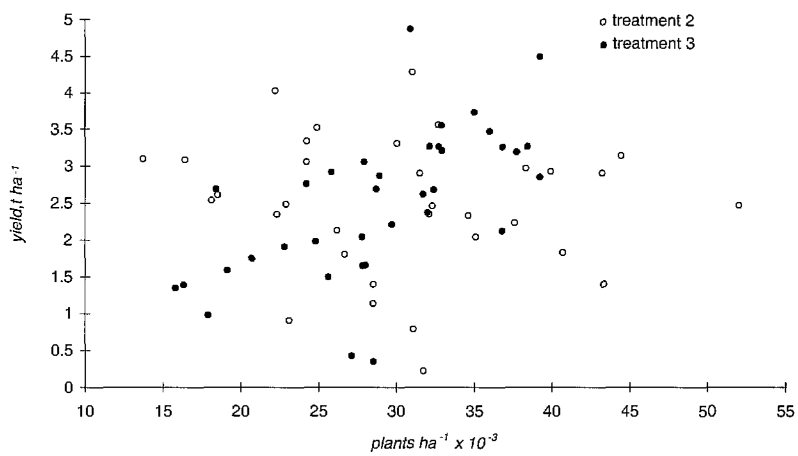


Figure 7.6: Scatter plot of maize yields against (a) average shade in the field, (b) initial plant stand for plots without and with timely weeding (treatment 2 vs. 3): stepwise maize + cassava trial, southwest Nigeria, 1988

Table 7.12: ANOVA for Regression of Mean Site Yield on Measured Variables, Stepwise Trial, Ayepe, 1988 (see Tables 7.8 and 7.9)

Source	D.F.	MS	P–value
Mean	1	201.64	
Shade	1	3.61	0.0002
Planting date	1	0.35	0.1929
Stand at establishment	1	5.56	<0.0001
Weeds	1	0.05	0.6107
Grass cutter losses	1	4.80	<0.0001
Termite losses	1	2.76	0.0009
Stand at tasseling	1	1.32	0.0151
Stand at harvest	1	1.14	0.0230
Gender	1	0.13	0.4162
Age	1	0.22	0.2912
Origin	1	0.40	0.1637
Residual	24	0.1923	
R–square	0.82		

The following SS were found (see Annex II):

interaction of fertilizer effect (contrast 1) with:

average shade	SS = 0.13 (1 df)	P = 0.2454
stand at establishment	SS = 0.44 (1 df)	P = 0.1293
stand at harvest	SS = 0.24 (1 df)	P = 0.2613

None of these interactions were significant.

The 'cross-over' of the weeding effect with shade (Fig. 7.6) suggests a closer look at the contrast of treatments 1 and 3 (contrast 5 in Table 7.10), i.e., the effect of a *package* consisting of fertilizer and timely weeding:

interaction of contrast 5 (treatment 1 vs. 3) with:

average shade	SS = 1.40 (1 df)	P = 0.0076
stand at establishment	SS = 0.89 (1 df)	P = 0.0324
stand at harvest	SS = 0.26 (1 df)	P = 0.2448

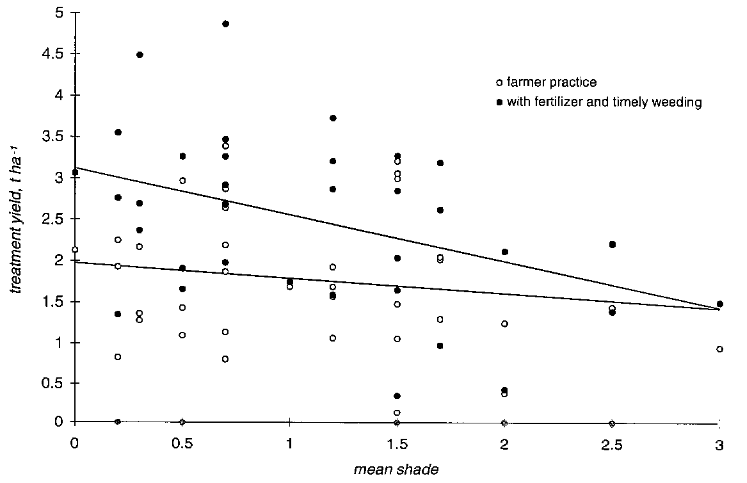
Interestingly, the interactions with both shade and early plant stand are significant. Shady conditions generally occur in fields that have not been used extensively for foodcrops or have recently been cleared. Weed pressure is probably less severe in such fields. They respond less to inputs and management such as timely weeding. A good initial plant stand also appears to be a condition for a response to these factors.

We will now plot the yield for treatments 1 and 3 (i.e., the contrast between farmers' practice and a package of fertilizer and timely weeding) against average shade level and against initial plant stand (Fig. 7.7). The plots where more than 7,500 plants/ha were lost due to termites or grasscutter are shown by special symbols. The graph shows that the effect of the package was lower as shade was higher and initial stand was lower. Grasscutter and termite damage occurred over the whole range of shade levels and generally reduced the beneficial effect of fertilizer.

We conclude that farmers growing maize in exposed fields should be advised to apply fertilizer and practice timely weeding and ensure an adequate initial plant stand (at least 30,000 plants/ha). The scatter of the data points in Fig. 7.7 suggests that, even under low or no shade, there is a considerable risk of non-profitability. The risk would be reduced if the incidence of grasscutters and termites could be predicted. The data do not allow of such predictions but some research should be initiated into a study of the ecology of grasscutter and termite incidence. Farmers themselves may be knowledgeable about this. Fertilizer should not be applied where damage by these two pests is expected.

If there is not enough knowledge available about the factors that cause differences between sites, or if a factor, like grasscutters, is not predictable, the researcher cannot adequately target a technology which depends for its performance on mean site yield. Thus, the need for further diagnostic research at the field level through, for example, field monitoring arises. Some factors cannot be influenced by farmers and are themselves a function of other unpredictable events. Fertilizer application in Alabata, for example, was identified as being more profitable with early planting in the year the trial was carried out (Figs. 7.2 and 7.3). Early season rainfall, however, is highly unpredictable, and farmers will continue to stagger their planting to spread risk.

(a)



(b)

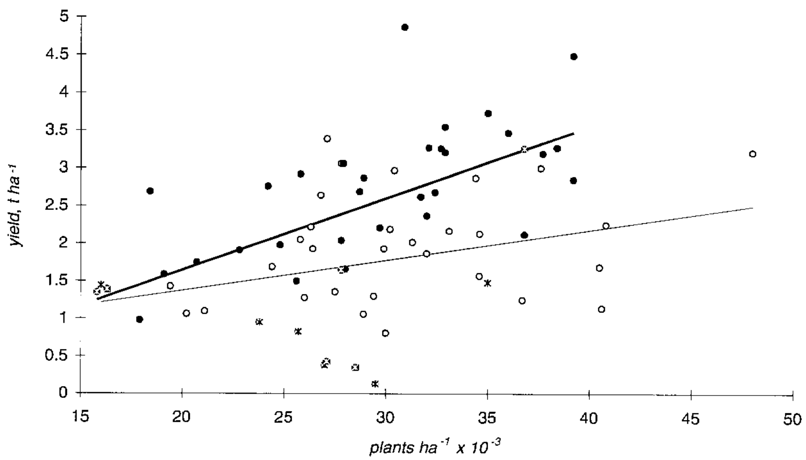


Figure 7.7: Relationship between maize yield and (a) average shade and (b) initial plant stand for plots without and with a fertilizer + weeding package. Crosses in (b) indicate plots where more than 7,500 plants/ha were lost to grasscutter and termite damage.

On-farm researchers should try to reduce the risk of farming and to increase the productivity by targeting technologies to the most responsive environments.

Analysis for mixed crops

In Africa, mixed cropping is much more common than sole cropping. When testing improved technology, we must always consider its effect on all the (major) crops grown in association or relay. In the previous sections, we have shown analytical techniques applied to a single crop and we must now extend the discussion to multiple crops.

Bivariate techniques have been used for the analysis of intercropping trials (Dear and Mead, 1983), but we recommend a simpler approach, consisting of two parts:

1. First conduct the analysis for each crop individually as outlined above for single crops.
2. Then look at combined yields which may reveal whether a positive effect on one crop may be undone by a negative effect on the other.

Analysis of combined yield requires that all crop yields are transformed to the same units, which may then be added up. In the case of maize and cassava in southwest Nigeria, for example, we converted cassava yield to 'equivalent maize yield' by multiplying fresh tuber weight by a factor of 0.2. This takes into account the cost of processing cassava into an edible form and the relative prices of maize grain and cassava flour. Maize and converted cassava yield may now be added and the combined yield is analyzed in the same way as single crops. We will give an example for the stepwise trial of Table 7.8.

Mean treatment yields for the individual crops maize and cassava and combined yields are presented in Table 7.13. The ANOVA for maize, cassava and combined yield are shown in Table 7.14. A Newman-Keuls multiple range test for cassava yield using the residual MS of Table 7.14 only showed a significant effect of the combination of fertilizer and timely weeding. The treatment with fertilizer (applied to maize) and normal weeding had a lower mean yield than the unfertilized treatment (Table 7.13), but the effect was not significant. In earlier trials,

Table 7.13: Mean Yields of Maize and Cassava and Combined Yield for a Stepwise On-Farm Trial, Ayepe, Southwest Nigeria, 1988 (Same Trial as Tables 7.8 and 7.9)

				Yields		
Treatment	Fertilizer	Weeding	Maize density	Maize	Cassava	Combined[1]
1	0	farmers'	farmers'	1.78 a	15.2ab	4.91a
2	300	farmers'	farmers'	2.45 b	14.0a	5.42b
3	300	'timely'	farmers'	2.50 b	16.5b	5.94c
4	300	'timely'	increased	2.74 c	14.9ab	5.95c

no depressant effect on cassava yield due to fertilizer had been found, and this trial does not provide sufficient evidence to refute that finding. Differences in cassava stand losses among plots were very large. For the combined cassava and maize yields, the effects of both fertilizer and timely weeding were significant.

We may now once again visually examine the (significant) 'treatment x sitemean' interaction, using plots of yield against sitemean for each treatment separately as before.

We can also carry out a multiple regression analysis of combined yield against different measured variables. This is not essentially different from the analysis for individual crops, so we will not discuss this further. We do recommend, however, that the researcher look carefully at the correlation matrix for different variables measured on both crops. In the example it turned out, for instance, that stand losses in maize and cassava were strongly correlated and could be traced back in part to grasscutter damage.

Table 7.14: ANOVA of Maize, Cassava and Combined Maize and Cassava Yield, Stepwise Trial, Ayepe, Southwest Nigeria, 1988 (see Tables 7.9 and 7.13)

	Maize			Cassava			Combined		
Source	D.F.	Mean Square	P	D.F.	Mean Square	P	D.F.	Mean Square	P
Mean	1	795.83		1	25652.0		1	3397.36	
Site	35	2.83	<0.0001	27	211.71	< 0.0001	26	13.74	<0.0001
Treatments	3	6.04	<0.0001	3	30.60	0.0337	3	4.99	0.0004
Treatments x Sitemean	3	0.98	0.0022	3	22.70	0.0880	3	2.65	0.0169
Regressors									
Shade	1	0.18	0.3283	1	55.25	0.0216	1	1.53	0.1512
Weeds	1	0.03	0.6946	1	17.80	0.1868	1	1.30	0.1865
Maize stand									
establishment	1	3.88	<0.0001	–	–		1	4.14	0.0198
tasseling	1	0.63	0.0003		–		1	0.64	0.3519
harvest	1	8.04	<0.0001		–		1	10.06	0.0004
Cassava stand									
maize harvest		–		1	180.72	<0.0001	1	8.91	0.0008
cassava harvest		–		1	459.66	<0.0001	1	15.37	<0.0001
Residual	94	0.1879		74	10.0251		66	0.7269	
R–square		0.88			0.90			0.90	
CV		18.2%			20.9%			15.2%	

Annex

I Decision Support Systems

The choice of technologies for on-farm as well as for on-station testing is a crucial step towards identifying adapted and adoptable technologies for a specific mandate area. The more heterogeneous the area and the more complex the technological options, the more difficult will be the decision process, as it requires a detailed knowledge of the agroecological, agroeconomic and farming systems conditions in the mandate area, as well as insight into the characteristics of the available technologies.

Computerized database management systems are now being developed which support the decision process by making expert knowledge of technologies and decision criteria available to the user. Such systems are usually called "expert systems" or "decision support systems" (DSS). DSS can be looked upon as 'partially digested scientific literature'. In developing countries, scientists often experience great difficulty in accessing scientific knowledge because of libraries which are incomplete, outdated or simply non-existent. If DSS were available, it would be a help in overcoming these problems.

The integration of legume-based technologies into farming systems, for example, is a complex task of this kind. The leguminous species to be chosen must be ecologically adapted to climate and soil conditions. They must also effectively fulfill their purpose with regard to soil improvement, erosion control, weed suppression, etc.. Also, they should have other benefits, if possible, such as being suitable for edible grain or fodder for livestock. Finally, they should fit into the existing cropping system. It is difficult for an on-farm team to make the best choice unless there is an expert on the team who is knowledgeable about the wide range of legume-based technologies available. A DSS has therefore been developed which makes available detailed information on more than 100 legume species

(COMBS, 1993). The system (LEXSYS, Legume Expert System) can be installed on most personal computers and guides researchers in making their choice.[1] Other expert systems are available or under development, such as

- multipurpose tree species (MPT, Winrock, F/FRED, Hawaii)
- alley cropping (IITA, University of Hawaii)
- mineral nutrition (Fertility Capability Classification, North Carolina State University)
- mineral nutrition (Quantitative Evaluation of the Fertility of Tropical Soils, QUEFTS, Agricultural University, Wageningen, The Netherlands)
- agroforestry (ICRAF, Nairobi)

Other areas where the development of DSS may be taking place or would be desirable are

- erosion control
- choice of crop varieties (maize, rice, cowpeas, etc.)

They will be increasingly powerful tools in supporting on-farm and on-station researchers in the future. However, they are not a substitute for the crucial steps of on-farm testing in collaboration with farmers, they precede them.

1. A copy of LEXSYS may be obtained free of charge from the Resource and Crop Management Division, IITA.

Annex II

Calculation Techniques

Introduction

This annex gives details of the analyses presented in Chapter 7. We will first briefly discuss the general characteristics of ANOVA, multiple regression, and GLMs. Next, we will look at the concepts underlying the analysis of complex on-farm trials with 'treatment x sitemean' interaction, (covariates), regressors and missing values and the steps involved in their analysis. Finally we will demonstrate the calculations with the examples from Chapter 7.

The calculations are best done with a computer package which has a flexible GLM routine, allowing for both classifications and numerical variables. Many statistical computer packages have a GLM facility, but there are large differences in their flexibility. Most of them only allow covariates, and they need some manipulation to carry out the analysis with 'treatment x sitemean' interaction and regressors. If a suitable GLM package is not available, any package with a flexible multiple regression routine can be used, but this can become quite tedious and requires rather elaborate manual work.

We carried out all the analyses using the GLM-based STAN package, which is very flexible and accepts classifications, factors and numerical (or ordinal) variables, and we will show how it can be used to carry out the full analysis. We will indicate how the calculations would be different when using a less flexible GLM routine or a multiple regression routine. In some cases we will demonstrate hand calculation as an alternative for the analysis of trials where no (covariates and) regressors are considered. The raw data are given with each analysis. This allows the readers to repeat the analyses for themselves.

ANOVA, multiple regression and GLM

Standard ANOVA is suitable for the 'balanced' linear models which are commonly used in the designs for station trials. The calculations are simple and fast because of the 'orthogonality' or 'independence' of classes and treatment factors. Such trials can also be analyzed with a GLM routine, but an ANOVA package uses much faster shortcut calculation procedures for SS, similar to those given in standard textbooks. The output of an ANOVA package is an ANOVA table with the SS, MS and F-tests for each of the classifications, factors, and interactions.

In the standard use of *multiple regression analysis,* the user specifies a number of variables, usually quantitative, which are expected to affect the value of the dependent variable (e.g., yield). The regression equation gives the linear combination of the independent variables which most closely matches the values of the dependent variable. When used for the analysis of *experiments,* however, multiple regression analysis must be used with caution and requires rather extensive manipulations for four reasons:

1. We cannot associate an *a priori* value with a particular class (e.g., a farmer's field) or factor (e.g., variety). We must therefore use 'dummy variables' for treatments and classes. A dummy variable for a particular class or treatment has the value 1 for a plot which belongs to that class or treatment, and 0 for all other plots. For each classification or treatment, we could therefore include as many separate variables as there are classes or treatments. The multiple regression routine will assign one degree of freedom to each dummy variable. In trial designs, however, the degrees of freedom for classifications and factors are one less than their number. A GLM will make that correction automatically, but most multiple regression routines will not, in which case the user must make the correction manually.

2. In factorial trials, we want to test for the effect of the individual factors themselves, as well as their interaction. We could create separate dummies for each level of each factor, but entering the interactions in a multiple regression model then becomes very clumsy. It is therefore preferable to use contrast variables to represent the factors instead of simple dummies. This will also produce the correct degrees of freedom for the factors and interactions. The use of contrasts will be further explained later on.

3. Entering and analyzing dummy variables for sites is a laborious process when there are many farmers' fields, because there is a separate variable for each field with value 1 for all the plots of that field and 0 elsewhere. We will give an example later on.

4. A multiple regression package will calculate the variance associated with the best fitting linear combination of the variables, but it will often not give a breakdown of the contributions of each factor to the variance as in an ANOVA or GLM. We can, however, obtain this breakdown by repeating the regression analysis a number of times, each time with an additional class, factor or variable included. The contribution of each entry is found by subtracting the total variance of the previous step from that of the current one. An example is given in the next section.

A GLM, as its name indicates, is the most general form of a linear model. In some GLM packages, the model may include factors and classifications as well as quantitative variables, and the design does not have to be balanced. In most packages, however, quantitative variables are only allowed as covariates, but we will show how they can be manipulated to carry out the calculations we need. The output of a GLM package is an ANOVA table, which shows the SS, MS and F-tests and/or probability values for each of the classifications, factors, and interactions, as specified by users.

For our analyses we prefer a GLM routine which allows the use of quantitative variables as regressors. Alternatively, any GLM with the option to include several covariates may be used, but these require some manual calculations. If neither is available, a multiple regression routine can be used at the cost of extensive manipulations.

Analytical concepts for on-farm trials

The analysis of on-farm trials is a fairly straightforward combination of well-known ANOVA and regression concepts. Compared with station trials, the analysis is complicated by the following unavoidable and, in the first case, even desirable variations occurring in farmers' fields:

- variation of treatment effects among farmers, captured in the 'treatment x sitemean' interaction term
- unscheduled variation, captured in (covariates and) regressors
- missing plots

We will distinguish three situations:

The simplest case occurs when all the measured ('concomitant') variables may be treated as regressors, and there are no missing plots. We build up the full model in the usual way and carry out the ANOVA, with the model terms entered in the usual order (sites-treatments-'treatment x sitemean' interaction-regressors). Note that the regressors are included as the final terms in the analysis. The presence of 'treatment x sitemean' interaction and regressors requires the use of a GLM, usually with some additional manipulation, or a regression package.

A somewhat more complicated situation arises when values for one or several plots are missing. In that case, the missing values must be estimated to obtain unbiased mean (yield) values for the treatments. For valid tests of significance, however, only the values actually measured are used, so that the GLM treats the design as unbalanced. The steps for analyzing such trials are as follows:

1. Define the 'full model', including terms for sites, treatment factors, 'treatment x sitemean' interaction and regressors.
2. Estimate missing values by the Rubin method (see below).
3. Conduct the ANOVA with the actual data, excluding the missing values, for the full model with regressors included in the last position. The residual SS of this analysis will be used for all the subsequent tests of significance.
4. For the calculation of mean site yield, use the estimated missing values as well as the measured values.

The most complicated analysis occurs when there are also covariates. The first part of the analysis proceeds in practically the same way as the previous case:

1. Define the 'full model', including terms for sites, treatment factors, 'treatment x sitemean' interaction, covariates and regressors.
2. Estimate missing values by the Rubin method (see below).
3. Conduct the ANOVA with the actual data, excluding the missing values, for the full model with regressors included in the last position. The residual SS of this analysis will be used for all the subsequent tests of significance.
4. For the calculation of mean site yield, use the estimated missing values as well as the measured values.

The following additional steps complete the analysis:

5. Repeat the analysis without regressors and note the residual SS.
6. Repeat the analysis without regressors a number of times, each time excluding one of the model terms. The difference between the residual SS of these analyses and that obtained under 5. is the 'corrected SS' for the excluded term.

We will present detailed examples of the analyses in the following sections.

Creating the data file

Different software packages have specific requirements for the way the data file for a trial is set up. Instructions for this format can be found in the manuals.

Table II.1 shows a typical data set showing all the variables needed for the analyses, except dummy variables for 'sites' which are needed when using a regression package. Which of these have to be created and entered manually depends on the software package used (see Annex IV). We strongly recommend the creation of 'contrast' variables for the treatments or factors in the data file. Contrast variables are easily found for simple factorial trials with only two levels for each factor. In that case, there is a single contrast variable for each factor. It has value -1 for plots with the first level of the factor and +1 for the others (see Table II.1). Examples for a 2 x 3 factorial are given in Table II.2. The linear and quadratic contrasts in the table have an interpretation when there are real levels, e.g., equally spaced fertilizer levels or different planting densities. When a factor does not have real 'levels' (e.g., different varieties), we may still use linear, quadratic and higher power contrasts (called orthogonal polynomia) but, though statistically valid, they have no intrinsic meaning. Sitemean, i.e., the mean yields over all treatments in a field should also be represented as a variable in the data file for each plot (see Table II.1). When there are missing values, however, sitemean of the fields with missing plots can only be calculated after estimating values for the empty cells.

Variables consisting of the sum of the yields of plots with the same factor level are needed for 'adaptability' plots. Table II.1 contains this variable for fertilizer levels only because the variety effect did not vary significantly with mean site yield. If an 'adaptability plot' for 'variety' is desired anyway, then an additional variable should be created for the sums of plots having the same variety.

As indicated before, when using a multiple regression package, we must explicitly create 'indicator' or 'dummy' variables for sites, while a GLM will create these variables automatically. For treatments we recommend the use of contrast variables as explained above. Some multiple regression packages will also require that the interactions between treatment factors are entered explicitly as variables in the data file. These are obtained as the products between the contrast variables for each factor. In the case of two factors at two levels each, there is only a single interaction variable (Table II.1), in a 2x3 factorial there are two (see Table II.2), etc. The interaction variables for 'treatment x sitemean' also have to be created explicitly in the data file as the product between the contrast variables for the treatment factors and the 'sitemean' variable. For some regression packages it is advisable to use '*reduced sitemean*' instead of 'sitemean', i.e., sitemean minus the overall mean yield of the trial (Table II.1). This gives the same results, but it

Table II.1: Data Set of the 2^2 Variety-Fertilizer Trial, Alabata, 1988

								Stand at						
Site	Treatment	Variety[1]	V[2]	Fertilizer[1]	F[2]	VxF	Yield	Establ.	Tass.	Harvest	Shade	Sum for fertilizer[3]	Sitemean[3]	Reduced sitemean[3,4]
1	1	LOCAL	-1	0	-1	1	2.62	20.3	18.4	17.6	1	*5.75*	*3.24*	*0.8223*
1	2	LOCAL	-1	300	1	-1	3.19	15.6	15.2	14.9	0	7.22	*3.24*	*0.8223*
1	3	TZSR	1	0	-1	-1	3.13	31.2	26.4	24.0	0	*5.75*	*3.24*	*0.8223*
1	4	TZSR	1	300	1	1	4.03	25.3	23.7	22.1	1	*7.22*	*3.24*	*0.8223*
2	1	LOCAL	-1	0	-1	1	2.25	28.9	25.2	22.2	0	5.17	3.30	0.8823
2	2	LOCAL	-1	300	1	-1	4.55	38.5	28.9	28.9	0	8.04		
2	3	TZSR	1	0	-1	-1	2.92	56.3	47.4	37.0	0			
2	4	TZSR	1	300	1	1	3.49	33.2	30.8	28.4	0			
3	1	LOCAL	-1	0	-1	1	1.55	29.6	25.2	23.7	0	3.79	2.61	0.1923
3	2	LOCAL	-1	300	1	-1	2.65	28.4	24.1	23.7	0	6.66		
3	3	TZSR	1	0	-1	-1	2.24	37.7	33.9	31.7	0			
3	4	TZSR	1	300	1	1	4.01	48.6	41.9	39.0	0			
4	1	LOCAL	-1	0	-1	1	1.98	15.6	15.6	15.4	0	4.16	2.53	0.1123
4	2	LOCAL	-1	300	1	-1	2.69	17.6	16.6	15.2	2	5.98		
4	3	TZSR	1	0	-1	-1	2.18	27.7	27.1	26.3	1			
4	4	TZSR	1	300	1	1	3.29	26.5	25.9	25.3	0			
5	1	LOCAL	-1	0	-1	1	1.92	35.5	32.0	27.3	0	4.94	2.74	0.3223
5	2	LOCAL	-1	300	1	-1	2.71	43.2	37.3	28.4	0	6.01		
5	3	TZSR	1	0	-1	-1	3.02	38.3	34.4	28.9	0			
5	4	TZSR	1	300	1	1	3.30	40.9	36.1	33.8	0			
6	1	LOCAL	-1	0	-1	1	1.51	17.6	15.8	14.4	0	2.51	1.48	-0.9377
6	2	LOCAL	-1	300	1	-1	1.76	20.2	18.7	14.8	0	3.42		
6	3	TZSR	1	0	-1	-1	1.00	28.1	27.7	17.7	2			
6	4	TZSR	1	300	1	1	1.66	27.2	26.2	19.6	2			

Table II.1: Data Set of the 2^2 Variety-Fertilizer Trial, Alabata, 1988 (Contd.)

Site	Treatment	Variety[1]	V^2	Fertilizer[1]	F^2	VxF	Yield	Stand at Establ.	Stand at Tass.	Stand at Harvest	Shade	Sum for fertilizer[3]	Sitemean[3]	Reduced sitemean[3,4]
7	1	LOCAL	-1	0	-1	1	3.13	30.5	29.5	28.1	0	6.31	3.25	0.8323
7	2	LOCAL	-1	300	1	-1	3.32	31.9	29.0	28.1	0	6.69		
7	3	TZSR	1	0	-1	-1	3.18	20.6	19.8	19.0	0			
7	4	TZSR	1	300	1	1	3.37	23.4	23.0	22.2	0			
8	1	LOCAL	-1	0	-1	1	1.29	19.0	16.9	14.3	1	3.50	1.96	-0.4577
8	2	LOCAL	-1	300	1	-1	1.96	21.7	20.2	16.9	0	4.35		
8	3	TZSR	1	0	-1	-1	2.21	25.7	24.0	22.0	1			
8	4	TZSR	1	300	1	1	2.39	26.0	23.7	19.0	1			
10	1	LOCAL	-1	0	-1	1	2.00	35.9	33.6	18.5	1	3.89	3.21	0.7923
10	2	LOCAL	-1	300	1	-1	4.55	39.2	35.2	27.6	0	8.95		
10	3	TZSR	1	0	-1	-1	1.89	42.0	39.6	13.2	0			
10	4	TZSR	1	300	1	1	4.40	41.9	37.8	22.7	0			
11	1	LOCAL	-1	0	-1	1	1.59	21.9	21.6	20.4	0	3.74	2.14	-0.2777
11	2	LOCAL	-1	300	1	-1	2.07	20.1	19.6	17.2	0	4.81		
11	3	TZSR	1	0	-1	-1	2.15	29.0	27.0	22.0	0			
11	4	TZSR	1	300	1	1	2.74	23.7	22.0	20.7	0			
12	1	LOCAL	-1	0	-1	1	3.01	28.0	26.7	25.6	1	5.85	3.57	1.1523
12	2	LOCAL	-1	300	1	-1	3.76	20.7	19.3	18.1	0	8.42		
12	3	TZSR	1	0	-1	-1	2.84	27.4	25.6	24.8	0			
12	4	TZSR	1	300	1	1	4.66	25.7	24.3	23.7	0			
13	1	LOCAL	-1	0	-1	1	1.45	18.2	17.8	15.3	0	2.80	1.58	-0.8377
13	2	LOCAL	-1	300	1	-1	1.47	21.5	19.3	13.7	0	3.51		
13	3	TZSR	1	0	-1	-1	1.35	25.2	20.2	11.5	1			
13	4	TZSR	1	300	1	1	2.04	28.5	19.4	16.3	0			

Table II.1: Data Set of the 2^2 Variety-Fertilizer Trial, Alabata, 1988 (Contd.)

Site	Treatment	Variety[1]	V[2]	Fertilizer[1]	F[2]	VxF	Yield	Stand at Establ.	Stand at Tass.	Stand at Harvest	Shade	Sum for fertilizer[3]	Sitemean[3]	Reduced sitemean[3,4]
14	1	LOCAL	-1	0	-1	1	1.73	29.3	25.8	21.8	0	3.05	2.32	-0.0977
14	2	LOCAL	-1	300	1	-1	2.87	34.7	28.9	24.0	1	6.22		
14	3	TZSR	1	0	-1	-1	1.32	40.4	32.0	19.1	1			
14	4	TZSR	1	300	1	1	3.35	38.1	34.3	31.4	0			
15	1	LOCAL	-1	0	-1	1	1.83	21.8	20.7	15.6	0	3.34	2.14	-0.2777
15	2	LOCAL	-1	300	1	-1	1.34	14.0	13.5	11.2	1	5.23		
15	3	TZSR	1	0	-1	-1	1.51	19.7	17.9	13.2	1			
15	4	TZSR	1	300	1	1	3.89	31.8	29.9	25.1	0			
16	1	LOCAL	-1	0	-1	1	1.56	21.2	19.8	19.1	0	3.52	3.16	0.7423
16	2	LOCAL	-1	300	1	-1	6.03	83.6	79.3	64.1	0	9.13		
16	3	TZSR	1	0	-1	-1	1.96	29.4	28.7	17.1	1			
16	4	TZSR	1	300	1	1	3.10	31.4	30.5	23.5	0			
18	1	LOCAL	-1	0	-1	1	1.09	66.3	64.6	36.3	0	2.91	2.27	-0.1477
18	2	LOCAL	-1	300	1	-1	2.52	51.3	54.3	44.0	0	6.18		
18	3	TZSR	1	0	-1	-1	1.82	56.6	59.1	50.7	0			
18	4	TZSR	1	300	1	1	3.66	45.8	50.2	43.1	0			
19	1	LOCAL	-1	0	-1	1	1.66	18.7	16.0	16.0	1	3.59	2.16	-0.2577
19	2	LOCAL	-1	300	1	-1	2.35	19.1	18.8	18.8	0	5.07		
19	3	TZSR	1	0	-1	-1	1.93	22.1	20.3	18.7	1			
19	4	TZSR	1	300	1	1	2.72	30.4	29.3	26.1	1			
20	1	LOCAL	-1	0	-1	1	1.87	27.7	25.8	25.2	0	3.36	2.01	-0.4077
20	2	LOCAL	-1	300	1	-1	2.62	26.3	25.1	24.7	0	4.67		
20	3	TZSR	1	0	-1	-1	1.49	28.1	25.6	23.5	0			
20	4	TZSR	1	300	1	1	2.05	21.7	20.7	19.1	0			

Table II.1: Data Set of the 2^2 Variety-Fertilizer Trial, Alabata, 1988 (Contd.)

Site	Treatment	Variety[1]	V[2]	Fertilizer[1]	F[2]	VxF	Yield	Stand at Establ.	Stand at Tass.	Stand at Harvest	Shade	Sum for fertilizer[3]	Sitemean[3]	Reduced sitemean[3,4]
21	1	LOCAL	-1	0	-1	1	2.12	19.4	18.2	17.0	0	4.61	2.50	0.0823
21	2	LOCAL	-1	300	1	-1	2.31	16.7	16.4	14.5	0	5.41		
21	3	TZSR	1	0	-1	-1	2.49	23.6	21.8	20.3	0			
21	4	TZSR	1	300	1	1	3.10	21.8	20.6	18.5	0			
22	1	LOCAL	-1	0	-1	1	1.92	31.8	28.6	13.6	0	3.07	1.80	-0.6177
22	2	LOCAL	-1	300	1	-1	2.43	24.8	21.9	16.5	0	4.13		
22	3	TZSR	1	0	-1	-1	1.15	20.0	19.0	16.8	1			
22	4	TZSR	1	300	1	1	1.70	27.0	21.0	16.8	1			
23	1	LOCAL	-1	0	-1	1	1.53	22.6	20.5	17.0	1	2.82	1.83	-0.5877
23	2	LOCAL	-1	300	1	-1	1.87	31.6	29.6	18.9	1	4.52		
23	3	TZSR	1	0	-1	-1	1.29	26.1	24.5	23.2	0			
23	4	TZSR	1	300	1	1	2.65	29.1	30.2	26.1	0			
25	1	LOCAL	-1	0	-1	1	1.05	36.7	32.4	29.2	0	2.80	1.39	-1.0277
25	2	LOCAL	-1	300	1	-1	1.12	31.8	28.3	19.1	0	2.77		
25	3	TZSR	1	0	-1	-1	1.75	37.3	31.1	26.8	0			
25	4	TZSR	1	300	1	1	1.65	38.6	33.0	28.0	0			

[1] Some statistical packages do not accept 'text' (alphanumeric) variables; in that case the 'variety' and 'fertilizer' variables must be coded (e.g., as 1 an2).
[2] These contrast variables are only needed when using a multiple regression package or when carrying out covariance analysis.
[3] In the data file for analysis, *all* the cells of each site must be filled with the appropriate values as shown for the first site.
[4] For use in covariance analysis; four decimals to avoid rounding errors in the calculations.

Table II.2: Examples of Contrast Variables for Factor Combinations (Treatments)

Factor levels		Contrasts		
		Factor 1		Factor 2
Factor 1	Factor 2	Linear	Quadratic	Linear only
1	1	-1	-1	-1
1	2	-1	-1	1
2	1	0	2	-1
2	2	0	2	1
3	1	1	-1	-1
3	2	1	-1	1

can make the calculations much easier. Again, in the case of missing plots, this variable can only be created after obtaining estimates for the empty cells.

For an analysis with covariates, factor combinations should always be represented by 'contrasts' rather than by indicator ('dummy') variables, while the 'sitemean' variable should be replaced by 'reduced sitemean', i.e., sitemean minus the overall average of all trial plots. The use of these variables makes it possible to carry out the most complex analysis with all the statistical packages we reviewed. Examples of these new variables are shown in Table II.1. We refer to the textbooks for a more complete discussion of contrasts and polynomials. Snedecor and Cochran (1967) give a table with polynomial variables for up to six treatments or factor levels.

Carrying out the calculations

In the analysis of on-farm trials, we will usually want to consider all the classifications, treatment factors, interactions, covariates and regressors simultaneously. For the sake of clarity of exposition, however, we will introduce the different analytical components one by one, starting with straightforward ANOVA, followed by 'treatment x sitemean' interaction, regressors, (covariates) and missing plots.

Analysis of variance

In Chapter 7, we were dealing with a 2^2 maize variety-fertilizer factorial trial with yields from 22 single replicate farmers' fields (Table 7.1). The detailed data set for this trial is presented in Table II.1. The simple ANOVA without 'treatment x sitemean' interaction, covariates and regressors was given in Chapter 7 only for comparison with the more complete analyses. It presents no special problems when carried out with an ANOVA or GLM routine.

When a multiple regression package is used, we must use contrast variables for the treatment factors (Table II.1). Some packages also require that a separate variable for interaction be included in the data set. In this example, this is the product between V and F (VxF in Table II.1). Most multiple regression routines do not give a breakdown of the SS for each successive term in the equation, but we can obtain this by repeating the analysis a number of times, each time with an additional class, factor or interaction variable included. The contribution of each entry is found by subtracting the total explained variance of the previous step from that of the current one, or by subtracting the residual variance from that of the previous step, which is the same. The SS contributed by each classification, factor (or treatment) and interaction is entered in the ANOVA table with the correct degrees of freedom. This stepwise approach is shown for this trial in Table II.3. The 'column of differences', calculated by hand, gives the SS of the individual contributions, as in Table 7.1, Chapter 7.

Table II.3: Stepwise ANOVA Using a Regression Package; Data as in Table II.1

		D.F.	S.S.	Difference with previous
	Mean	1	514.93	
Step 1, include sites	Regression	21	35.20	**35.20**
	Residual	66	46.59	
Step 2, include variety	Regression	22	36.64	**1.44**
	Residual	65	45.15	
Step 3, include fertilizer	Regression	23	56.60	**19.96**
	Residual	64	25.19	
Step 4, include variety x fertilizer	Regression	24	56.70	**0.10**
interaction	Residual	63	**25.09**	

Treatment x sitemean interaction; adaptability analysis

The 'treatment x sitemean' interaction term measures whether treatment effects differ with a field's level of production, reflected in its mean yield. Stated differently but equivalently: is there a significant difference in the slope of the regression of yield on mean site yield for different treatments? Since we are dealing with a factorial trial, we will ask more specifically for the 'variety x sitemean' and the 'fertilizer x sitemean' interactions.

We will first show how the calculations can be done manually. The *interaction between treatments and sitemean* is the sum of the SS for regression on sitemean of all the treatments taken individually minus the SS for regression of all the treatments together. The SS of regression for treatment 1 equals:

$$SS_{regr1} = (\Sigma x_i y_{i,1} - \Sigma x_i \Sigma y_{i,1/n})^2 / (\Sigma x_i^2 - (\Sigma x_i)^2/n) \quad (1)$$

where $y_{i,1}$ = yield of treatment 1 in field i
x_i = mean yield in field i
n = number of fields (sites)

$$= (103.7179-98.3048)^2/(137.4049-128.5989)$$
$$= 3.3275$$

This is repeated for all four treatments. The sum of the four individual regression SS is the total SS for regression of treatments on sitemean:

$$SS_{regr,trt} = 3.3275 + 18.8531 + 5.5775 + 11.1390 = 38.8971$$

The reader should verify these results. The SS of regression for all the treatments taken together equals:

$$SS_{regr,all} = (\Sigma x_i y_{i,j} - \Sigma x_i \Sigma y_{i,j/n})^2 / k(\Sigma x_i^2 - (\Sigma x_i)^2/n)$$
$$= 35.1967$$

where

k = number of treatments (= 4)

Note that for a particular field i, we multiply the yield of all the plots in the same field with the same value for sitemean (x_i). The SS of regression for all treatments together is, of course, the same as the SS for sites (see Table 7.1 in Chapter 7), and does not have to be calculated separately.

The 'treatment x sitemean' interaction now equals:

$$SS_{interactions} = SS_{regr,trt} - SS_{regr,all}$$
$$= 38.8971 - 35.1967$$
$$= 3.7004$$

This analysis does not specify what exactly causes the interaction, whether it is associated with the variety or the fertilizer effect, or both. With a factorial trial, it is better to calculate the separate interaction components, viz. those for 'variety x sitemean' and for 'fertilizer x sitemean'. We will demonstrate manual calculation of the 'fertilizer x sitemean' interaction. It involves calculating the SS for regression of the plots without fertilizer and those with fertilizer on sitemean, adding these up and subtracting the SS for sites (which is the same as regression for all plots together):

for F_1:

$$SS_{regr,F_1} = (\Sigma x_i y_{i,1} - \Sigma x_i \Sigma y_{i,1/n})^2 / 2(\Sigma x_i^2 - (\Sigma x_i)^2/n)$$

where $y_{i,1}$ = sum of yield of plots with fertilizer level 1 in field i (column 13 in Table II.1)

x_i = mean yield in field i

n = number of fields (sites)

$$= (219.0887 - 206.6673)^2/2(137.4049 - 128.5989)$$
$$= 8.7606$$

For F_2 the calculations are repeated with the plots with fertilizer level 2 and the SS equals 29.4876. Thus, the total SS for regressions equals:

$$SS_{regr,fert} = 8.7606+29.4876 = 38.2482$$

We subtract SS for sites:

$$SS_{interaction} = 38.2482-35.1967 = 3.0515$$

The calculations for variety are equivalent and the 'variety x sitemean' interaction equals:

$$SS_{interaction} = 19.0107+16.2404-35.1967 = 0.0545$$

The separate interaction terms for variety and fertilizer do not add up to the SS for 'treatment x sitemean' interaction, because there is a third term, viz. the three-way interaction between variety, fertilizer and sitemean, which will usually not be very interesting. For the sake of completeness, this is found as the simple difference:

$$SS_{var\ x\ fert\ x\ sitemean} = 3.7004-3.0515-0.0545 = 0.5944$$

Readers who only have a standard ANOVA package should carry out a simple ANOVA first and then subtract the manually calculated interaction terms from the error SS to arrive at the results of Table 7.2 in Chapter 7.

With some GLM packages, it is easy to calculate the separate interaction components. This involves introducing the interaction terms 'variety x sitemean' and 'fertilizer x sitemean' as variables in the analysis after the site and treatment effects (see Table 7.2, Chapter 7).

Most GLM, however, only accept quantitative variables as covariates. In that case we proceed as follows:

1. Carry out the ANOVA with sites and treatment factors and note the residual SS.
2. Introduce the 'variety x sitemean' interaction as a covariate and run again. The *decrease* in residual SS equals the SS for the interaction.
3. Also introduce 'fertilizer x sitemean' as a covariate. The resulting decrease in residual SS equals the SS for this interaction term.

The analyses may also be done with a multiple regression package using the stepwise approach outlined earlier. Separate variables may have to be created for each interaction with sitemean. They are obtained as the product between V and Sitemean and F and Sitemean (Table II.1)

The significant 'fertilizer x sitemean' interaction was further examined in Chapter 7 by plotting the mean yields at each fertilizer level against the mean site yields of each field. In column 13 of Table II.1, the first figure for each site is the sum of the yields of the two plots without fertilizer, the second for the plots with fertilizer. The *average* yields at each fertilizer level are regressed separately on the corresponding mean site yields (column 13). Any statistical computer package or scientific calculator will do these regressions.

The general regression equation is:

$$y = a + bx \qquad (2)$$

In this case, the y is the average yields at a particular fertilizer level (i.e., the values in column 12 divided by 2) and the x are the corresponding mean site yields (column 13). The equations at the two fertilizer levels are

$$F_1: \quad y = 0.2376 + 0.7053\,x$$
$$F_2: \quad y = -0.2332 + 1.2939\,x$$

They were plotted in Fig. 7.2 of Chapter 7. The significant interaction between fertilizer effect and mean site yield means that the two slopes (coefficient b) are significantly different for the two fertilizer levels.

The regression coefficients a and b in equation (2) may be calculated manually as follows:

$$b = (\Sigma x_i y_i - \Sigma x_i \Sigma y_i/n)/(\Sigma x_i^2 - (\Sigma x_i)^2/n)$$
$$a = \Sigma y_i/n - b\Sigma x_i/n$$

where x_i and y_i are, respectively, the mean site yield and the average yield at a particular fertilizer level at site i.

The reader should work out the regression equations for the two fertilizer levels.

Regressors

We argued in Chapter 7 for the use of regressors (and sometimes covariates) to increase the precision of on-farm trials. The gain in precision comes at a price: the calculations are more involved than for a straightforward ANOVA (especially with covariates). It is absolutely necessary that the reader understands the analysis with regressors and can repeat it, otherwise on-farm trials will be found to be very frustrating because of their variability.

We use regressors to remove random effects from the residual variance. The regressor variables must be included in the analysis as the *last* terms, *sequentially adjusted for the preceding terms.* As a result, that part of the regressor values which is *caused by* the treatments becomes part of the treatment SS, as it should. This point was explained in more detail in Chapter 7. The analysis is straightforward with a flexible GLM. The regressor variables are simply entered as the final terms in the model. With a GLM which only allows covariates, proceed in the same way as shown for 'treatment x sitemean' interaction on pages 191–192. Run the analysis repeatedly, entering the successive concomitant variables, after the interaction terms with sitemean. The SS for each variable equals the corresponding decrease in residual SS. When using a regression package, extend the steps of Table II.3 to include the 'treatment x sitemean' interactions, followed by the regressors. The complete analysis is shown in Table 7.5 in Chapter 7. The readers are urged to carry out the calculations using the data set of Table II.1.

Covariates

In covariance analysis, we actually wish to remove that part of the SS of the different model terms (sites, treatments, interactions, etc.) which is caused by the covariates, in order to obtain only the independent part. Before we present the appropriate calculation procedures, we must dwell briefly on the statistical nature of covariance analysis. In covariance analysis, we first define the 'full model' for a trial, with terms for classifications, treatment factors, interactions and covariates but without regressors, and obtain the residual SS for this model. Next, the analysis is repeated a number of times, each time excluding one of the model terms. The difference between the residual SS of the reduced model and that of the full model is the SS for the excluded term, corrected for covariates. If one of the model terms is strongly associated with the covariates, we will find that, by excluding that term, the residual SS is only slightly increased and the term's corrected SS will turn out to be small. Since the F-test for significance is based on the ratio between a term's corrected SS and the residual SS for the full model, we now have a test for the 'pure' effect of that term. We showed in Chapter 7 that this analysis is not appropriate for the type of variables we defined as 'regressors'. The model terms should not be corrected for these variables and they must be included in the analysis after covariance analysis as the last terms, sequentially adjusted for the preceding terms.

Many statistical packages can carry out covariance analysis as part of the ANOVA routine for the usual trial designs. The presence of 'treatment x sitemean' interaction in our model, however, creates a complication which cannot be handled by most ANOVA packages and requires the use of a flexible GLM or multiple regression routine. We will assume that the reader does not have a sophisticated GLM which can carry out all the calculations automatically. Some hand calculations will then be needed and we will show the successive steps in the analysis. We will only consider a single covariate— the need for more will seldom arise. In the maize 'variety x fertilizer' trial, in fact, none of the variables qualified for covariance analysis (see Chapter 7), but we will use 'shade' for demonstration purposes only.

Remember that, when there are also covariates, the interactions must be represented by the products between the contrasts and reduced sitemean; in terms of the variables in Table II.1: 'V x reduced sitemean' and 'F x reduced sitemean' instead of 'variety x sitemean' and 'fertilizer x sitemean'. The numerical results are exactly the same, but the former will allow us to carry out the calculations for covariance analysis with practically any statistical package.

First, we run the full model with covariates but without regressors. The order of inclusion is not important in this case. We use the contrasts (V, F and VF) instead of the original factors as well as the reduced sitemean for reasons explained below. We only need the residual SS from this analysis, which is shown in the first row of Table II.4. We now repeatedly run the analysis with the full model minus each of the treatment factors, interactions and covariates, noting the residual SS each time (second column in Table II.4). The difference with the residual SS of the full model is the corrected SS for the excluded model terms. We cannot run this analysis with the original indicator variables for treatments and (gross) sitemean, because part of the SS of the excluded term will then turn up in the interactions! This is avoided by the use of contrasts and 'reduced sitemean'. The corrected SS corresponding with each model term are shown in the last column. Note that we did not correct the SS for sites. Covariates are chosen because of the bias they may cause on the treatment SS. The effect of shade on the site SS, however, is not biasing the site effect, rather, it is part of the causes of site differences and should therefore not be removed. We will normally subject site yield to a separate regression analysis with a number of explaining variables, including mean values of

Table II.4: Calculation of Corrected SS for Successive Terms in the ANOVA with Shade as Covariate, Regressors Excluded

Model	Sums of squares of residuals	Corrected SS of model terms
Full (excluding regressors)	20.3069	
— Variety (V)	22.1848	1.8779
— Fertilizer (F)	38.3105	18.0036
— Variety x fertilizer interaction (VxF)	20.3486	0.0417
— V x reduced sitemean	20.6586	0.3517
— F x reduced sitemean	23.1501	2.8432
— Shade	21.9814	1.6742

covariates and regressors (see Table 7.6 in Chapter 7). Finally, we must account for the effect of the regressors. We will therefore run the full model again, now augmented with the regressors in the last position, sequentially adjusted for all the other terms. This run gives us the residual SS for the F tests as well as the SS for the regressors. The complete analysis is shown in Table II.5.

Table II.5: Complete ANOVA with Corrected SS for All Model Terms Except Sites, and Sequentially Adjusted Regressors

Source	Sum of squares	D.F.	Mean square	P-value
Mean	514.93	1	514.9277	
Site (not corrected)	35.20	21	1.68	<0.0001
Treatments				
Variety	1.88	1	1.88	<0.0001
Fertilizer	18.00	1	18.00	<0.0001
Variety x Fertilizer	0.04	1	0.04	0.6192
Interactions with sitemean				
Variety x Sitemean	0.35	1	0.35	0.1449
Fertilizer x Sitemean	2.84	1	2.84	<0.0001
Covariate				
Shade	1.67	1	1.67	<0.0001
Regressors				
Stand, establishment	7.19	1	7.19	<0.0001
Stand, tasseling	0.24	1	0.24	0.2260
Stand, harvest	3.75	1	3.75	<0.0001
Residual	9.1294	57	0.1602	

Treatment means corrected for a covariate

Mean yields for the different treatments are biased if the differences are partly due to the covariate. We find the corrected means by subtracting from each treatment mean its regression on the covariate:

$$y_i = y_{i.} - b(x_{i.} - x_{..})$$

where b = regression coefficient
$y_{i.}$ = mean yield for treatment i
$x_{i.}$ = mean value of the covariate for treatment i
$x_{..}$ = overall mean value of the covariate

The regression coefficient b is obtained from the full model, including covariates, sites, treatments and interactions in any order, but without the regressors. The only coefficient we are interested in is that for the covariate 'shade'. When asking for the regression coefficients, some packages will respond that the coefficients for classifications and factors are not estimable, but this can be ignored. The regression coefficient and mean covariate value for the present experiment are shown in Table II.6. The readers should verify these results. The values from the table are entered in the above expression to obtain the corrected means for each treatment. For example, for treatment 1 we get:

$$y_i = 1.85 + 0.3424\ (0.2727 - 0.3068)$$
$$= 1.84$$

The values for the other treatments are shown in Table II.7. They are not much different from those in Table 7.1 in Chapter 7.

Table II.6: Regression Coefficient and Means for the Covariate Shade, 2^2 Variety-Fertilizer Trial, Alabata, 1988

	Regression	Means of covariate				
Covariate	Coeff. b	V_1F_2	V_1F_1	V_2F_1	V_2F_2	Overall
Shade	-0.3424	0.2727	0.2273	0.4545	0.2727	0.3068

Table II.7: Mean Treatment Yield, Adjusted for Covariate 'Shade', 2^2 Variety-Fertilizer Trial, Alabata, 1988

	Fertilizer, kg ha^{-1}		
Varieties	0	300	Mean
Local	1.84	2.70	2.27
TZSR-W	2.09	3.05	2.57
Mean	1.97	2.87	2.42

Analysis of mean site yield and 'treatment x sitemean' interaction

The analysis of mean site yield by multiple regression (see Chapter 7) is straightforward and will not be further demonstrated. When one or more variables show a significant effect on mean site yield, it is useful to repeat the ANOVA of Table 7.5, replacing the (significant) 'fertilizer x sitemean' interaction by interaction terms containing those variables, in the present example: 'fertilizer x shade' and 'fertilizer x date of planting'. Table II.8 shows these two interaction terms followed by the original 'fertilizer x sitemean' interaction. By including them in the analysis in that order, the latter measures the *remaining* interaction after accounting for the first two. Note that the SS for regressors and residual have changed somewhat by the inclusion of the new interaction terms.

Table II.8: ANOVA of a 2^2 Maize Variety x Fertilizer Trial, Alabata, Southwest Nigeria, 1988, with Interaction of the Fertilizer Effect with 'Shade' and 'Date of Planting' as Table 7.5 in Chapter 7

Source	Sum of squares	D.F.	Mean square	P-Value
Mean	514.93	1	517.93	
Sites	35.20	21	1.68	<0.0001
Treatments				
Variety	1.44	1	1.44	0.0044
Fertilizer	19.96	1	19.96	<0.0001
Variety x Fertilizer	0.10	1	0.10	0.4407
Interactions of fertilizer effect with				
Shade (mean)	0.06	1	0.06	0.5527
Date of planting	0.67	1	0.67	0.0483
Sitemean	2.51	1	2.51	0.0002
Regressors				
Shade	1.31	1	1.31	0.0065
Stand at establishment	7.35	1	7.35	<0.0001
Stand at tasseling	0.23	1	0.23	0.2461
Stand at harvest	3.78		3.78	<0.0001
Residual	9.1835	56	0.1640	

Stepwise trials

In Chapter 7, we suggested the use of contrasts to test for the effects of fertilizer, increased density and weed control in a stepwise trial with these 'factors' (see Table 7.10). Table II.9 shows the break-down of the treatment SS into three contrasts. The first two (for fertilizer and density) were explicitly introduced as separate variables (see Table 7.10 in Chapter 7), while the 'remainder' results from including 'treatments' as a third term. This automatically gives the remaining SS for treatments, after accounting for the two contrasts. A major part of the remainder is also caused by a fertilizer effect, viz. treatment 1 versus 3 and 4, as well as the weeding effect (treatment 2 versus 3 and 4). The weeding effect cannot be tested independently from the other two contrasts, but we may still perform a valid test by introducing the third contrast variable of Table 7.10 alone in the ANOVA. The resulting SS is 0.03 (verify!). This must be tested against the residual SS of Table II.9, resulting in a P value of 0.6904, i.e., the effect is not significant. This test is identical to an LSD test which is valid, because the weeding contrast was included explicitly in the trial design.

Table II.9 also tests for interaction between the two significant contrasts and sitemean, which shows that only the interaction of the fertilizer effect was significant. A separate test for interaction between contrast 3 (weeding effect, not orthogonal with the others) and sitemean had a SS of 0.18 and was not significant.

Table II.9: ANOVA for a Stepwise Trial, Ayepe, Southwest Nigeria, 1988, with Treatment Contrasts

Source	Sum of squares	D.F.	Mean square	P-Value
Mean	795.83	1	795.83	
Sites	99.16	35	2.83	<0.0001
Treatment contrasts				<0.0001
Fertilizer	8.08	1	8.08	0.0166
Density	1.12	1	1.12	<0.0001
Remainder	8.91	1	8.91	
Interactions with sitemean				
Fertilizer	0.81	1	0.81	0.0404
Density	0.08	1	0.08	0.5054
Remainder	2.04	1	2.04	0.0014
Regressors				
Shade	0.18	1	0.18	0.3294
Weeds	0.03	1	0.03	0.6944
Stand at establishment	3.88	1	3.88	<0.0001
Stand at tasseling	2.63	1	2.63	0.0003
Stand at harvest	8.05	1	8.05	<0.0001
Residual	17.66	94	0.1879	
R-square	0.88	CV	18.2%	

Criss-cross trials

A criss-cross trial is a combination of two split plot trials and must be analyzed accordingly. We will demonstrate the analysis with the data set of Table II.10. The ANOVA model is shown in Table II.11. The variety and system effects and their interactions with mean site yield are tested against their own residual terms, which are part of the 'variety x field' and the 'system x field' interactions. The 'variety x system' interaction is tested against the plot level residual ($Residual_3$).

A criss-cross trial without 'treatment x sitemean' interaction, (covariates) and regressors can of course be analyzed by standard ANOVA procedures, treating it as a double split plot, otherwise a GLM or multiple regression must be used[1]. We will demonstrate the analysis first without (1) and then with regressors (2). (Calculations for covariates become very complicated, and we will not discuss them).

1. The use of a standard GLM (which only allows covariates) or a multiple regression routine involves the same steps as described on pages 191 to 192.

Table II.10: Data Set for the Criss-Cross Trial with 3 Maize Varieties, with and without Pigeon Peas (P. pea)(Versteeg and Huijsman, 1991)

			Contrasts					Weedscore[1]		
Field	Variety	System	V_1	V_2	S	Yield	Site mean	Plot	Var. strips	Sys. strips
1	LOCAL	Sole	-2	0	-1	2.38	2.40	4.0	4.0	4.1
1	LOCAL	P. pea	-2	0	1	2.36		4.1	4.0	2.2
1	TZSR	Sole	1	-1	-1	2.08		3.4	2.5	4.1
1	TZSR	P. pea	1	-1	1	2.44		1.7	2.5	2.2
1	HYBRID	Sole	1	1	-1	3.54		4.9	2.8	4.1
1	HYBRID	P. pea	1	1	1	1.57		0.8	2.8	2.2
2	LOCAL	Sole	-2	0	-1	1.81	2.56	3.8	3.4	3.5
2	LOCAL	P. pea	-2	0	1	2.44		3.1	3.4	2.6
2	TZSR	Sole	1	-1	-1	1.70		4.5	3.6	3.5
2	TZSR	P. pea	1	-1	1	2.68		2.7	3.6	2.6
2	HYBRID	Sole	1	1	-1	2.98		2.1	2.1	3.5
2	HYBRID	P. pea	1	1	1	3.76		2.1	2.1	2.6
3	LOCAL	Sole	-2	0	-1	3.07	3.28	1.5	2.9	2.3
3	LOCAL	P. pea	-2	0	1	2.11		4.4	2.9	4.0
3	TZSR	Sole	1	-1	-1	3.08		2.9	3.1	2.3
3	TZSR	P. pea	1	-1	1	3.76		3.3	3.1	4.0
3	HYBRID	Sole	1	1	-1	4.13		2.5	3.4	2.3
3	HYBRID	P. pea	1	1	1	3.52		4.4	3.4	4.0
4	LOCAL	Sole	-2	0	-1	2.09	1.81	2.6	2.5	3.9
4	LOCAL	P. pea	-2	0	1	1.96		2.4	2.5	4.6
4	TZSR	Sole	1	-1	-1	1.21		5.2	6.2	3.9
4	TZSR	P. pea	1	-1	1	1.19		7.3	6.2	4.6
4	HYBRID	Sole	1	1	-1	2.06		3.8	4.0	3.9
4	HYBRID	P. pea	1	1	1	2.35		4.2	4.0	4.6
5	LOCAL	Sole	-2	0	-1	1.49	1.96	3.9	4.7	3.9
5	LOCAL	P. pea	-2	0	1	1.48		5.5	4.7	4.7
5	TZSR	Sole	1	-1	-1	2.21		2.6	3.5	3.9
5	TZSR	P. pea	1	-1	1	2.27		4.5	3.5	4.7
5	HYBRID	Sole	1	1	-1	2.04		5.2	4.6	3.9
5	HYBRID	P. pea	1	1	1	2.29		4.0	4.6	4.7
6	LOCAL	Sole	-2	0	-1	1.13	1.44	2.6	2.4	3.5
6	LOCAL	P. pea	-2	0	1	1.52		2.2	2.4	2.8
6	TZSR	Sole	1	-1	-1	1.24		4.7	3.8	3.5
6	TZSR	P. pea	1	-1	1	1.65		3.0	3.8	2.8
6	HYBRID	Sole	1	1	-1	1.27		3.1	3.2	3.5
6	HYBRID	P. pea	1	1	1	1.82		3.3	3.2	2.8
7	LOCAL	Sole	-2	0	-1	2.33	2.95	1.2	4.2	2.8
7	LOCAL	P. pea	-2	0	1	1.66		7.2	4.2	3.0
7	TZSR	Sole	1	-1	-1	2.57		5.1	2.8	2.8
7	TZSR	P. pea	1	-1	1	3.13		0.5	2.8	3.0
7	HYBRID	Sole	1	1	-1	4.16		2.1	1.6	2.8
7	HYBRID	P. pea	1	1	1	3.85		1.2	1.6	3.0
8	LOCAL	Sole	-2	0	-1	1.46	1.25	4.1	3.4	3.2
8	LOCAL	P. pea	-2	0	1	0.83		2.8	3.4	5.3
8	TZSR	Sole	1	-1	-1	1.84		1.2	4.6	3.2
8	TZSR	P. pea	1	-1	1	0.58		8.0	4.6	5.3

Table II.10: Data Set for the Criss-Cross Trial with 3 Maize Varieties, with and without Pigeon Peas (P. pea)(Versteeg and Huijsman, 1991) (Contd.)

			Contrasts					Weedscore[1]		
Field	Variety	System	V_1	V_2	S	Yield	Site mean	Plot	Var. strips	Sys. strips
8	HYBRID	Sole	1	1	-1	1.80		4.3	4.6	3.2
8	HYBRID	P. pea	1	1	1	0.98		5.0	4.6	5.3
9	LOCAL	Sole	-2	0	-1	1.99	2.27	4.4	3.1	4.1
9	LOCAL	P. pea	-2	0	1	2.28		1.9	3.1	3.7
9	TZSR	Sole	1	-1	-1	2.41		3.9	4.4	4.1
9	TZSR	P. pea	1	-1	1	1.65		5.0	4.4	3.7
9	HYBRID	Sole	1	1	-1	2.57		3.9	4.0	4.1
9	HYBRID	P. pea	1	1	1	2.75		4.1	4.0	3.7
10	LOCAL	Sole	-2	0	-1	1.32	1.51	3.6	4.2	3.4
10	LOCAL	P. pea	-2	0	1	0.99		4.8	4.2	4.3
10	TZSR	Sole	1	-1	-1	1.69		2.8	3.8	3.4
10	TZSR	P. pea	1	-1	1	0.71		4.9	3.8	4.3
10	HYBRID	Sole	1	1	-1	2.32		3.7	3.4	3.4
10	HYBRID	P. pea	1	1	1	2.00		3.2	3.4	4.3
11	LOCAL	Sole	-2	0	-1	1.78	1.92	4.4	3.2	2.8
11	LOCAL	P. pea	-2	0	1	1.70		2.0	3.2	2.8
11	TZSR	Sole	1	-1	-1	1.65		2.1	3.0	2.8
11	TZSR	P. pea	1	-1	1	2.23		4.0	3.0	2.8
11	HYBRID	Sole	1	1	-1	2.05		2.0	2.3	2.8
11	HYBRID	P. pea	1	1	1	2.09		2.5	2.3	2.8
12	LOCAL	Sole	-2	0	-1	1.08	1.46	3.3	4.7	5.0
12	LOCAL	P. pea	-2	0	1	1.20		6.1	4.7	4.6
12	TZSR	Sole	1	-1	-1	1.55		4.4	4.8	5.0
12	TZSR	P. pea	1	-1	1	1.80		5.3	4.8	4.6
12	HYBRID	Sole	1	1	-1	1.58		7.2	4.8	5.0
12	HYBRID	P. pea	1	1	1	1.56		2.5	4.8	4.6
13	LOCAL	Sole	-2	0	-1	1.39	1.99	3.8	4.1	3.3
13	LOCAL	P. pea	-2	0	1	1.14		4.4	4.1	3.4
13	TZSR	Sole	1	-1	-1	2.10		3.0	2.9	3.3
13	TZSR	P. pea	1	-1	1	2.80		2.8	2.9	3.4
13	HYBRID	Sole	1	1	-1	1.45		3.1	3.1	3.3
13	HYBRID	P. pea	1	1	1	3.07		3.1	3.1	3.4
14	LOCAL	Sole	-2	0	-1	1.25	1.69	4.9	3.7	4.7
14	LOCAL	P. pea	-2	0	1	1.23		2.6	3.7	2.6
14	TZSR	Sole	1	-1	-1	1.68		5.3	4.2	4.7
14	TZSR	P. pea	1	-1	1	1.94		3.2	4.2	2.6
14	HYBRID	Sole	1	1	-1	1.99		3.9	2.9	4.7
14	HYBRID	P. pea	1	1	1	2.05		2.0	2.9	2.6
15	LOCAL	Sole	-2	0	-1	2.60	3.36	0.1	0.8	1.6
15	LOCAL	P. pea	-2	0	1	2.95		1.6	0.8	2.5
15	TZSR	Sole	1	-1	-1	3.47		3.4	3.4	1.6
15	TZSR	P. pea	1	-1	1	3.02		3.4	3.4	2.5
15	HYBRID	Sole	1	1	-1	4.56		1.3	1.9	1.6
15	HYBRID	P. pea	1	1	1	3.53		2.5	1.9	2.5

Table II.10: Data Set for the Criss-Cross Trial with 3 Maize Varieties, with and without Pigeon Peas (P. pea)(Versteeg and Huijsman, 1991) (Contd.)

			Contrasts					Weedscore[1]		
Field	Variety	System	V_1	V_2	S	Yield	Site mean	Plot	Var. strips	Sys. strips
16	LOCAL	Sole	-2	0	-1	1.93	2.71	5.9	4.2	4.5
16	LOCAL	P. pea	-2	0	1	1.80		2.5	4.2	3.1
16	TZSR	Sole	1	-1	-1	3.08		3.1	2.6	4.5
16	TZSR	P. pea	1	-1	1	3.55		2.2	2.6	3.1
16	HYBRID	Sole	1	1	-1	2.80		4.4	4.4	4.5
16	HYBRID	P. pea	1	1	1	3.12		4.5	4.4	3.1
17	LOCAL	Sole	-2	0	-1	0.19	0.32	1.4	2.8	3.0
17	LOCAL	P. pea	-2	0	1	0.19		4.3	2.8	3.7
17	TZSR	Sole	1	-1	-1	0.05		3.6	3.1	3.0
17	TZSR	P. pea	1	-1	1	0.16		2.7	3.1	3.7
17	HYBRID	Sole	1	1	-1	0.79		3.9	4.0	3.0
17	HYBRID	P. pea	1	1	1	0.56		4.1	4.0	3.7
18	LOCAL	Sole	-2	0	-1	2.32	2.40	2.9	2.3	3.5
18	LOCAL	P. pea	-2	0	1	1.92		1.7	2.3	2.9
18	TZSR	Sole	1	-1	-1	2.63		1.5	1.8	3.5
18	TZSR	P. pea	1	-1	1	1.99		2.1	1.8	2.9
18	HYBRID	Sole	1	1	-1	2.97		6.2	5.6	3.5
18	HYBRID	P. pea	1	1	1	2.56		5.0	5.6	2.9
19	LOCAL	Sole	-2	0	-1	0.65	1.31	8.3	7.5	4.8
19	LOCAL	P. pea	-2	0	1	0.92		6.7	7.5	5.5
19	TZSR	Sole	1	-1	-1	1.91		2.7	4.1	4.8
19	TZSR	P. pea	1	-1	1	2.45		5.6	4.1	5.5
19	HYBRID	Sole	1	1	-1	0.81		3.5	3.8	4.8
19	HYBRID	P. pea	1	1	1	1.13		4.1	3.8	5.5
20	LOCAL	Sole	-2	0	-1	1.62	1.22	2.3	2.4	2.5
20	LOCAL	P. pea	-2	0	1	0.99		2.5	2.4	3.2
20	TZSR	Sole	1	-1	-1	1.43		3.2	2.8	2.5
20	TZSR	P. pea	1	-1	1	0.66		2.4	2.8	3.2
20	HYBRID	Sole	1	1	-1	1.63		2.1	3.4	2.5
20	HYBRID	P. pea	1	1	1	0.97		4.8	3.4	3.2
21	LOCAL	Sole	-2	0	-1	1.46	1.87	2.0	1.2	2.7
21	LOCAL	P. pea	-2	0	1	1.51		0.4	1.2	2.6
21	TZSR	Sole	1	-1	-1	2.22		1.7	2.1	2.7
21	TZSR	P. pea	1	-1	1	1.90		2.5	2.1	2.6
21	HYBRID	Sole	1	1	-1	2.79		4.4	4.6	2.7
21	HYBRID	P. pea	1	1	1	1.32		4.9	4.6	2.6
22	LOCAL	Sole	-2	0	-1	1.32	1.27	3.9	4.3	4.1
22	LOCAL	P. pea	-2	0	1	0.89		4.8	4.3	4.1
22	TZSR	Sole	1	-1	-1	1.92		3.3	3.4	4.1
22	TZSR	P. pea	1	-1	1	2.28		3.6	3.4	4.1
22	HYBRID	Sole	1	1	-1	0.49		5.2	4.5	4.1
22	HYBRID	P. pea	1	1	1	0.71		3.8	4.5	4.1
23	LOCAL	Sole	-2	0	-1	0.73	0.57	2.4	3.6	3.4
23	LOCAL	P. pea	-2	0	1	0.48		4.8	3.6	3.4

Table II.10: Data Set for the Criss-Cross Trial with 3 Maize Varieties, with and without Pigeon Peas (P. pea)(Versteeg and Huijsman, 1991) (Contd.)

			Contrasts					Weedscore[1]		
Field	Variety	System	V_1	V_2	S	Yield	Site mean	Plot	Var. strips	Sys. strips
23	HYBRID	Sole	1	1	-1	0.58		3.3	3.1	3.4
23	HYBRID	P. pea	1	1	1	0.11		2.9	3.1	3.4
24	LOCAL	Sole	-2	0	-1	1.62	1.75	6.5	4.9	4.5
24	LOCAL	P. pea	-2	0	1	1.31		3.3	4.9	3.0
24	TZSR	Sole	1	-1	-1	1.49		4.0	3.3	4.5
24	TZSR	P. pea	1	-1	1	1.50		2.6	3.3	3.0
24	HYBRID	Sole	1	1	-1	2.23		2.9	2.9	4.5
24	HYBRID	P. pea	1	1	1	2.38		3.0	2.9	3.0
25	LOCAL	Sole	-2	0	-1	1.46	1.12	3.4	4.5	3.9
25	LOCAL	P. pea	-2	0	1	0.48		5.7	4.5	3.0
25	TZSR	Sole	1	-1	-1	1.03		2.3	2.4	3.9
25	TZSR	P. pea	1	-1	1	1.33		2.6	2.4	3.0
25	HYBRID	Sole	1	1	-1	0.88		6.1	3.4	3.9
25	HYBRID	P. pea	1	1	1	1.53		0.7	3.4	3.0

[1] Constructed variable, not part of the real data set.

1. A criss-cross trial can be considered as a combination of two split plot trials and we will distinguish main plots (strips of varieties and strips of systems) and subplots in the usual way. Since, in on-farm trials, we want to test for 'treatment

Table II.11: Model for the Analysis of the Data of Table II.10, without Regressor

Source of variation	D.F.	Remarks
Mean	1	
Sites	24	
Varieties		Analysis for strips of varieties
Varieties	2	
Varieties x Sites	2	
Residual_1	46	
[Varieties x Sites	74]	
System		Analysis for system strips
System	1	
System x Sitemean	1	
Residual_2	23	
[Systems x Sitemeans	49]	
Varieties x System	2	Analysis for subplots
Residual_3	48	

x sitemean' interactions, the calculations are slightly more complicated than for straightforward split plot trials. We present the calculations in some detail to demonstrate the underlying concepts. Table II.10 gives the raw data set for readers to carry out the analysis for themselves. We are assuming, as before, that a suitable GLM or multiple regression package is used. The only complication is the calculation of the 'variety x site' and 'system x site' interactions (Table II.11) which are needed to obtain the first two residuals. If these interaction terms are introduced in the model, a GLM package will calculate the residuals 1 and 2 directly. In order to do that, the package will automatically create dummy variables for treatments, sites and their interaction, but the number of dummies may exceed the limitations of the statistical package (or the computer) when the number of sites is large. With a regression package, all the dummies must be created manually and this quickly becomes prohibitively laborious. It is therefore better to avoid this complication and calculate the residual terms manually, as this does not present undue problems. We suggest carrying out the calculations by means of the following steps:

a. First we carry out an ordinary ANOVA as if the trial were a factorial, ignoring the criss-cross design. This yields the correct SS for all the effects and interactions (Table II.12[a]). Remember that, when using a multiple regression package, we may have to create the 'variety x sitemean' and 'system x sitemean' (dummy) variables in the data file first. They are found as the product of the variety and fertilizer contrasts and the sitemean variable.

b. Next, we find the three different residual terms which are needed for the tests of significance.

   Residual$_1$ is calculated as follows:

   $SS_{\text{vars x sites}} = (4.74^2 + 4.52^2 + 5.11^2 + \ldots.. + 2.41^2)/2 - 516.27 = 108.90$

   4.47, 4.52 and 5.11 are the total yields of variety$_1$ in site$_1$, etc (see Table II.10). Division by 2 is because there are 2 plots for each variety per site; 516.27 is SS_{mean} (see Table II.12A)

   $$\begin{aligned} SS_{\text{resid1}} &= SS_{\text{var x sites}} - SS_{\text{site}} - SS_{\text{var}} - SS_{\text{vars x sitemean}} \\ &= 108.90 - 83.75 - 8.76 - 3.83 \\ &= 12.56 \end{aligned}$$

   For residual$_2$:

   $SS_{\text{sys x site}} = (8.00^2 + 6.37^2 + \ldots.. + 3.34^2)/3 - 516.27 = 90.27$

   8.00 and 6.37 are the total yields of system$_1$ in site$_1$, etc. (see Table II.10). Division by 3 is because there are 3 plots for each system per site; 516.27 is SS_{mean} (see Table II.12A)

Table II.12: ANOVA for the Data of Table II.10, without Regressor

A. Sums of squares for all factors and interactions, without residuals

Source	Sum of squares	D.F.
Mean	516.27	1
Sites	83.75	24
Varieties		
Varieties	8.76	2
Varieties x Sitemean	3.83	2
System		
System	0.21	1
System x Sitemean	0.01	1
Var x System	0.33	2
[Residual	25.2747]	

B. Full ANOVA with hand-calculated residuals (see text)

Source	Sum of squares	D.F.	Mean square	P-value
Mean	516.27	1	515.98	
Sites	83.75	24	3.49	
Varieties				
Varieties	8.76	2	4.39	<0.0001
Varieties x Sites	3.83	2	1.92	0.0022
Residual_1	12.56	46	0.2730	
[Varieties x Sitemeans	108.90	74]		
System				
System	0.21	1	0.21	0.3906
System x Sites	0.01	1	0.01	0.8503
Residual_2	6.31	23	0.2743	
[System x Sitemeans	90.27	49]		
Varieties x System	0.33	2	0.17	0.2892
Residual_3	6.41	48	0.1335	

$$
\begin{aligned}
SS_{\text{resid2}} &= SS_{\text{sys x site}} - SS_{\text{site}} - SS_{\text{sys}} - SS_{\text{sys x sitemean}} \\
&= 90.27 - 83.75 - 0.21 - 0.01 \\
&= 6.30
\end{aligned}
$$

Residual_3 equals the residual of Table II.12A minus residual_1 and residual_2

$SS_{\text{resid3}} = 25.27 - 12.56 - 6.30 = 6.41$

The full ANOVA is shown in Table II.12B.

The MSTAT computer package can do the full analysis, including interactions with sitemean, in one go (criss-cross trials are then called "strip-plot" in MSTAT).

2. Extension of the calculation procedures with regressors is straightforward. For this particular experiment, no additional measurements were reported, but in order to demonstrate the full analysis, we generated an imaginary regressor, say, a weed score between 0 and 10, which is shown in Table II.10. We must use average values of the regressor for each varietal strip and for each system strip, rather than the plot values. One way to obtain them is by running the GLM with 'variety x site' as the only model term and with the regressor as the dependent variable. Next, we generate the estimated values corresponding to this model—these are the averages we are looking for. Most GLM and multiple regression routines can generate estimated (sometimes called 'predicted') values and automatically insert them as a new variable in the data file. Alternatively, the average values may simply be calculated by hand and entered in the data file. The values for this trial are given in Table II.10. For the analysis we follow the same steps as before.

   In step *a* we include the regressor three times; first, the average values for strips of varieties; secondly for strips of systems; and, finally, the plot values. (see Table II.13A for the correct position).

   In step *b* we calculate the three residuals:

$$
\begin{aligned}
SS_{resid1} &= SS_{vars\ x\ site} - SS_{site} - SS_{var} - SS_{vars\ x\ sitemean} - SS_{regressor} \\
&= 108.90 - 83.75 - 8.76 - 3.83 - 2.26 \\
&= 10.30
\end{aligned}
$$

$$
\begin{aligned}
SS_{resid2} &= SS_{sys\ x\ site} - SS_{site} - SS_{sys} - SS_{sys\ x\ sitemean} \\
&= 90.27 - 83.75 - 0.21 - 0.01 - 0.70 \\
&= 5.60
\end{aligned}
$$

   $Residual_3 = 21.96 - 10.30 - 5.60 = 6.06$

   The full ANOVA is shown in Table II.13B. Extension to more than one regressor is straightforward.

Missing values

We will demonstrate the estimation of missing values with part of the data from the stepwise trial of Tables 7.8 and 7.9 in Chapter 7. We will only use a subset of 8 farmers so that readers can repeat the calculations without too much trouble. The data for the 8 farmers' fields are shown in Table II.14. They include the 2

Table II.13: ANOVA for the Data of Table II.10, with Regressor (Weediness)

A. Sums of squares for all factors and interactions, without residuals

Source	Sum of squares	D.F.
Mean	516.27	1
Sites	83.75	24
Varieties		
Varieties	8.76	2
Varieties x Sitemean	3.83	2
Weeds	2.26	1
System		
System	0.21	1
System x Sitemean	0.01	1
Weeds	0.70	1
Varieties x System	0.33	2
Weeds	0.36	1
[Residual	21.9607]	

B. Full ANOVA with hand-calculated residuals (see text)

Source	Sum of squares	D.F.	Mean square	P-value
Mean	516.27	1		
Sites	83.75	24	3.49	
Varieties				
Varieties	8.76	2	4.39	<0.0001
Varieties x Sitemean	3.83	2	1.92	0.0008
Weeds	2.26	1	2.26	0.0030
$Residual_1$	10.30	45	0.2289	
[Var x Sites	108.90	74]		
System				
System	0.21	1	0.21	0.3735
System x Sitemean	0.01	1	0.01	0.8447
Weeds	0.70	1	0.70	0.1114
$Residual_2$	5.60	22	0.2545	
[System x Sites	90.27	49]		
Var x System	0.33	2	0.17	0.2772
Weeds	0.36	1	0.36	0.1013
$Residual_3$	6.06	47	0.1289	

fields with, respectively, one and two missing yield data, while the other 6 were taken randomly from the complete set of 34 farmers who had a full yield record.

We will demonstrate estimating the missing values directly by means of a GLM (or even an ANOVA) package, and with the Rubin method (Rubin, 1972). The direct method can only be used if the GLM package has the option of generating estimated (or 'predicted') values for empty cells. It involves carrying out the

Table II.14: Data Set for Demonstrating Calculation of Missing Values; Subset of 8 Farmers from the Stepwise Trial of Tables 7.8 and 7.9, Chapter 7. Figures Between Brackets are Estimated Missing Values (see text)

					Stand			
Site	Treatment	Shade	Weeds	Yields	Establishment	Tasseling	Harvest	Sitemean
3	2	0	1.6	1.33	22.9	20.1	14.3	1.15
3	1	0	1.0	0.83	25.7	21.7	11.3	1.15
3	5	1	0.8	1.36	29.9	20.8	14.0	1.15
3	4	0	0.8	(1.08)	23.8	15.8	10.0	1.15
7	2	2	1.5	2.49	13.7	49.2	31.1	1.56
7	5	3	2.1	0.91	28.2	36.6	24.3	1.56
7	1	3	1.7	1.44	16.0	38.5	30.4	1.56
7	4	2	2.2	1.39	16.3	25.0	16.2	1.56
9	5	1	1.0	4.77	58.0	51.7	58.0	3.39
9	1	1	1.6	1.57	34.6	29.4	28.3	3.39
9	4	1	1.5	3.21	32.9	26.6	26.2	3.39
9	2	2	1.5	4.03	44.4	40.0	38.4	3.39
11	5	1	1.3	2.69	45.6	40.1	29.9	2.57
11	4	1	1.3	2.87	28.9	26.2	21.1	2.57
11	1	1	1.0	(1.97)	38.1	29.9	24.6	2.57
11	2	2	1.0	(2.75)	26.7	24.9	21.7	2.57
18	1	0	0.5	2.87	34.4	34.4	31.8	3.61
18	5	1	0.3	4.59	67.6	67.6	68.2	3.61
18	2	1	0.3	4.28	37.6	37.6	38.9	3.61
18	4	1	0.3	2.69	28.7	28.7	27.8	3.61
21	1	1	1.3	2.02	31.3	30.9	26.9	2.34
21	5	2	1.1	2.50	70.8	65.5	49.2	2.34
21	2	2	1.0	2.23	32.1	30.9	28.4	2.34
21	4	2	0.9	2.62	31.7	32.4	26.4	2.34
26	1	0	1.0	1.69	24.4	25.3	18.1	2.06
26	4	0	1.0	1.75	20.7	18.1	12.3	2.06
26	2	2	1.5	1.40	18.1	16.4	11.7	2.06
26	5	2	1.5	3.39	77.5	66.4	46.9	2.06
39	2	2	1.8	1.14	35.9	30.0	22.6	1.55
39	4	1	1.6	2.04	27.8	25.3	23.7	1.55
39	5	1	1.4	1.96	51.0	48.7	37.8	1.55
39	1	2	1.6	1.06	28.9	24.7	22.5	1.55

ANOVA without 'treatment x sitemean' and regressors and requesting the program to calculate estimated values for all cells. The values for the empty cells are the best (least squares) estimates for the missing values. For the 3 missing values of Table II.14, we found 1.076, 1.973 and 2.747.

The Rubin method involves carrying out the ANOVA a number of times in a special way, and each time obtaining the residuals for the missing cells. This means that the computer package must have the option of generating residuals after the ANOVA.

The vector **X** of missing values (3 in the present case) is calculated from:

$$\mathbf{X} = \rho\mathbf{R}^{-1} \qquad (2)$$

Here, ρ_k is the residual in the k^{th} missing cell when the ANOVA is carried out with the available data but with all empty cells assigned value zero. The k^{th} row of matrix **R** contains the residuals in the missing cells when the ANOVA is carried out with all cells set equal to zero except the k^{th} missing cell, which is set equal to one.

We use the ANOVA model of Table 7.9, Chapter 7 but without 'treatment x sitemean' interaction and regressors to obtain residuals.

First we carry out the ANOVA with all the measured yield data, but with zero in the 3 empty cells, and obtain the vector of residuals. The residuals corresponding with the empty cells are the elements of ρ. They are shown in the first row of Table II.15. Next we carry out the ANOVA with the yield values replaced by zero, except in the first missing cell, where we insert one. The residuals corresponding

Table II.15: Vector ρ and Matrix **R** of Residuals for Missing Value Estimation

	x_1	x_2	x_3
ρ	-0.49	-0.10	-1.09
	0.40	-0.05	-0.03
R	-0.05	0.38	-0.25
	-0.03	-0.25	0.58

with the missing cells are shown in the second row of Table II.15. This is repeated twice more, with value one in the second or the third missing cell and zero everywhere else. The residuals for these runs are shown in rows 3 and 4. Rows 2, 3 and 4 together are the elements of matrix **X**. This matrix must be inverted. This is an elementary technique, which can be found in any standard text on linear algebra. The results are inserted in expression (2):

$$\mathbf{X} = -\,(-0.8537 \quad -0.7275 \quad -1.4050) \begin{pmatrix} 1.5341 & -0.1096 & -0.1096 \\ -0.1096 & 1.7220 & 0.5793 \\ -0.1096 & 0.5793 & 1.7220 \end{pmatrix}$$

$$= (1.0760 \quad 1.9732 \quad 2.7474)$$

The results are, of course, the same as for the direct method. Mean treatment yields and sitemeans are now obtained from the data set completed with the estimated missing values. In preparation for the ANOVA, we will calculate mean site yield, also from the completed data set.

For the ANOVA, in Chapter 7 we recommended using only the data actually measured but with 'sitemean' calculated from measured plus estimated values. The easiest way is to use 'forward inclusion' of the ANOVA terms in the order shown in Table II.16. This does not exactly give the correct SS but is acceptable *as long as the number of missing values is less than 5% of the total number of plots,* as was the case with the full trial of which these data were a subset. The results are shown in column A of Table II.16.

If the data of the example of Table II.14 were the full data set, the 5% condition would not be satisfied and the data should be treated as an unbalanced design. The correct SS are obtained in the same way as for covariance analysis. We first define the 'full model' for the trial as usual, with terms for classifications, treatment factors, interactions (and covariates if appropriate) but without regressors, and obtain the residual SS for this model. Next, the analysis is repeated a number of times, each time excluding one of the model terms. The difference between the residual SS of the

Table II.16: Three Options for ANOVA of a Design with Missing Values, Data from Table II.14; A. without Missing Values, Forward Inclusion; B. ibid., Exact Solution (see text), and C. Data Completed with Estimated Missing Values

		A		B		C	
Source	D.F.	MS	F	MS	F	MS	F
Mean	1	155.35		155.35		166.17	
Sites	7	2.94	<0.0001	2.72	0.0001	3.13	<0.0001
Treatments	3	1.53	0.0035	1.58	0.0032	1.70	0.0036
Tr x Sitemean	3	0.99	0.0147	0.99	0.0147	0.93	0.0243
Regressors							
Shade	1	0.24	0.2646	0.24	0.2646	0.29	0.2457
Weeds	1	0.38	0.1661	0.38	0.1661	0.26	0.2700
Stand at establishment	1	1.99	0.0068	1.99	0.0068	1.52	0.0181
Stand at tasseling	1	0.50	0.1185	0.50	0.1185	0.87	0.0584
Stand at harvest	1	1.04	0.0337	1.04	0.0337	1.23	0.0294
Residual	10	0.1720		0.1720	0.0337	0.1907	

reduced model and that of the full model is the correct SS for the excluded term. Remember that for most computer packages we will have to use contrast variables for the treatments and 'reduced sitemean' instead of sitemean. Finally, we must account for the effect of the regressors. We will therefore run the full model again, now augmented with the regressors in the last position, sequentially adjusted for all the other terms. This run gives us the residual SS for the F tests as well as the SS for the regressors. The results for the data of Table II.14 are shown in column B of Table II.16. They are only marginally different from column A, in spite of a rather high percentage of missing cells (10%).

Finally, we calculated the ANOVA for the measured data plus the estimated values, reducing the df of the residual term by 3. The results (Table II.16, column C), although substantially different, still lead to the same conclusions. In other cases, however, different conclusions may result and we do not recommend this approach when more than 5% of the cells are empty.

Annex

III Multivariate Techniques

Introduction

We will introduce three multivariate techniques which should be of interest to on-farm researchers. The techniques cannot be treated in detail, because this is outside the scope of this book. We will simply present the results and their interpretation in some concrete examples. Readers who wish to know more should consult one of the numerous textbooks in this area. Software packages which have a capability for multivariate analysis usually contain detailed instructions on how to carry out the analyses.

Principal component analysis (PCA)

Principal component analysis (PCA) is a multivariate technique for analyzing relationships among several quantitative variables measured on a number of objects, such as persons, soils, fields, plants, etc. It provides information about the relative importance of each variable in characterizing the objects. New variables are calculated, which consist of (usually linear) combinations of the old ones. A small number of these new variables will usually be sufficient to describe the observational objects.

Chemical and textural properties were measured on soils from 18 farmers' fields in Yamrat, Bauchi State, Nigeria (Table III.1). The table has 18 observational units (fields), each with 11 measured variables (soil characteristics). The questions which arise are which soil properties are correlated, which contribute most to the overall variance in soil characteristics, and how the number of variables can be reduced without losing too much information.

Table III.1: Variables Describing Soil Characteristics of 18 Farmers' Fields in Yamrat, Bauchi State, Nigeria

Field	pH	OC	TN	P	K	Ca	Mg	Mn	SAND	SILT	CLAY
1	5.7	0.49	0.044	5.2	0.17	2.25	0.57	0.07	42	48	10
2	7.1	0.39	0.039	1.1	0.29	4.30	1.12	0.07	54	30	16
3	6.0	0.54	0.045	24.4	0.31	2.66	0.71	0.07	48	44	8
4	5.5	0.34	0.035	2.2	0.21	2.10	0.63	0.10	54	38	8
5	6.2	0.54	0.045	3.1	0.32	4.40	1.01	0.10	52	32	16
6	5.8	0.32	0.037	4.0	0.15	1.88	0.42	0.04	68	26	6
7	6.0	0.29	0.032	10.3	0.38	4.91	0.89	0.08	58	30	12
8	6.1	0.27	0.045	4.4	0.31	4.02	0.94	0.07	58	30	12
9	5.9	0.21	0.039	12.3	0.15	1.81	0.57	0.03	68	26	6
10	6.4	0.10	0.025	7.9	0.18	2.59	0.68	0.05	72	22	6
11	6.3	0.45	0.044	4.9	0.23	2.42	0.70	0.04	68	22	10
12	5.8	0.18	0.039	11.0	0.17	2.66	0.67	0.10	58	34	8
13	6.6	0.25	0.030	2.9	0.26	2.73	0.78	0.07	60	32	8
14	6.2	0.66	0.058	2.5	0.17	4.34	0.92	0.10	52	34	14
15	5.3	0.09	0.038	33.2	0.17	3.38	0.73	0.10	60	30	10
16	6.1	0.52	0.043	34.5	0.32	4.40	1.01	0.10	52	36	12
17	6.0	0.22	0.030	27.5	0.14	2.55	0.63	0.10	68	24	8
18	6.6	0.47	0.042	4.1	0.18	4.14	0.91	0.15	54	36	10

The first step is to compute correlations among the soil characteristics in order to reveal relationships between variables (Table III.2). This provides a preliminary insight in the data set, indicating in this case, for example, a positive correlation between soil clay content and Ca and Mg contents for the soils in these fields. The correlation table, however, is quite complex and the relative importance of the different soil characteristics is not clear.

The correlation matrix can now be converted into principal components. The coefficients of the principal components are the eigenvectors of the correlation matrix. Thus, each principal component is a linear combination of the original variables. As many principal components can be computed as there are original variables. However, only the most important ones are of relevance for further analysis. The importance of the principal components is calculated from their eigenvalues and their contribution in explaining the overall variance (Table III.3). In our example, principal component 1 (Prin1) explains 43.4% of the overall variance, Prin2, Prin3, Prin4 and Prin5 contribute an additional 20.2%, 12.9%, 7.8% and 7.1% respectively. All five principal components together in this case explain 91.6% of the overall variance, and the first three already explain 76.6%.

Table III.2: Correlation Coefficients of Soil Characteristics of 18 Farmers' Fields from Table III.1

	OC	TN	P	K	Ca	Mg	Mn	SAND	SILT	CLAY
pH	0.25	–0.01	–0.41	0.30	0.39	0.60	–0.01	0.04	–0.22	0.39
OC		0.77	–0.19	0.30	0.36	0.39	0.25	–0.66	0.52	0.55
TN			–0.11	0.08	0.33	0.33	0.19	–0.56	0.42	0.53
P				0.01	0.02	–0.06	0.18	0.03	0.04	–0.17
K					0.64	0.67	0.03	–0.37	0.17	0.56
Ca						0.91	0.52	–0.39	0.08	0.83
Mg							0.44	–0.40	0.08	0.86
Mn								–0.47	0.39	0.36
SAND									–0.92	–0.53
SILT										0.16

The remaining six principal components (Prin6 to Prin11) explain only the residual 8.4%.

The biological meaning of principal components can tentatively be assessed from the relative contribution of the different soil characteristics to each principal component according to the eigenvectors (Table III.4). Prin1 is most strongly affected by the soil clay content and the Ca and Mg content, which were seen to be correlated earlier on. Prin2 is most strongly associated with soil pH and soil silt content. Prin3 is closely related to soil P.

Care has to be taken in the interpretation. Each principal component is a mathematical number without a defined unit or a definite biological meaning. It is a combination of variables measured on different scales. The relative contribution of one or other variable to each principal component, however, gives an indication of their meaning.

Table III.3: Eigenvalues of the Correlation Matrix and the Proportion and Total of Variance Explained by the Five Largest Principal Components

Principal component	Eigenvalue	Difference	Proportion	Cumulative
PRIN1	4.78151	2.55972	0.434683	0.434683
PRIN2	2.22179	0.79831	0.201981	0.636664
PRIN3	1.42348	0.56145	0.129408	0.766071
PRIN4	0.86204	0.07773	0.078367	0.844439
PRIN5	0.78431	—	0.071301	0.915740

Table III.4: Eigenvectors of Principal Components Representing a Linear Combination of the Original Variables

	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5
pH	0.175	0.451	-0.290	0.125	-0.265
OC	0.337	-0.210	-0.336	-0.006	0.221
TN	0.288	-0.265	-0.284	0.151	0.583
P	-0.054	-0.151	0.670	-0.166	0.408
K	0.285	0.225	0.142	-0.689	-0.094
Ca	0.379	0.247	0.257	0.093	0.078
Mg	0.391	0.302	0.145	0.049	0.001
Mn	0.237	-0.153	0.408	0.619	-0.305
SAND	-0.349	0.378	0.011	0.152	0.268
SILT	0.223	-0.513	-0.010	-0.200	-0.398
CLAY	0.405	0.165	-0.006	0.051	0.191

For each field we can now calculate values for the different components, called 'principle component scores'. These scores are obtained by multiplying the original data matrix with the principal component matrix. The new variables (scores) have zero mean and a variance equal to the corresponding eigenvalues.

A standardization of the scores to unit variance is often recommended. The standardized scores are new variables which may be used for further analysis. For example, we could use the three new variables in a multiple regression analysis instead of the original soil parameters to relate yield of a crop to soil characteristics. The three new variables comprise 76.6% of the total variance from the original 11 soil characteristics (Table III.5).

The special feature of PCA is its potential to reduce a large number of variables to a few new variables which comprise most of the original overall variance. Its major weakness is that the new variables are purely mathematical concepts (principal components or scores), which have no units and are often difficult to interpret biologically.

Cluster analysis

Whereas PCA was used to find relationships among variables, measured on a number of units, cluster analysis can be used to group ('cluster') units according to similarity for certain characteristics or response patterns. We could, for instance, try to group agricultural areas together according to the yield response of several crop varieties. Or we could even look again at the three principal

Table III.5: Standardized Principal Component Scores Used as Three New Variables Representing 76.6% of the Variance from the Original 11 Soil Characteristics

Field	PRIN1	PRIN2	PRIN3
1	0.211	-2.205	-1.021
2	1.238	1.678	-0.698
3	0.439	-1.419	0.075
4	-0.407	-1.164	-0.070
5	1.451	0.438	-0.185
6	-1.470	-0.211	-1.116
7	0.554	1.039	1.039
8	0.534	0.680	-0.073
9	-1.442	0.018	-0.660
10	-1.460	1.397	-0.016
11	-0.458	0.749	-1.380
12	-0.524	-0.611	0.442
13	-0.352	0.762	-0.377
14	1.348	-0.542	-1.140
15	-0.570	-0.557	2.232
16	0.131	-0.193	1.557
17	-1.094	0.245	1.304
18	0.874	-0.104	0.092

components of the previous section and examine whether fields can be grouped according to similar combinations of principal component scores.

Here we are using an example of 35 farmers' fields in the northern Guinea savannah of Nigeria, where nitrate-nitrogen ($N0_3$-N) levels were monitored between 0 and 8 weeks after planting (WAP) maize (Table III.6). All management was done by the farmer, researchers only standardized the amount of fertilizer application at a nitrogen rate of 92 kg/ha. Previous research had indicated that there was a large variation in $N0_3$-N concentrations in farmers' fields. In these preliminary studies, it was the only soil characteristic which showed a consistent and strong effect on grain yields in farmers' fields. Each field has its own pattern of $N0_3$-N concentrations over the season. The researchers want to find out if there is any consistent pattern in these fields and if they can group together those fields which have the same pattern of $N0_3$-N availability. Such field groups can then be the basis for defining recommendation domains for future on-farm testing, for example, in terms of fertilization practices.

Table III.6: Nitrate-Nitrogen Concentrations in 35 Farmers' Fields from 0-8 Weeks after Planting (WAP); Soil Characteristics in these Fields and History of Field Management

	Nitrate-nitrogen (ppm)				Soil description				Frequency non-cereals	Stover
Field	0WAP	2WAP	5WAP	8WAP	pH	OC	Sand	Clay	1989-91	1991
1	2.78	15.75	11.21	10.52	5.6	0.52	53	13	0.67	0
2	20.70	9.08	7.64	3.23	6.1	0.57	56	13	0.00	1
3	3.18	4.27	9.17	2.85	5.2	0.30	48	18	0.67	0
4	3.90	6.08	6.56	6.64	5.5	0.49	49	15	0.00	1
5	5.73	9.69	25.76	2.94	6.5	0.50	50	16	0.67	0
6	3.43	4.17	12.41	15.63	5.6	0.60	52	12	0.67	0
7	2.63	9.71	3.78	10.24	5.7	0.54	54	14	0.67	0
8	3.19	12.98	4.55	6.25	5.0	0.52	51	17	0.00	0
9	8.61	11.50	7.34	9.25	5.1	0.37	45	14	0.67	0
10	11.20	10.80	15.88	9.34	5.6	0.39	52	14	0.67	0
11	9.50	4.60	13.68	15.61	6.0	0.35	48	13	1.00	0
12	14.90	14.06	20.15	5.82	6.0	0.36	78	13	0.00	0
13	13.74	15.12	18.14	11.20	6.1	0.42	76	13	0.33	0
14	12.73	17.32	12.20	11.30	6.1	0.36	48	20	0.00	0
15	3.60	20.74	9.05	14.56	5.7	0.44	82	10	0.33	0
16	5.83	6.13	6.97	3.24	5.2	0.61	62	11	0.67	1
17	5.48	6.20	4.86	1.53	6.3	0.50	50	19	0.67	0
18	3.14	5.53	3.27	3.11	6.2	0.47	56	17	1.00	0
19	3.00	6.34	2.84	4.33	5.8	0.61	56	16	0.33	0
20	9.03	5.19	4.86	8.58	5.4	0.54	62	11	0.67	0
21	7.48	7.53	4.78	2.47	5.4	0.47	69	10	0.67	1
22	4.97	12.35	4.20	15.88	6.9	0.41	53	16	0.67	0
23	9.37	7.06	4.50	2.45	6.6	0.41	51	14	0.67	1
24	6.73	7.40	6.11	3.91	6.0	0.60	49	14	1.00	1
25	7.00	7.20	4.42	4.35	6.0	0.59	60	15	0.67	1
26	9.40	4.88	6.65	16.34	6.0	0.52	58	14	0.33	1
27	10.21	4.42	5.91	10.43	5.3	0.51	71	13	0.33	1
28	6.34	5.96	4.69	5.70	5.4	0.41	55	15	0.33	1
29	4.25	4.91	2.08	5.27	5.0	0.36	43	15	0.00	1
30	2.24	3.81	4.32	4.98	5.9	0.43	61	12	0.67	1
31	3.07	4.68	7.58	9.62	6.1	0.61	44	22	0.00	0
32	13.48	6.49	8.58	11.86	5.3	0.51	78	12	0.67	1
33	9.12	8.64	10.78	14.59	5.9	0.34	72	13	0.67	0
34	1.84	5.07	3.93	6.11	5.9	0.48	57	17	1.00	0
35	5.12	9.08	8.24	10.14	6.0	0.61	78	13	0.67	0

Note: Stover=0 indicates removal of stover after harvest; stover=1 indicates that stover was left in the field and was only removed before land preparation in the subsequent year.

A grouping of fields according to similar NO_3-N availability patterns can be done with cluster analysis. It is a stepwise procedure of calculating similarities and dissimilarities between observations and grouping together those which are most similar. Initially, each observation is a "cluster" by itself. Then, in a first step, the two most similar clusters (observations) are grouped together to form a new cluster. Merging clusters together step by step is done in that way until all observations are grouped together into one final cluster. Initially, when each observation is a cluster by itself, all variance is among clusters. At the end, all variance is within the final cluster (all observations grouped together). The researcher tries to group as many observations together as possible, maintaining a maximum of the variance between clusters and minimizing the variance within clusters.

There are many different cluster procedures, and, in this case, Ward's clustering was used. It minimizes the within-cluster sums of squares. The output of clustering of the 35 fields according to NO_3-N concentrations at 0, 2, 5, and 8 WAP is given in Table III.7. The first step, number 34, joins fields F18 and F19 into a cluster called CL34. The next step, number 33, joins fields F24 and F25 into CL33. The procedure continues until all fields have been grouped together into the last cluster CL1, which is a combination of CL2 and CL4. The relationship between fields can best be interpreted by visualizing it in a dendrogram, as shown in Figure III.1. The dendrogram already suggests some groupings; each of the clusters CL4, CL8, CL7 and CL6 seem to cluster a number of distinct fields together into a group. In addition to the visual assessment, the percentage of the total variance included within the cluster-groups against the variance between cluster-groups should be evaluated. Moving up from the bottom of Table III.7, it can be seen that splitting the first cluster CL1 into CL2 and CL4 explains about 31% (reduction of R^2) of the variance, while 69% of the variance still remains within CL2 and CL4. The researchers want groups to be as homogeneous as possible and therefore try to maximize the R^2 of explained variance. At the same time, they want a small number of groups. Thus a compromise has to be sought. In general, the R^2 should be at least above 50%. The grouping of fields in this example into CL4, CL8, CL7 and CL6 explains 63% of the variance. Note that the reduction within cluster R^2 diminishes very quickly with each further step, and that further subdivisions of groups contribute little to increase R^2 between clusters.

After a decision has been made about the most appropriate grouping, an analysis of variance can be done by assigning each field to its group and comparing group means of the NO_3-N levels at different times using multiple range tests (Table III.8). The results show that CL4 had high initial NO_3-N levels at 0-5 WAP, whereas CL6 and CL7 had a delayed peak. CL8 groups fields together which had low NO_3-N concentrations throughout the season.

Table III.7: Cluster Analysis of 35 Fields According to N03-N Levels during the Season Using Ward's Cluster Analysis

No. of new cluster	Clusters joined		No. of fields in new cluster	R^2 between clusters	Reduction of R^2
34	F18	F19	2	0.9996	0.0004
33	F24	F25	2	0.9991	0.0005
32	F30	F34	2	0.9985	0.0006
31	F21	F23	2	0.9978	0.0007
30	CL33	F28	3	0.9967	0.0011
29	F20	F27	2	0.9956	0.0011
28	F16	F17	2	0.9943	0.0013
27	CL34	F29	3	0.9930	0.0013
26	F04	F31	2	0.9908	0.0022
25	CL27	CL32	5	0.9879	0.0029
24	CL28	CL30	5	0.9849	0.0031
23	F09	F35	2	0.9815	0.0034
22	CL24	CL31	7	0.9779	0.0036
21	F11	F33	2	0.9735	0.0044
20	F07	F08	2	0.9687	0.0047
19	F10	F13	2	0.9629	0.0058
18	F26	F32	2	0.9555	0.0074
17	F03	CL26	3	0.9478	0.0077
16	F01	F15	2	0.9398	0.0080
15	CL19	F12	3	0.9314	0.0084
14	F06	CL21	3	0.9220	0.0094
13	CL29	CL18	4	0.9117	0.0104
12	CL20	CL23	4	0.9006	0.0110
11	CL12	F22	5	0.8860	0.0146
10	CL15	F14	4	0.8714	0.0147
9	CL17	CL25	8	0.8566	0.0148
8	CL9	CL22	15	0.8291	0.0275
7	CL14	CL13	7	0.7960	0.0330
6	CL16	CL11	7	0.7574	0.0386
5	F05	CL10	5	0.7018	0.0557
4	F02	CL5	6	0.6328	0.0689
3	CL6	CL7	14	0.5229	0.1099
2	CL3	CL8	29	0.3162	0.2067
1	CL2	CL4	35	0.0000	0.3162

Note: F=Fields, CL=fields clustered into groups

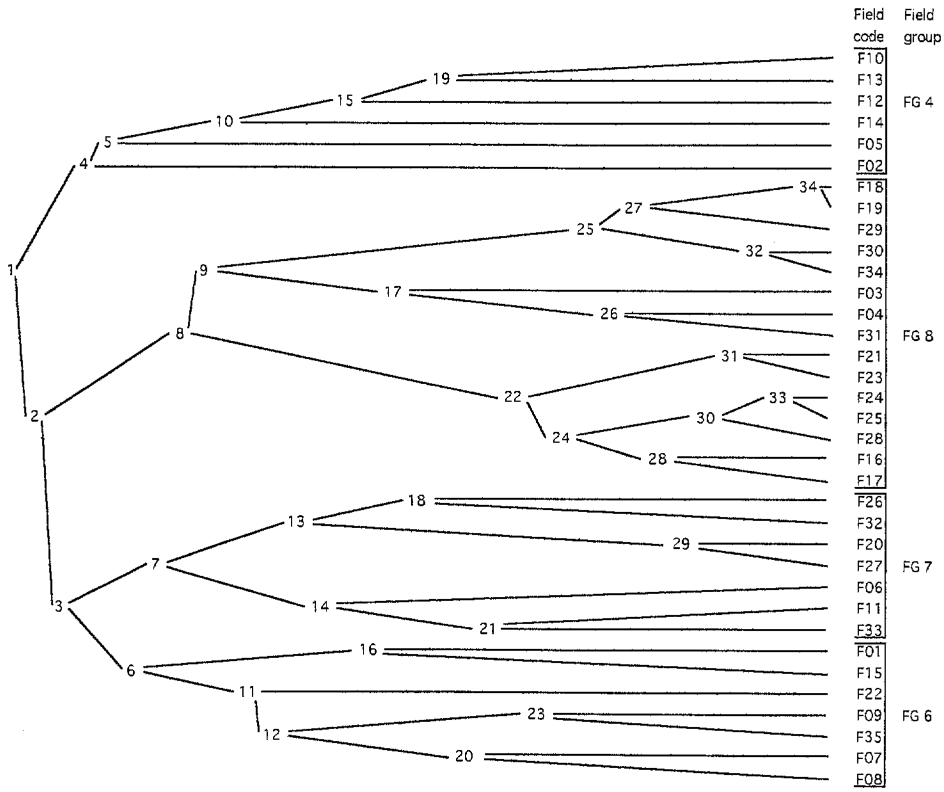


Figure III.1: Dendogram of field groups according to available nitrate from 0-8 weeks after planting. Data from farmers' fields in six villages in the northern Guinea savannah of Nigeria

Table III.8: Multiple Range Test for a Comparison of Means for Cluster Groups

Cluster group	ppm nitrate-nitrogen in soil 0 WAP	2 WAP	5 WAP	8WAP	Yield kg/ha
CL4	12.6a	11.9a	14.9a	6.6b	4254a
CL6	4.4c	13.2a	6.9b	11.0a	3666ab
CL7	9.2b	5.5b	9.0b	13.3a	2837ab
CL8	4.5c	5.8b	5.1e	4.6c	2256b

Note: Different letters after figures means indicate significant differences at P < 0.05.

Through cluster analysis, the information from 35 randomly selected fields has been structured into four groups of similar patterns. The analysis provides useful guidance for on-farm researchers for the definition of recommendation domains.

Discriminant analysis

Discriminant analysis is used to examine the factors which contribute to observed groupings. The grouping may be made *a priori,* based on field observations, or groups may be formed, for example, through cluster analysis. An example of the first type would be a distinction made by researchers between 'forest fields' and 'savannah fields', or a distinction made by farmers of fields suitable or unsuitable for a particular crop, such as yams or groundnuts. Here we use an example of the second type, viz. the previous example of fields grouped (clustered) according to nitrate patterns, and we want to examine which factors contribute most to explaining the different patterns among fields. Details of the calculations behind discriminant analysis are not explained here as they require considerable computations. Also, many of the modalities and options for using the procedure will not be mentioned. Rather, this Annex is intended to show what discriminant analysis can do and where it can be useful. The procedure should be used in consultation with a statistician.

First we must hypothesize which factors are likely to be responsible for, or at least associated with, differences in nitrate patterns. Variables which might influence the nitrate release pattern are soil characteristics such as clay content, organic carbon content and pH, as well as field history parameters such as the frequency of non-cereal cropping during the last three years before the trial and stover management in the previous year. Discriminant functions can now be developed with those variables which best explain the differences among field groups as a linear combination of the original variables (factors). Mathematically speaking, optimal discriminant functions need to describe all observations (here nitrate patterns in fields) in such a way that observations can clearly be assigned to a group so as to maximize the variance among groups and minimize the variance within groups. One discriminant function can be developed for each combination of groups, resulting in a total of n-1 functions for n groups. Often one or two discriminant functions are sufficient to adequately describe groupings. Three discriminant functions were developed for the example of the four NO_3-N groups, but only the first and the second discriminant functions were significant, and contributed about 95% to the total variance explained by the model (Table III.9). Canonical coefficients were calculated for discriminant function 1 and function 2 for each factor. Eigenvalues can be computed for each factor from the sum of the product of the absolute value of the coefficients and the contribution of the function. For example, for %clay, eigenvalue=1.084*0.595 + 0.500*0.36 and for

Table III.9: Discriminant Functions for Four Groups of Fields with Different NO_3-N Patterns

Function	Canonical correlation	Standard error	F-Value	Prob >F	Eigenvalue	Explained variance	
						Proportion	Cumulative
1	0.713	0.086	2.82	0.002	1.035	0.595	0.595
2	0.621	0.108	2.19	0.043	0.627	0.360	0.955
3	0.268	0.162	0.73	0.546	0.078	0.045	1.000

%OC, eigenvalue=0.300*0.595 + 0.363*0.36. Each eigenvalue can also be expressed as a proportion of the sum of all eigenvalues. The factor with the highest eigenvalue contributes most to the differentiation of groups. Stover management affected most of the groupings in the example followed by soil clay content (Table III.10).

Table III.10:Canonical Coefficients for Each Factor for Discriminant Function 1 and Function 2, Eigenvalues and Proportion of Contribution of Factors to Discrimination

Factor	Standardized canonical coefficients		Eigenvalue	Proportion
	CAN1	CAN2		
Clay	1.084	0.500	0.660	0.295
OC	0.300	-0.363	0.310	0.139
pH	-0.754	0.797	0.287	0.128
Non-cereal cropping 89-91	0.841	-0.470	0.160	0.072
Stover management	0.931	0.732	0.817	0.366

The precision of the discriminant model for assigning fields to groups can be tested by comparing the original grouping of fields with the new grouping of fields according to the discriminant model. This can best be done by calculating Fisher's linear discriminant functions. There are as many functions as there are groups, and four values were computed in our example for each field, one for each function. Each field is assigned to the group for which the value is highest. Fisher's functions are given in Table III.11 for the example case. A comparison of the old and new groupings shows that 71% of the fields were correctly put into the same group and 29% were wrongly classified. Group 7, in particular, could not easily be differentiated from group 6 (Table III.12). Fisher's discriminant functions can also be used to assign new fields which were not part of the previous sample into

Table III.11 Fisher's Discriminant Functions for the Example Case

Parameters	Field cluster groups CL4	CL6	CL7	CL8
Constant	-126.569	-107.077	-103.742	-116.723
Clay	1.563	1.527	1.554	2.370
OC	19.56481	30.888	29.029	30.797
pH	35.727	31.415	30.587	30.473
Non-cereal cropping	-10.629	-6.878	-4.527	-3.474
Stover management	11.929	9.593	11.439	15.078

one of the groups. The likely NO3-N pattern of such a field should be similar to the characteristic pattern of the group it is assigned to.

Results of our example show that stover management and soil clay content are the most important factors in farmers' fields in the study region which contributed to differences in N03-N availabilities over the season. Soil organic matter content seems to be less important. Not all patterns are well understood, and it is suggested that some representative fields be taken out of CL4 and CL8 and trials be implemented which try to manage N03-N levels in these fields according to the inherent N-dynamics.

Discriminant analysis has much in common with multiple regression analysis. They both express an effect as a linear combination of several variables. However, there are two major differences between them: (1) the dependent variable in

Table III.12:Test of Precision of Discriminant Model Comparing the Old Grouping with the New Group Assignments According to Fisher's Discriminant Functions

From original CL group	New cluster groups NCL4	NCL6	NCL7	NCL8	Total
	— No of observations and % of total —				
CL4	6	1	0	0	7
	85.7	14.3	0.0	0.0	100.0
CL6	1	5	1	0	7
	14.3	71.4	14.3	0.0	100.0
Cl7	1	2	1	2	6
	16.7	33.3	16.7	33.3	100.0
CL8	0	1	1	12	14
	0.0	7.1	7.1	85.7	100.0
Error %	14.3	28.6	83.3	14.3	29.4

regression analysis is a continuously distributed variable, while, in discriminant analysis, the grouping variable has a discrete distribution, and (2) regression analysis describes a randomly distributed dependent variable, while, in discriminant analysis, the groupings are predetermined and fixed. Discriminant functions are most valuable as a tool for mathematically developing hypotheses about observed groupings. Such hypotheses will subsequently need to be tested through experimentation.

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Photographs:	IITA
Design and illustrations:	Richard Claase, ISNAR
Layout:	Fionnuala Hawes, ISNAR
Printing:	Van Marken Printers, Delft, the Netherlands

ISBN 978–131–125–8