On-Farm Research
in Theory and Practice

Edited by H. J. W. Mutsaers and P. Walker

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Proceedings of a workshop on design
and analysis of on-farm trials
27 February to 3 March 1989

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P. Walker

About IITA

The goal of the International Institute of Tropical Agriculture (IITA) is to increase the productivity of key food crops and to develop sustainable agricultural systems that can replace bush fallow, or slash-and-burn, cultivation in the humid and subhumid tropics. Crop improvement programs focus on cassava, maize, plantain, cowpea, soybean, and yam. Research findings are shared through international cooperation programs, which include training, information, and germplasm exchange activities.

IITA was founded in 1967. The Federal Government of Nigeria provided a land grant of 1,000 hectares at Ibadan, for a headquarters and experimental farm site, and the Rockefeller and Ford foundations provided financial support. IITA is governed by an international Board of Trustees. The staff includes around 180 scientists and professionals from about 40 countries, who work at the Ibadan campus and at selected locations in many countries of sub-Saharan Africa.

IITA is one of 16 nonprofit, international agricultural research centers supported by the Consultative Group on International Agricultural Research (CGIAR). Established in 1971, CGIAR is an association of about 50 countries, international and regional organizations, and private foundations. The World Bank, the Food and Agriculture Organization of the United Nations (FAO), and the United Nations Development Programme (UNDP) are cosponsors of this effort.

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Contents

ANNEX

Foreword

The International Institute of Tropical Agriculture (IITA) was established in 1967. Among its aims was the development of systems for the management and conservation of natural resources for sustainable agriculture in the humid and subhumid tropical zones. In carrying out this mandate, the goal of its Resource and Crop Management Program is to develop economically and ecologically viable farming systems for increased and sustainable production by small-scale family farmers, while conserving the natural resource base.

Traditionally, farmers in the African tropics have solved the sustainability problem by permitting farmland to revert to natural vegetation and regain fertility during long fallow periods. Unfortunately, because of rapid population growth and demand for cropland, this balance has been upset in recent decades. There is thus an urgent need for new and better techniques of land development and management that will enable production to be increased, prevent degradation, and still be compatible with the prevailing farming systems, so that farmers can readily adopt them. Our task is, therefore, to conduct research that is relevant to the needs of the small farmers, in close collaboration with scientists of the national agricultural research institutes, which have the primary responsibility for producing technologies for the farmers. In order to ensure that the needs of small farmers are fully taken into consideration, and that our partners, the NARS, are fully involved and understand our research work, IITA operates on-farm research sites and conducts field studies with the NARS.

Over the last decade, a number of technical questions have arisen. How are we to elucidate the farmers' wishes and understand their constraints? What type of technologies should be tested on the farmers' fields? What kind of experimental designs should be used in these on-farm trials? What techniques in analysis should be used for interpreting the data? How should the results of the experiments be disseminated/communicated to farmers, as well as to the scientific community at large?

RCMP scientists and other collaborators in the region have had wide experience in addressing these issues. We have made great efforts to refine our techniques of on-farm research. We feel it is time to put these views to the wider community, and interact with our NARS and other international collaborators in the further refinement of our techniques and methods. This volume contains the main papers presented at a workshop held in Ibadan in 1989, as well as conclusions from working groups at the meeting. It is our hope that this volume will make some contribution to on-going discussions on appropriate methodologies for on-farm research. In particular, we hope that our NARS collaborators will test some of the techniques in their localities. The scientists in IITA continue to have a deep commitment to the development of appropriate methodologies in this area. We are grateful to the many donors and collaborators who have continued to make our work possible.

Dunstan S. C. Spencer
Director
Resource and Crop Management Program

Preface

On-Farm Research (OFR) has established a firm foothold in tropical agricultural research during the last decade. Both national and international institutes have left the confines of their research stations increasingly often to expose their technologies to the real world of the small-scale farmer. In that world, scientists have to cope with experimental conditions which frequently have only a remote resemblance to those of the well-organized and uniform experimental fields of the research station. Agronomists also have to cope with the skepticism of colleagues who doubt whether meaningful, and publishable, field research is at all possible under such conditions. Scientists working in a real farm situation, therefore, need reliable research methods and analytical techniques which are often outside the realm of conventional station research.

National scientists often look to international institutes for guidance on the choice and application of research methods appropriate for OFR, and IITA has developed close cooperation with several national research institutes on this subject. These collaborative activities have been supported by the Ford Foundation since 1982.

Early in 1989, a workshop was held at IITA to review progress in developing OFR methodology. The workshop, sponsored by the Ford Foundation, consisted of three parts:

- a series of methodological papers,
- a series of case studies from the field, and
- a thorough examination by three working groups of important methodological issues which had emerged from the presentations and discussions.

This book is the product of the workshop. It features all the papers that were presented and, in addition, summarizes the state of the art of OFR methodology and problems in need of solution.

The papers presented at the workshop were extensively edited but not subjected to a scientific review process. Their strengths and possible weaknesses are a reflection of the status of OFR as it is currently being implemented by practitioners.

We hope that this volume will contribute to the further development of reliable OFR methods.

H.J.W. Mutsaers and P. Walker

A Synopsis of Workshop Conclusions

H. J. W. Mutsaers, Joyotee Smith and Peter Walker

The presentations by workshop participants highlighted a range of issues relating to the design and analysis of trials which formed the raw material for the group discussions during the second part of the workshop (Table 1).

Some of the topics for discussion were of a general nature while others were specific to each of the disciplines represented. In keeping with the number of participants from each discipline, the specific topics were divided between the agricultural economists who formed one group, and the agronomists who, because of their numbers, formed two groups. Each of the two statisticians present at the workshop joined one of the agronomy groups. The general topics were addressed by the three groups separately (Table 1).

Rather than present the discussions point by point, this synopsis attempts to present a consolidated report. Although the topic of the workshop was "The design and analysis of on-farm trials", in actual fact the presentations and discussions seemed to focus more on cropping systems and cropping techniques.

Data collection through surveys and trials

The classical model of farming systems research (FSR) is often represented as a sequence of activities.

a. An initial informal or exploratory survey by the research team and the study of secondary data.

b. The choice of a first set of technologies for on-farm testing based on that survey.

c. Additional studies through focused (formal) surveys.

d. Continued testing with modified or new technologies based on previous results.

On-farm research thus consists of a combination of surveys and on-farm trials to identify and remove important constraints, or exploit the opportunities existing in farmers' systems. A disadvantage of this representation of the On-Farm Research (OFR) process is that it suggests a strict adherence to a sequence of steps. In actual practice, surveys and trials may be carried out simultaneously, while formal or informal surveys may be conducted at any time, depending on the issues being addressed. A different way to describe the on-farm research process is by considering the two major components, diagnosis and on-farm testing, and describing the objectives and appropriate tools for each.

Table 1. Discussion topics on the design and analysis of on-farm trials and surveys

General topics

1. What types of questions can be answered by what types of trials or surveys or combinations of the two? How are resources to be allocated between different activities/trials?
2. What are the minimum data set and analyses for on-farm adaptive trials?
3. What is the proper sequence for going from identified problems to possible solutions and choice of treatments?

Economic topics

1. The use of partial budgets:
   a. Returns to capital, labor, land (or all factors)
   b. Statistical analysis of net benefits.
2. The use of response curves versus discrete analysis.
3. Risk analysis (methods, combining cross-section and time-series data).
4. Farmer assessment (roles, methods, reliability).
5. Measuring labor data.
6. Appropriate pricing for economic analysis.
7. Investment in on-farm adaptive research versus extension.

Agronomic and statistical topics

1. The usefulness of laboratory soil analysis for on-farm trials versus simpler characterization methods.
2. The necessity for within-site replication.
3. Scoring versus objective measurements of pests and weeds.
4. The number, selection, and stratification of trial sites.
5. The need for pre-extension trials jointly monitored by researchers and extension workers, as a last phase in the OFR process.
6. The role of covariates at site and plot levels.
7. The ordering of measured environmental variables in regression analysis.
8. Extrapolation methodology.
9. The use of uniform checks.
10. The role of stability analysis.
11. How to test technologies addressing long-term fertility issues.
12. The choice of experimental designs.
13. The need for testing a range of innovations in a pilot area.
14. Standardization or non-standardization of non-treatment variables.
15. The importance of statistical significance.

Diagnosis

The aims of diagnosis are:

- to delineate zones and subzones and stratify the farming population within zones.
- to identify problems in farmers' production systems and potential solutions.

Zoning and stratification are needed for the identification of more or less homogeneous target groups for research. They are based on information about cropping and livestock systems, and on the physical and socioeconomic production environment. Although initial zoning and stratification are done prior to field trials, these may be modified in the course of on-going research. The delineation of zones is conducted through the collection of secondary data, informal surveys, structured farmer group-interviews, and extension agent surveys. For stratification within zones and identification of production constraints of farmer target groups, informal and formal surveys as well as diagnostic trials are appropriate tools. The use of informal surveys is now wide spread but formal surveys are much less common.

A formal agroeconomic survey is characterized by intensive monitoring at field, farm, and village levels. Field level data are collected on production practices and measurement of appropriate agronomic variables such as plant stand and weed count. In land-abundant/labor-scarce regions, labor data should also be collected. Field monitoring requires about three visits/field/season, timed to coincide with critical stages of crop growth. Farm level data are obtained on the farmers' resource base, cropping pattern, non-farm activities, and livestock/crop interaction. Village level data would include seasonal changes in output prices and wages. To keep the scope of the survey manageable, it is important to identify critical variables from prior informal surveys and focus resources on the accurate quantification of those variables. Multidisciplinary participation of specialists, such as entomologists and weed scientists is required if reliable data are to be obtained. Where current farmer practices limit the scope of the data that can be obtained from surveys, additional variability can be created by superimposing simple trials on farmers' fields. For example, if hybrid maize is grown in a very limited area, or fertilizer is applied by a minority of farmers, simple trials testing a few varieties or fertilizer rates can be spread out over the surveyed area. For an example of this type of survey, see the paper by Byerlee and Triomphe in this volume. Ideally, multidisciplinary formal surveys should be carried out before technology testing commences, but they can also be done concurrently with trials, particularly if these trials are themselves analyzed diagnostically.

If detailed formal surveys are not feasible, a combination of an informal survey and diagnostic trials with a few simple treatments and intensive monitoring of trial plots is recommended. The advantage of using formal surveys instead of trials for diagnosis is that surveys can usually cover a broader area.

Data from diagnostic surveys or trials are analyzed to identify constraints and solutions. Prioritizing of constraints should take the following criteria into consideration:

a. Impact of constraint on profitability. This can be quantified if a formal agroeconomic survey has been carried out.

b. Farmers' perspective of the relative importance of constraints.

c. Subjective ranking of constraints by researchers, extension agents, and other sources.

d. Availability of technologies for resolving constraints.

Ex-ante economic analysis of potential solutions is recommended before technologies are tested. Technologies which build on farmer-developed solutions are most likely to be economically viable.

Diagnosis should continue after the initial phase of the OFR program. This may take the form of surveys on specific issues, as well as extensive researcher observations and plot monitoring in on-farm trials. The diagnostic findings provide priorities for subsequent on-farm research and feedback to station research.

Technology testing

The aims of technology testing are:

- to identify technical components, or design new components for farmers' systems (exploratory trials).

- to test and, if necessary, adapt the components to farmers' conditions (adaptive trials).

- to test acceptable components and monitor farmers' assessment and adoption of these components (validation trials).

In addition to physical measurements, informal and formal interviews with farmers as well as labor use data are essential (particularly in the case of adaptive and validation trials).

The balance between diagnosis and technology testing

The majority of OFR programs rely on an informal exploratory survey for diagnosing constraints, but in most cases attention is soon turned to technology testing. More emphasis is needed on diagnosis combining socioeconomic and agronomic data. Trials usually cover a limited population which increases the potential for biases. Survey data on the wider population are needed to redress these biases.

Likewise, on-farm trials can be better exploited as a source of information on farmers' practices and conditions by collecting data on socioeconomic and agronomic issues, rather than by merely collecting yield data, as often seems to happen.

A drawback in laying more emphasis on surveys is that national institutes often do not have the resources to mount intensive surveys requiring frequent visits. In these cases, it is recommended that more frequent and more detailed data collection should be carried out in conjunction with the trials— in spite of the risk of a possibly biased sample.

The issues discussed above are summarized in Figure 1. The flowchart, although still sequential, emphasizes that diagnosis is an integral part of all OFR phases/activities.

Typology of on-farm trials

Different typologies have been proposed, based on:

- the state of knowledge;
- the degree of farmer involvement;
- the type of technology being tested.

Table 2 summarizes the consensus on how trial types could be classified, taking into account the objectives, the state of knowledge, and how these affect

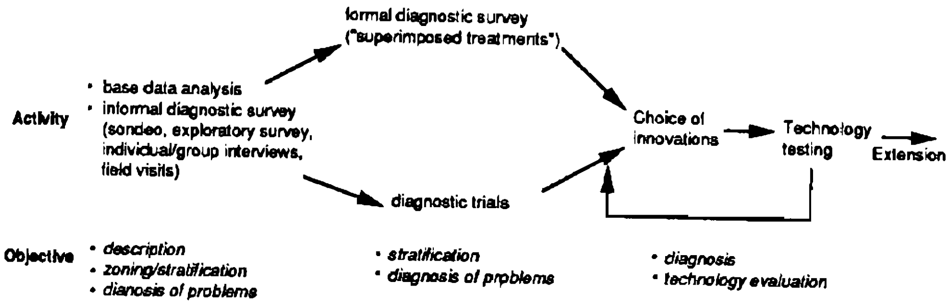

Figure 1. Flowchart of OFR activities

farmer and researcher involvement in design, implementation and analysis of results. The number of testing sites and variability in the trials will increase from types 1 to 3. Furthermore, since researcher and farmer confidence levels increase proportionately, the size of experimental plots can also be increased. It was also suggested that more emphasis be placed on trials involving farmers, than on research trials.

Table 2. Types of on-farm trials and their characteristics

Type	Objective	Design	Implementation	Assessment
0	Diagnosis	R	F	R/F
1a.	Physical testing of new components with "unknown" effects (exploratory tests)	R	R	R
1b.	Feasibility tests of new crop or crop combination	R	R/F	R/F
2a.	Adaptive tests of technically feasible technology	R	R-treatments F-non-experimental variables.	R/F
2b.	Adaptive tests by experienced farmers.	R	F	R/F
3a.	Validation tests	R/F (same trial on all farms)	F	F
3b.	Individual farmers' tests of new technology	F (individual)	F	F

Note: R = researcher F = farmer

Diagnostic trials (type 0) are similar to type 3 in that a small number of treatments are tested with a large number of farmers. The emphasis in the former is on the collection of agronomic and economic information, and in the latter on the acceptability of new technology. It was stressed that farmers should be consulted more on the type of technology to be tested and on methods of testing— irrespective of the type of trial.

Participatory trials, in which farmers are involved in the design of experiments, were suggested. In this type of trial, farmers, with the assistance of scientists, decide on the treatments to be included in the trial (Ashby 1986). This approach focuses research on technologies relevant to the needs of small farmers. It also improves the reliability of trial results because farmers become interested in the outcome of the trial. Consequently common problems, such as farmers' neglect of trial plots, obstruction of data collection, and following of atypical practices for non-test factors, are reduced.

On a more technical note, a sample list was put forward of typical issues for experimental research which may arise in an OFR program (Table 3). The topics are arranged in order of increasing complexity and novelty. For a number of these research issues, some key aspects of design and implementation were examined which are summarized in Table 4. The table provides a checklist of issues to be considered when designing a field trial, and should be seen as tentative as far as its actual content is concerned. A number of these issues are further discussed in later sections.

Two special types of trials were discussed in some detail, viz., the testing of technologies addressing long-term fertility issues, and pre-extension tests.

Table 3. Examples of typical experimental issues in OFR ordered according to increasing complexity and novelty

1. Variety comparison for existing crops in existing systems
2. Methods of land preparation or weeding in existing patterns
3. Improved storage
4. Fertilizer response in existing patterns and simple pest control methods
5. Crop residue management/utilization
6. Optimum planting arrangements
7. Optimum planting dates
8. Potential for new crops in the system
9. Control of weeds by new or existing low-growing crops (legumes, egusi melon, etc.)
10. Improving fertility by multiple cropping with leguminous species
11. New cropping patterns to reduce pest and weed incidence or improve soil fertility
12. Alley cropping
13. Changing land use with existing plant species/crops
14. Changing land use with new crops
15. Integration/intensification of livestock rearing in crop-based systems
16. Land protection/erosion control
17. Food-crop/tree-crop systems (agroforestry systems)

It was pointed out that in long-term testing it is almost impossible to keep farmer interest over several seasons (quite apart from the problems of returning to exactly the same plots each year). The problems of running long-term rotation experiments even on-station are formidable. In practice, we are restricted to possible sampling of soils/crops in the year immediately after one (single-year) experiment, or to collecting data on the length of time the field had been out of fallow. Almost all the workshop presentations dealt with trials which moved to fresh plots each year, the only exceptions being the presentations by Palada and Diomandé which dealt with researcher-managed trials, and the paper by Cobbina and Atta-Krah on alley farming.

As for pre-extension tests, there was little agreement on the need for such trials. Technologies which were shown to be technically and economically viable on a small scale in on-farm trials are often not adopted by many farmers. Certain socioeconomic constraints or the mere practicality of implementing these technologies on a larger scale may cause this phenomenon. Pre-extension tests can be useful in identifying its causes. In such tests, the extension service (in close collaboration with OFR researchers) could try out the technology on a realistic scale, using existing extension channels, and including the appreciation of such aspects as the adequacy of the information transfer to farmers, input supply and credit.

Generally it was felt that for rather simple innovations such as improved varieties, there was no need for such tests. However, some felt that they were useful for more complicated and more costly "packages", such as a fertilizer application coupled with a planting density adaptation.

Trial design

Researcher-managed trials are not different in essence from station trials, since the same principles apply to both. Examples of designs appropriate for researcher-managed on-farm trials which are uncommon in station research are first order designs (see the paper by Walker). They are useful to estimate the main effects of a large number of factors in exploratory types of trials.

The following discussion deals mainly with on-farm trials with a high degree of farmer involvement. The most important recurrent discussion topics relating to trial design were:

a. limits on the allowable number of treatments per farmer;

b. the best arrangement of treatments or factors (trial design) within the limitations set by (a)

c. the need for within-site replication;

d. the number of trial sites and the need for stratification;

e. the use of uniform checks versus checks varying with farmers; and

f. standardization (or non-standardization) of non-treatment conditions (concomitant variables).

Number of treatments and replications per farmer, choice of design, and statistical analysis

In trials with a high degree of farmer involvement, the number of differently-treated plots should probably not exceed six, so that farmers do not lose sight of the purpose of the trial. This puts a limitation on the types of design, and on replication.

Maximizing the number of sites is generally more important in on-farm trials than replication within sites. Treatment x site interaction will be most strongly expressed in the interaction between treatments and the linear component of mean site yield (yield averaged over all treatments per site) (Morris 1981). This allows a test on a major part of the treatment x site interaction in the absence of within-site replication (Table 5, column 1). If it

Table 4 Aspects of experimental design and implementation for some of the experimental issues of Table 3 (numbers refer to experimental issues in Table 3)

		1,2,4,5,6,9	7	8,13,14 and 18 exploratory	8,13 and 14 refining	10 and 11
1	Number of factors	1-3[1]	1-3	0-1	1-3	2-3
2	No. of treatments per field	3-6	≤8	1-2	3-6	3-6
3	Experimental design	(a) Stepwise (b) confounded 2^3 (c) confounded $2^3 + 2$ extra treatments	Split plot	Single plot or two plots	As in column 1	Split plot
4	Within-site replication	Not essential; consider repetition of some treatments	Essential	No	Not essential: repetition of some treatments	Not essential
5	Size of experiment	Natural field	Small plot size	Experimental size		Experimental size modified according to treatment
6	Need for ancillary data for size/plot characteristics	High	Low	Medium	Medium	Medium to high
7.	No of sites or fields	Large	Small	Medium	Medium	Medium
8.	Supervisor's skill	Low	High	High	High	High
9.	Standardize non-experiment variables?	No	Yes	Yes	No	Yes
10.	Level of risk	Low	Medium-high	Medium-high	Medium	Low
11.	Farmer's skill	–	–	–	Low	Medium
12.	Degree of farmer management	Complete	Low	Medium	Medium	Partial
13.	Standardize farmer's check?	Do not standardize	n.a[2]	n.a	Yes	Yes

Notes: 1. Although one factor may be of primary interest, researchers will often wish to include more in a trial; e.g. when testing new varieties one or two levels of fertilizer is an obvious extension of the trial. 2. n.a. not applicable is felt, however, that we must have some estimate of variability within sites, there are simple ways to obtain this information short of full within-site replication. These issues will be further discussed below and in the chapter on trial analysis.

In the exceptional case where there is full within-site replication, there is no justification for these replicates to be grouped into blocks, since it is difficult to choose a sensible basis for blocking in unknown sites which is consistent across sites.

Trials with non-factorial treatments

Examples of this type of trial are simple varietal comparisons or comparisons of pre-selected unstructured combinations of factor-packages. With one replication per farm, the ANOVA follows the procedure of Table 5 (column 1) including a test for treatment x site mean (linear) interaction. Full replication is only possible with three treatments or less. With a greater number an idea of within-site variability can be obtained by replicating one or two treatments only (e.g., the check treatment, local variety). The ANOVA for this case is shown in Table 5, second column.

Table 5. ANOVA for (1) a trial with 6 non-factorial treatments and 20 sites, unreplicated, with analysis of treatment x site mean (linear) interaction; (2) same with one treatment replicated and conventional analysis of treatment x site interaction; (3) 3 x 2 factorial (F_1 = factor 1, F_2 = factor 2) with conventional analysis of main effect x site interaction

1		2		3[1]	
Sites	19	Sites	19	Sites	19
Treatments	5	Treatments	5	F_1	2
Trt x site mean	5	Trt x sites	95	F_2	1
Residual	90	Residual	21	F_1 x F_2	2
				F_1(lin) x sites	19
Total	119	Total	140	F_2 x sites	19
				Residual	57
				Total	119

Note: 1 The residual term in column 3 is actually the sum of F_1 (quadratic) x sites (19 df), F_1 (lin) x F_2 x sites (19 DF), and F_1 (quad) x F_2 x sites (19 DF). The best procedure would be to start with the last of these as residual, and only pool the other 38 DF in if they were not significant.

Factorial treatment combinations (number of possible factor combinations ≤ 6)

One full replicate of a 3 x 2 trial (e.g., three varieties at two fertilizer levels) can be accommodated on six plots per site. In the case of a 2^2 factorial replication of one factor combination across sites would be possible if some within-site replication is required, but a better solution would be to increase the number of levels of one of the (quantitative) factors to three, and equate the quadratic part of the interaction to error (Table 5, third column).

Factorial treatment combinations (number of possible factor combinations > 6)

When the number of factors is larger than two, even one full replicate of all possible factorial combinations per site would require more than six plots. By confounding higher order interactions with sites ("blocks"), the number of plots per site can be reduced but the demonstration effect, which would (for example) require at least the zero levels of all factors, is lost.

One option is to use a "stepwise design," starting with the baseline (all factors at zero level), and upgrading every factor in turn according to its assumed importance. This requires previous knowledge about the expected effects of the experimental factors.

In some cases, it is possible to use a combination of a confounded factorial and a stepwise design. Consider a trial with three factors each at two levels. Each site would first get a half replicate of the factorial (with three-factor interaction confounded with site). Two treatments are added to each site to arrive at a stepwise set (Table 6). This allows comparison of the analysis as a stepwise trial and as a confounded factorial. It includes the baseline treatment at each site and it still only requires six plots per site (see Mutsaers and Walker 1990 and the paper by Walker in these proceedings).

Table 6. Treatment combinations in a stepwise-cum-confounded factorial trial with 3 factors (maize variety, fertilizer, cassava variety), each at 2 levels

Type I sites	Type II sites
$M_0F_0C_0 a\ b$	$M_0F_0C_0 b$
$M_1F_0C_0 b$	$M_1F_0C_0 a\ b$
$M_1F_1C_0 a\ b$	$M_0F_1C_0 a$
$M_1F_0C_1 a$	$M_0F_1C_1 a$
$M_0F_1C_1 a$	$M_1F_1C_0 b$
$M_1F_1C_1 b$	$M_1F_1C_1 a\ b$

Notes: *a* plots: half replicate of 2^3 factorial; *b* plots: stepwise treatments

Replication between sites and site stratification

The required number of trial sites is based on an expectation of a treatment x site (farmer) interaction and the expected amount of between-farmer variability. If possible, important pairs of farm-level variables are formulated and trial sites selected with combinations of high and low levels of each variable. Many important farmer-related variables (management variables), however, will only show up during the trial. A sufficiently large number of sites is, therefore, needed in order to capture the effect of this source of variability. Although we would not wish to be prescriptive, it is likely that trials which are largely farmer-managed will often require a minimum of 20 trial sites.

Control treatments and non-treatment variables

The issues were: (1) Should uniform checks be used or is it permissible to let the check vary with farmer? (2) Should the non-treatment variables be standardized? Table 4 contains suggested answers for a few types of trials but some qualifying remarks are in order.

First of all, these terms are relative. We can never ensure absolute standardization since there will always be considerable variation caused by shade, number of years out of fallow, and so on. Even in researcher-managed trials, the scientists cannot be continually present and inconsistencies can occur, such as the premature harvesting of parts of a plot, extra or fewer weedings, or random interplanting with another crop.

Having said this, when considering checks, we have the farmer's adjacent plot on which he grows the crop his own way. If properly sampled by a crop-cut, this would suffice to estimate the gains from various interventions. If we intend to proceed into cross-site analyses, then the feeling among the group was that it was worth including a standard check-plot at each site instead of— or even better, as well as— using farmers' plots. Farmers' varieties, fertilizer practices, and weeding habits will vary from site to site, and therefore make cross-site comparisons difficult in the absence of a uniform check (although some of this can be taken care of by the measurement of ancillary variables).

On the standardization of non-treatment variables, the cases presented during the workshop focused on:

a. how to arrange fertilizer and weedings in predominantly variety trials;

b. how to arrange varieties and weedings in predominantly fertilizer trials;

c. how to arrange varieties and fertilizer in predominantly weeding (tillage) trials;

d. the desirability of standardizing the timings of all other operations, such as planting dates.

Most participants felt that some degree of standardization was desirable as, for example, in (a) by applying any fertilizer uniformly at each site, or in (c) by standardizing any fertilizer. Each case needs to be considered on its merits, because the more background conditions vary across sites, the more difficult will be attempts at explaining differences. On the other hand, if the main concern is simply estimating effects, background variation becomes less important.

The degree of standardization will decrease, going from type 1 trials (Table 2) to type 3. In purely researcher-managed trials, everything should be under the researcher's control, and all non-treatment conditions fixed by the researcher. At the other end of the scale (type 3) there is no interference by the researcher, and farmers apply their own management practices as they wish. The higher the degree of farmer decision-making, the more need there is to observe and measure non-treatment conditions to explain differences.

Data collection in on-farm trials (minimum data set)

Different types of trials require different data collection methods, and the researcher should carefully spell out at the inception of the trial the type of data to be collected and, most importantly, how they will be used in the analysis. Many practitioners clamor for guidelines on the type of data that will almost always be required, i.e., the minimum data set. There is also much debate on the need for certain costly and time-consuming pieces of information, such as:

- detailed soil analyses,
- detailed observations on crop disorders (pests, diseases, weeds),
- data on use of labor.

What follows is a brief account of the discussions on these three types of data followed by the tentative minimum data set proposed by the workshop participants.

Soil analysis

The value of detailed chemical soil analysis in explaining differences among sites is often not enough to justify its cost. Moreover, many field workers do not have access to laboratory facilities. Organic matter and pH are regarded as the most important chemical parameters one would generally wish to measure and these studies require laboratory analysis. Experienced agronomists should be able to estimate textural class manually. It was recommended that the quality and reliability of commercial soil-testing kits be investigated. Such kits could enable field workers to carry out some elementary analyses themselves.

The use of indicator maize plants (at low density scattered in experimental plots and measured at 4 WAP) was recommended as a qualitative measure of general fertility (see paper by Osiname et al. in this volume). This has the same disadvantage as mean site yield or site index that it grades soil on the basis of crop growth itself, but at least it is independent of the experimental yields.

Crop disorders (pests, diseases, weeds)

It is generally felt that scoring of crop disorders is as much as most field workers can attempt, although for certain types of trials more quantitative measurements may be required (e.g., when studying new weed control techniques). Scoring of crop disorders is often conducted in such a way that the data collected are not useful in the analysis of trial results. The problems are (1) the lack of objectivity of the scores, (2) the unknown relation between scores and expected crop losses and (3) the timing of scoring.

For a score to be objective, 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. In the absence of such data, such research may be required. Purely subjective scores are often meaningless.

Timing and the frequency of scoring form another important factor. 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 stage, which is most sensitive to weed competition. If this is not possible, it may as well be omitted altogether. A good sampling plan designed before the cropping season is, therefore, crucial.

Labor

In land-abundant areas, such as exist in most of West and Central Africa, labor is the most important agricultural input. Calculations of the profitability of technologies being tested require an estimate of labor cost. Measuring labor use is, however, difficult and costly. Physical measurement of labor input, at the time when each operation is carried out, is rarely possible because of logistic problems. Collection of labor data by recall, i.e., by interviewing the farmer after the event, is subject to inaccuracies because of memory lapses. In many cases secondary data from surveys in the area where the trial was carried out 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 has developed a simple method of collecting labor data by recall (see Spencer's paper in this volume). He shows that data collected by recall can remain accurate for at least 28 days after the event, provided each operation for which data are required is made into a significant event in the farmer's memory. In Spencer's example this was done by marking out measured plots in farmer's fields and requesting farmers to remember the time spent in various operations. A range of plot sizes was used to pick up the effect of economies of scale.

The issue of whether it is necessary to collect labor data from on-station or on-farm researcher-managed trials was discussed. It was pointed out that calculating the *ex-ante* profitability of technologies in an early stage of development may be useful for providing guidance on the potential profitability of those technologies.

Minimum data set

Table 7 presents a tentative minimum data set which is assumed to be common to most on-farm trials. More specialized trials may require additional data. A distinction is made between those data which are required at the plot- (and treatment- level and those for which site- or field-level and village-level observations are sufficient. The data with an asterisk (*) may not be absolutely necessary but are recommended.

Analysis of on-farm trials

On-farm trials are different from station-trials in a number of respects, such as the wide range of trial conditions, the range of concomitant variables measured at the plot and site level, and the importance of economic analysis. In order to fully exploit the data, a careful and thorough analysis is recommended.

Descriptive statistics

It is recommended to graph yields of each treatment in turn against various measured site-level variables, as well as stability graphs, i.e., treatment yield against site mean yield. Caution should be adopted in the interpretation of these stability graphs, since they may suggest differences in slopes even when there are no statistically significant differences. It is, therefore, necessary that differences in slope between treatments be tested in the ANOVA (see below).

Table 7. Tentative minimum data set for on-farm trials. Data marked (*) are recommended but not absolutely necessary

Plot-level
1. Establishment, mid-season (*) and final stand counts
2. Density of secondary crops
3. Pest and disease scores (ordinal)
4. Weed scores (ordinal)
5. Shade scores (if applicable)
6. Crop yields
7. Variable inputs (i.e., inputs which differ between treatments), including labor

Treatment-level (in unreplicated trials this is identical to plot level)
1. Farmer assessment (ordinal)

Site/Field-level
1. Soil texture (sandy, medium, heavy) at two depths
2. Soil pH, phosphorus (*) and organic matter (OM), aggregation, color, at 0-15cm and 15-30cm
3. Slope and position on slope
4. Crop management information which is not held constant and is not part of the treatments (date of planting, field history, land preparation, varieties, plant arrangement)
5. Age and sex of farmer

Village-level
1. Rainfall (daily, mm)
2. Prices of inputs
3. Wage rate during the season
4. Output prices, end of season

ANOVA; tests on differences in regression of treatments on environmental index

Standard tests of significance for treatment effects and interaction between factors should, of course, be conducted.

In addition, measured variables should be used as regressors or covariates in the analysis in order to (1) reduce the error term of the analysis, and (2) test for interaction between covariates and treatments (differences in slope of the regression of treatment yields on the covariates). (See paper by Mutsaers in these proceedings and Mutsaers and Walker 1990.) Unfortunately, individual variables often interact with treatments at an insignificant level. It is for that reason that modified stability analysis (Hildebrand 1984) has become widely accepted. Here treatment yields are regressed on the environmental index (i.e., the mean site yield). Mean site yield integrates the effect of a number of environmental factors and pronounced differences in slope are often observed. Of course, this analysis does not have predictive power; it only shows *a posteriori* the manner in which treatments react to overall environmental conditions.

Furthermore, apparent differences in slope should not be accepted without question but be subjected to a statistical test. There are several options for such a test. Consider, for concreteness, a case of four treatments (unreplicated at sites) over 20 sites. Simple ANOVA gives:

	DF
Sites	19
Treatments	3
Sites x treatments	57
Total	79

If the treatments are varieties (the classical case) then Finlay and Wilkinson (1963) propose the calculation of an "environmental index" (EI) which in the absence of external information is taken as the site mean of all varieties. Yields over sites of each variety in turn are then regressed on the EI, and the slopes and heights of these lines give useful information about the relative stability of the varieties over the range of sites encountered. The modified ANOVA would be:

	DF
Sites	19
Treatments (varieties)	3
Regressions	4
Sites x treatments (remainder)	53
Total	79

The second ANOVA, however, does display some features which make it suspect. The slopes for the different treatments are not independent (their average must be 1.0). This is less important when there are a large number of treatments (as often occurs in variety trials) but becomes acute in on-farm trials when there are few treatments.

Where the treatments are not varieties, Hildebrand (1984) suggested the same technique could be useful in finding which of the treatments is most environment-proof, i.e., most stable across environments. This seems a legitimate extension, but the same objection applies when only a small number of treatments is compared, as is usually the case. Several methods are available to avoid this statistical pitfall

(1) An analysis directly related to stability analysis evaluates the interaction between treatment contrasts and mean site yield, "site index", as a test for any differences in slopes:

For example, with 20 sites and four treatments:

	DF
Sites	19
Treatments	3
Sites x treatments:	
Treatment x site index	3
Remainder	54
Total	79

or, in case of a 2^2 factorial (factors A and B):

	DF
Sites	19
A	1
B	1
A X B	1
Sites x treatments:	
A x site index	1
B x site index	1
A x B x site index	1
Remainder	54
Total	79

The average slope of the regression lines of treatments against site index would, of course, be 1.

(2) An alternative, which has merit from a statistical standpoint, is to use the baseline treatment (A_0B_0) as an independent site index, rather than the mean of all four. This implies at least a degree of standardization of basal conditions over sites. We then restrict ourselves to an ANOVA for the remaining treatments only, which gives us:

	DF
Sites	19
Treatments	2
A_0B_1 x site index	1
$A_1 B_0$ x site index	1
$A_1 B_1$ x site index	1
Treatments x sites (remainder)	35
Total	59

(3) If the treatments have a factorial structure— say a 2 x 2 (AxB)— then a more standard test for interaction between the main effects and sites can also be used:

	DF
Sites	19
A	1
B	1
A x B	1
A x sites	19
B x sites	19
A x B x sites (remainder)	19
Total	79

and now not only do we have separate parts of the (sites x treatment) interaction against which to test the various effects, but we can also separately examine the regressions of these effects against site index, of which they are independent.

Economic analysis

Partial Budgets. Partial budgets were recognized to be the main technique for economic analysis of trials. The following aspects were emphasized:

a. The importance of calculating the return to limiting factors. Recommendations based on comparison of net benefits/ha may not be appropriate for land abundant regions where returns to other inputs may be more important in farmers' choice of technologies. Calculation of the marginal rate of return to cash and labor was recommended in these situations.

b. Calculations should be based on the field price, i.e., the price which the farmer would receive for output or pay for an input at the farm gate.

c. Where prices of output or inputs are seriously distorted by government policy, (examples are fertilizer subsidies or overvalued exchange rates), it was recommended that social profitability calculations should be carried out using shadow prices, or prices which would operate in free markets without government intervention.

d. Sensitivity analysis should be routinely done, by varying values of parameters which are difficult to estimate accurately. Market data on price variability should be collected to guide the extent to which parameter values need to be varied.

e. Economic analysis should be carried out to identify the least cost treatment, even when there are no statistically significant differences between treatment yields.

f. If statistical analysis shows that a treatment is superior to farmers' practice, but economic analysis shows that it is inferior, it is unlikely to be adopted.

g. Economic analysis should provide an indication of the reliability of estimates by giving confidence limits of estimates and by repeating calculations using the upper and lower confidence limits, as well as the mean.

h. The way in which net benefits are distributed among trial farmers should be indicated. Profitability calculations should be carried out separately for each farmer, and the shape of the distribution studied to see if those whose net benefits increase outweigh those who would suffer losses if the new technology were adopted.

Response curves vs discrete analysis. Usually an analysis of the profitability of alternative treatments should be enough. Estimating response curves may not be worthwhile, since typically data are available for only a few points (e.g., a few fertilizer rates) on the response curve. As a result the major part of the response curve is essentially an interpolation between treatment levels.

Response curves are often used to calculate optimum levels of inputs for use by extension agents. It was pointed out that recommendations on levels of inputs are, in reality, no more than broad guidelines, which individual farmers adapt to their own biophysical and socioeconomic circumstances. Therefore, a high degree of precision in recommended levels is not required. Economic analysis of each of the treatment levels may be sufficient for developing broad recommendations.

Estimation of response curves may, however, be useful for analyzing the interaction between input response and environmental variables. Usually data from several sites/years are pooled to generate sufficient variability in environmental factors. In cases like this it is advisable to take account of the type of analysis being planned at the time when the experiment is designed. If the objective is to estimate the effect of environmental differences, it may for instance be advisable to have fewer replications, but a larger number of treatment levels. In some cases, a larger number of treatments at the lower end of the response curve may be indicated, if the objective is to investigate the effect of environment on input response under farmers' management.

Risk analysis. Partial budget analysis identifies the treatment likely to yield the highest profitability on the average. It does not take year-to-year variability in profits into account. Risk-averse farmers may, however, prefer a treatment which gives lower average profits as long as it also reduces year to year variability of profits. Factors which vary from year to year and contribute to the riskiness of a technology include weather, pest and disease infestations, and output price variability. This aspect of farmer acceptance of technologies can be investigated by using stochastic dominance analysis. The principles of stochastic dominance analysis are given in Anderson, Dillon, Hardaker (1977) Ch. 9.

It was emphasized that if the results are to be relevant for understanding farmers' technology choices, the data should capture variability in the same site over time. This type of analysis should not, therefore, be carried out, as frequently happens, with pooled data from a number of locations. This is because the data pick up variability on factors such as soil quality and topography, which are not relevant for the discussion of individual farmers. Also, variability in environmental factors and pest/disease infestations over a number of locations is unlikely to be the same as variability in one site over time. Risk analysis, therefore, requires that the same trials be repeated on the fields of the same panel of farmers for a minimum of three years. Methods of utilizing such sparse data to extract more information are given in Anderson, Dillon, and Hardaker (1977) pp 42-44.

Pooled data from a number of locations can, however, be used to look at the robustness of recommendations. Plotting a cumulative distribution function of profits over locations would indicate the degree to which the technology is likely to benefit farmers in different locations.

Farmer assessment

The complementarity between economic analysis and farmer evaluation of technologies was recognized. Economic analysis without farmer assessment is likely to overlook factors which are not immediately obvious to researchers, but should be taken into consideration in the evaluation of the technology. Nor is reliance recommended on farmer assessment alone without data to verify their assertions. It was agreed, however, that if farmers are negative about a technology, it is unlikely to be adopted, even if economic analysis shows that it is profitable. A positive response by farmers need not, however, necessarily imply that the innovation will be adopted.

Methods of obtaining farmer assessment include group interviews, field days, follow-up surveys, and test panels. It was recommended that:-

a. Farmers should be involved in the design and management of trials. This improves assessment because they understand the trials better and are aware of inputs as well as output.

b. Evaluations should be done after farmers have had a chance to evaluate storage, processing quality, and marketability.

c. Open-ended questions should be used. Farmers should first be asked what they like or dislike about the technology. Later, more specific questions on yield and other factors may be asked. Questions should try to understand the farmers' objectives and should focus on the elements of the decision-making procedure.

d. For input-intensive technologies, it may be advisable to stratify farmers by asset ownership and conduct separate group interviews for each stratum. Examples of eliciting farmer evaluations of technology are given in Lightfoot (1987).

e. Caution must be exercised in weighting the different characteristics (of varieties, for example) which farmers claim are desirable. Methods of doing this are illustrated in Ashby (1989).

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I

Elements of On-Farm Research Methodology

The Use of Integrated Agronomic-Economic Surveys in the Diagnostic Stage of On-Farm Research

Derek Byerlee and Bernard Triomphe

On-farm research (OFR) — or farming systems research (FSR)[1] — has two major stages. The purpose of the diagnostic stage is to describe and understand the farming system and identify production constraints. Promising technological solutions to these constraints are tested under farmers' conditions during the experimentation stage.[2] Although OFR is multidisciplinary, social scientists tend to take the lead in diagnosis whereas agronomists assume responsibility for experimentation. This division of labor has given diagnostic surveys a strong socioeconomic orientation, emphasizing the description of the farming system and crop management practices (Byerlee, Collinson et al. 1980). Understanding and quantifying agronomic variables that influence crop growth and yields have received little attention in the diagnostic stage until recently.

Agronomic variables have been incorporated in a number of ways in formal diagnostic surveys in OFR. First, in some OFR studies, researchers have focused diagnosis on specific agronomic problems or constraints. Examples include management of the potato tuber moth in Tunisia (von Arx et al. 1988) and management of plant density for grain and fodder production in maize (Byerlee, Iqbal, and Fischer 1989).[3] Second, recent diagnostic surveys tend to include agronomic variables such as timing of crop operations, crop rotation, pest incidence, and plant density (for example, Byerlee, Heisey, and Hobbs 1989). These more comprehensive surveys generally aim to exploit the variability in management and yields in farmers' fields to establish hypotheses on yield-limiting factors as a basis for designing experiments (Edwards 1987). Finally, in OFR both in France and in French-supported OFR projects in developing countries, French agronomists[4] have a tradition of agronomic

1. The term OFR is used instead of FSR in this paper because of the wide range of activities described under the rubric of FSR (Merrill-Sands 1986).

2. Experimentation can also be used for diagnosis. However, surveys are normally the major tool for conducting diagnostic activities, whereas experiments are the major tool for testing solutions.

3. These studies in some ways resemble studies on crop losses However, crop loss studies usually focus narrowly on the estimation of yield losses to specific pests rather than on how management and other socioeconomic factors influence those losses. Also, crop loss studies are generally oriented to setting priorities for applied research programs, such as breeding for pest resistance (Weise 1982).

4. We refer to these agronomists as the French school, although they represent only a small number of researchers, strongly influenced by ideas developed by Professor M. Sebillotte at the Institut National Agronomique, Paris-Grignon.

monitoring with emphasis on determinants of individual yield components (Sebillotte 1987).

The increasing interest in agronomic diagnosis in OFR reflects the need to better define and understand problems from a technical or agronomic viewpoint. Earlier diagnostic studies often emphasized problems, such as a labor constraint at weeding time, that reflected the socioeconomic orientation of the researchers. In some cases, widespread and obvious agronomic constraints, such as a serious nitrogen deficiency, were also noted. However, in many cases insufficient attention was given to understanding how the environment (defined in a broad sense to include fertility, pest problems, etc.,) influences crop growth and performance, leading to incomplete identification of problems and inefficiencies in designing subsequent experiments.

These developments in the diagnostic stage of OFR are the background for this paper, which discusses the use of integrated agronomic-economic surveys in diagnosis. The paper is developed in three parts. First, we discuss the main concepts, objectives, and potential approaches to integrated crop production surveys that combine both agronomic and socioeconomic perspectives. Second, we describe an example of an OFR program in maize in Pakistan that integrated agronomic and socioeconomic variables in the diagnostic survey. Third, we discuss a range of methodological issues that impinge on the design of integrated agronomic-socioeconomic surveys and provide guidelines for choosing survey techniques which are based on cost-effectiveness. Our conviction is that the better integration of agronomic and socioeconomic perspectives into diagnosis, together with an analysis of the existing variability in management practices and yields in farmers' fields, can potentially improve the efficiency of OFR and, at times, partly substitute for costly experimentation.

Conceptual framework for integrated crop production surveys

Multidisciplinary crop production surveys that integrate agronomic and socioeconomic perspectives (hereafter called "integrated crop production surveys") are undertaken with three immediate objectives, all of which may contribute to more efficient experimentation:

1. To stratify farmers or fields into more homogeneous groups, usually called research or recommendation domains.
2. To describe and understand farmers' management practices for one or several crops in a system.
3. To analyze factors causing yield losses and variation in yields from field to field.[5]

Improved agronomic diagnosis has the potential to partially substitute for experimentation. It might reduce the need to conduct exploratory experiments to further identify limiting factors. In addition, if the diagnosis is conducted over a sufficiently wide area, it may help to extrapolate experimental results from a smaller area in which the experiments were conducted.

5. We use "yield" throughout this paper to refer to returns to the most limiting resource. In land-extensive systems based on manual labor, especially in sub-Saharan Africa, this may imply expressing yields in terms of returns per unit of labor.

Variables collected during an integrated crop production survey can be categorized into:

a. field characteristics (soil properties, topography, and location);

b. field management practices for the current crop;

c. crop rotation and field management practices for previous crops;

d. agronomic observations on crop growth, plant deficiency symptoms, and pest infestations; and

e. system-wide variables, such as access to draft power.

Except for the last category, all variables are field-specific. Some categories of variables, such as field characteristics and system variables, are exogenous, i.e., are taken as given and outside the control of the farmer. These exogenous variables influence the variable sets that are endogenous to the system such as cropping history, production practices, crop condition, and yield and its components (see Figure 1).

Most crop production surveys emphasize the causes of yield variability between fields (the center circle of Figure 1) at the expense of analyzing the variability in production practices among fields and the reasons for this variability (the outer circles of Figure 1). The analysis of production practices is particularly important in order to stratify farmers into more homogeneous groups, and to understand the causes of yield-limiting factors as a basis for screening solutions that will be acceptable to farmers (Tripp and Woolley 1989).

A major objective in conducting integrated agronomic-socioeconomic surveys is to analyze factors influencing yield variability between fields in order to identify major yield-limiting factors. Various approaches have been developed to analyze this variability. The most common is a statistical approach in which a yield function is specified as:

$$Y = F(X_i, C_j, E_k) \qquad (1)$$

where Y is yield, X_i are management practices, C_j are variables describing the crop condition, and E_k are environmental variables. The X_i variables are described in terms of levels of inputs, as well as the timing and method of their use. The C_j variables describe the condition of the crop and may include stand establishment and infestations of specific pests. The E_k variables measure soil and site characteristics as well as climatic variables. The precise specification of this function, especially the level of disaggregation of variables, varies substantially. Economists tend to focus on X_i variables, especially input levels, at the expense of C_j and E_k variables, whereas agronomists give more attention to C_j and E_k variables. The interdependence among the categories of variables also needs to be recognized. Hence, the analysis may have to be conducted in two or more stages, since typically the agronomic variables describing the condition of the crop are in turn a function of management and environmental conditions: $C_j = g(X_i, E_k)$. The statistically-derived yield function is also usually applied within a relatively homogeneous recommendation domain, in order to increase the proportion of variability that can be explained by crop management factors as opposed to environmental factors.

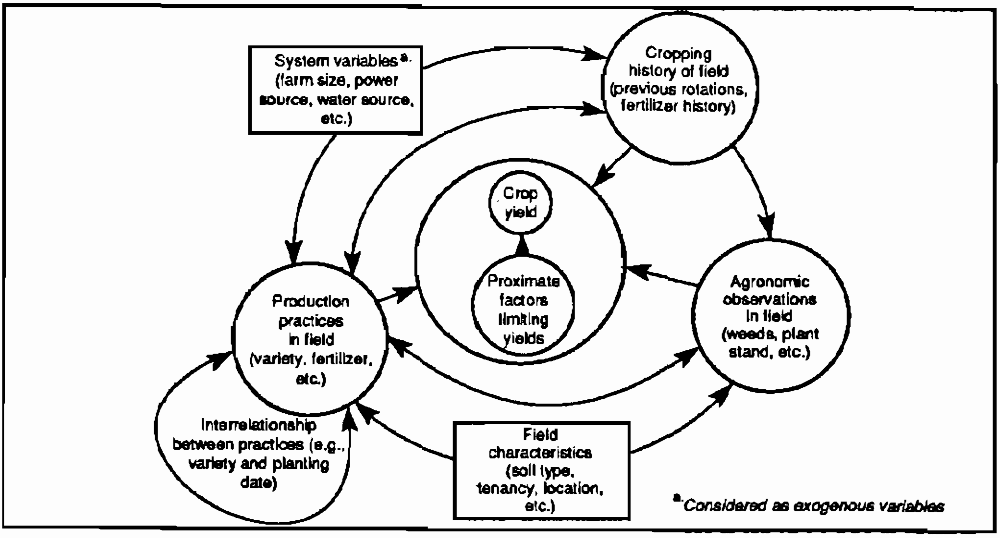

Figure 1. Schematic representation of interrelationships analyzed using data from an integrated crop production survey

The French school has adopted a rather different process-oriented approach in which methods of analysis are based on an explicit model of the biological mechanisms governing crop growth in the field and less on a statistical analysis of relationships between variables. While equation 1 and Figure 1 above envisage a direct relationship between the application of a specific management practice and yield, French agronomists prefer to see this relationship as indirect (Sebillotte 1987) in which management practices transform or modify the physical environment for crop growth that, with climate, determines yields (Fig. 2). In this approach, the farmer's objective consists of applying management practices to optimize the crop's physical environment continuously from land preparation to harvest— formally known as the "technical itinerary" (Sebillotte 1978). Yield is the final output of the yield elaboration process which is determined by levels of successive yield components, e.g., in maize, the number of plants/ha, ears/plant, and grains/ear, and the weight of a hundred grains (Fleury et al. 1982). This allows the analysis of the potential influence of environmental factors on the successive yield components and helps to identify the timing of individual stresses (Masle-Meynard 1980).

Whichever approach is used, site variables, such as soil physical and chemical properties, are a function of crop rotation and management in the previous crop. More formally:

$$E_{k,t} = h(X_{1,t-1}, X_{1,t-2}) \tag{2}$$

where $E_{k,t}$ are soil and site conditions in the current period, t, and $X_{1,t-1}$, $X_{1,t-2}$ are management practices in previous cycles. For example, Lagemann (1977) in a shrub-fallow system in Nigeria found that soil fertility indicators in the current period were highly correlated with length of the preceding fallow.

Comprehensive measurement of agronomic variables is often costly. Researchers have to weigh the costs of more in-depth diagnosis against the costs of running controlled experiments. The benefits of better diagnosis are likely to be highest where no obvious limiting factors can be detected through simple informal or formal surveys, especially when most farmers have adopted the obvious technological improvements such as variety and fertilizer (Crozat et al. 1986).

An example of integrated crop production survey

The following example illustrates the use of an integrated crop production survey conducted as part of the diagnostic stage of OFR in maize in Swat District in northern Pakistan. The example shows a relatively low-cost approach to analyzing a key probem: plant stand management. The research was conducted by local scientists largely within the limits of resources normally available to the research program, in contrast to many diagnostic studies referenced in this paper, which were conducted by expatriate researchers using much higher levels of resources.

In the Swat area of Pakistan, a major issue in designing maize technology is the high density at which maize is planted and the role of maize as a grain and fodder crop. The OFR project area is characterized by very small farms (60 percent of farmers cultivated less than 1 ha) and a relatively high number of livestock. Maize produced under irrigation is the dominant summer crop. The mild summer climate and fertile soils of the area are well suited to maize production and farmers achieve an average yield of 4 t/ha.

The methodology for the diagnostic survey had two parts (Byerlee et al. 1987). First, a sample of 20 maize fields was monitored over the growing season to record plant density at different stages of crop growth and obtain an estimate of the number of plants removed for green fodder.[6] Second, at harvest a larger sample of about 100 fields was surveyed to record management practices and cropping history in each specific field, as well as some system-level and farmer variables, especially livestock ownership. At the

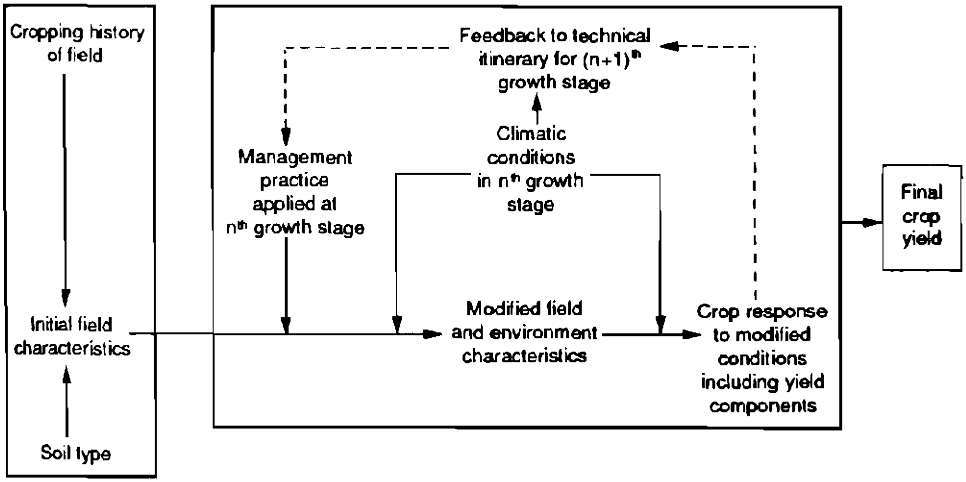

Figure 2. Conceptualization of effect of cropping history, management practices and climatic conditions on final crop yields following the French School (after Sebillotte 1987)

6. At each visit farmers were also asked about fodder given to livestock in the previous day.

same time, yield samples were obtained through crop cutting and some yield components such as harvest density and ears per plant were estimated. This survey, which consisted of only one visit at harvest, was conducted over three consecutive years to monitor year-to-year variability, although results from the first year of the survey were sufficient to initiate the experimental program.

The plant density survey revealed that plant density at emergence was about 250,000 plants/ha from an average seed rate of 96 kg/ha, about five times the standard rate for maize. Given the estimated number of seeds planted, the calculated seed germination and emergence rate were high; hence problems of stand establishment were not the main reason for using high seed rates. However, from emergence to harvest, plants were removed at a rate of approximately 1 percent of the remaining plants per day to arrive at a harvest density of about 80,000 plants/ha (Fig. 3). The plants that farmers removed were the major source of fodder for animals during the maize season.

Analysis of the harvest survey data focused on the determinants of harvest density, and the relationship between harvest density and yield. Harvest density was analyzed as a function of several management and system variables (Fig. 4). In particular, farmers with more livestock tended to use a higher seed rate. In turn, harvest density was closely related to the percentage of barren plants, with a correlation of 0.56. The yield function shown in Table 1 incorporates as independent variables management practices, agronomic variables (plant density), system variables, and dummy variables for year and

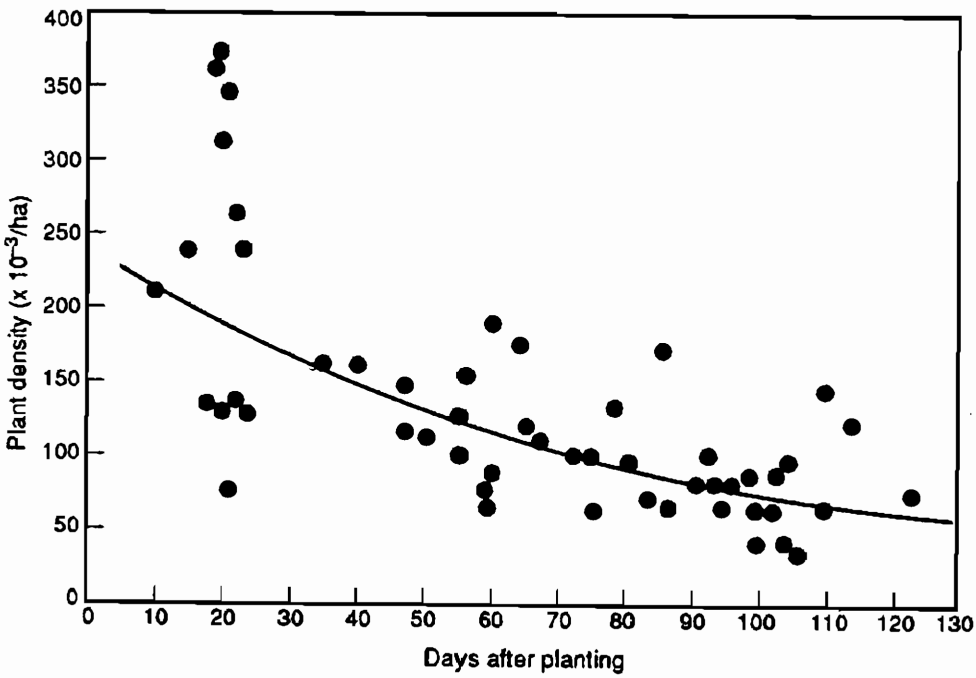

Figure 3. Plant density counts plotted against days from planting, Central Swat Valley, Pakistan

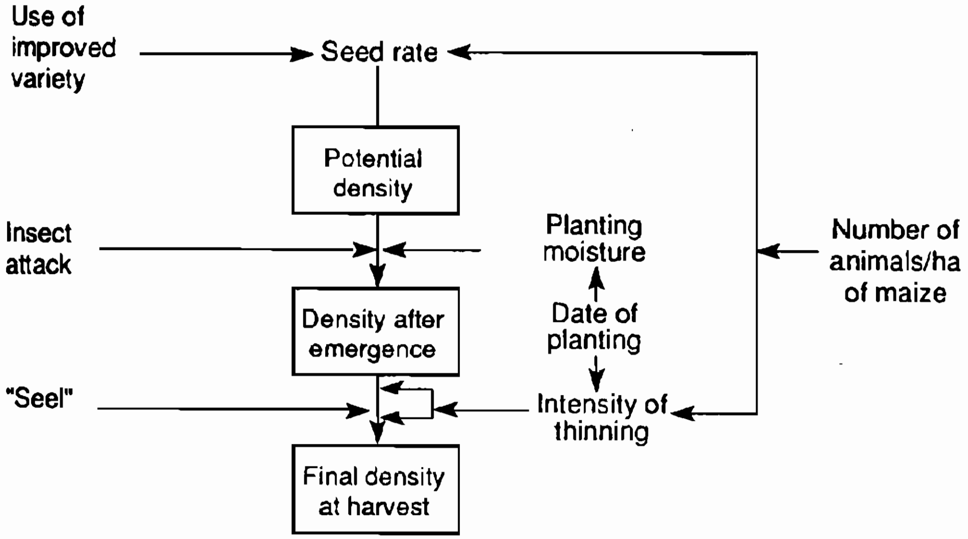

Figure 4. Factors influencing maize plant density, Central Swat Valley, Pakistan

location.[7] As expected, there is a statistically significant, inverse-U-shaped relationship between harvest density and yield. There is also a negative interaction effect of harvest density and use of an improved variety. The calculated optimum density for the leafier improved variety was 60,000 plants/ha compared to an optimum of 83,000 plants/ha for the local variety. The other major variables determining yield were the dosage of nitrogen applied and the date of planting. These results pointed toward the need for varieties with good density tolerance, good fodder characteristics, and early maturity. At the same time, nitrogen rather than phosphorus appeared to be the main fertility factor limiting yields.

In summary, the crop production surveys in Swat were a relatively low-cost method of analyzing important relationships in the maize production system, especially the management of plant density for grain and fodder. The multiple-visit survey was confined to a small sample of clustered fields to reduce travel and interview time. The harvest survey covered a much larger sample (250 fields over three years). Although the data were collected in one

7. A yield function incorporating only proximate determinants of yield (percent barren plants and percent grain moisture at harvest) was also fitted (Byerlee et al. 1987). This function gave somewhat more explanatory power but was less useful for diagnosis.

8. "Seeling" involves passing an ox-drawn plough over broadcast fields at approximately 3 weeks after germination to control weeds and reduce initial plant stands.

visit each year, the results were remarkably robust over years.[9] The effects of plant density, planting date, and fertilizer on yield, estimated from the crop production survey, were later confirmed in on-farm experiments (Khan et al. 1986; Khan 1986). Overall, the crop production survey for one year required only about six weeks of a researcher's and a laborer's time, compared with the OFR experimental program, which occupied one researcher and two technical assistants full time for one crop season.

Methodological issues in data collection and analysis for integrated crop production surveys

There are a number of important methodological issues in collecting and analyzing data in integrated crop production surveys. These issues are discussed below with reference to the different approaches that have been used, and always cognizant that the important criterion for choosing among methods should be their cost-effectiveness in obtaining an understanding of the system that is sufficient for selecting promising technological interventions.

Types of variables collected

Since both agronomic and socioeconomic perspectives are included in the diagnostic surveys, the number of potential variables is large. The major categories of variables follow the conceptual framework of Figure 1 and the types of variables that can be collected under each category are described in Table 2. Because the potential variables are so numerous, key variables must be selected carefully through informal surveys to understand important relationships in the system.

Level of observation

Incorporating agronomic variables into diagnostic surveys has implications for the level of observation used for diagnosis. Agronomic variables have little meaning at the level of the farm or even a crop enterprise, which are often the focus of diagnostic surveys. This is because farmers' management practices usually vary substantially from field to field within a farm, and often within a field, depending on labor constraints, location, land and soil type, and crop rotation. Agronomic variables describing soil type and other physical characteristics as well as crop growth and development are even more likely to vary between and within fields. Hence, successfully integrating agronomic variables into diagnosis requires the collection of data specific to a field or even a subplot within a field. Where within-field variability is small, relative to between-field variability, field-specific data will usually be adequate. But there are situations, especially in rainfed and hand hoe agriculture, where within-field variability in soil characteristics, micro-topography, and crop management is quite large and data are best collected from one or more subplots within a field (Milleville 1976; Edwards 1987).

Usually subplots are identified and marked at the beginning of the crop season and all measurements are recorded for these subplots. Although

9. The survey was conducted over three years as a methodological exercise to test the robustness of the results over years with different growing conditions. In practice, the results from only one year were sufficient to confirm the major findings reported here and initiate the experimental program.

agronomic observations are easier to record for a subplot than for an entire field (fewer samples are required), it is sometimes difficult to record exact management practices for subplots without intensive interaction with the farmer and even constant observation of farmers' operations.

Table 1. Regression analysis of maize yields (kg/ha), Swat, Pakistan

Variable	Definition	Coefficient
IMPVAR	Dummy variable for improved variety	2412 (3.55)***
NITROGEN	Applied nitrogen (kg/ha)	6.09 (2.64)***
PHOSUSER	Dummy variable for use of phosphorus	229 (1.19)
DENSITY	Harvest density (x103 pl/ha)	69.9 (2.83)***
DENSITSQ	$(DENSITY)^2$	-0.425 (3.33)***
IMPVAR*DENSITY	Interaction term	-21.9 (2.04)*
DUMLOC	Dummy variable for 1983	160 (.68)
DOM 83	Dummy variable for 1985	105 (.39)
Constant		628
n		180
R^2		.28

Note: t-values in brackets, ****, **, and * denote significance at the 1%, 5% and 10% levels

Degree of quantification of variables

Both agronomic and socioeconomic variables can be subject to various degrees of quantification. The degree to which agronomic variables are quantified will have an important bearing on the cost of the survey. For example, soils may be characterized by texture (loam, clay loam, and so on) at a relatively low cost or, with more resources, soil chemical properties can be measured. Lagemann (1977), for example, collected soil samples from 320 fields and analyzed several soil test variables including organic matter, soil test phosphate, and base saturation.

Pest infestations can be recorded by subjective scoring or by objective counts. Subjective scoring of weed, insect, or disease incidence on a scale of 0 to n, where 0 represents no infestation and n is the highest level of infestation, can be quite rapid. It is best done by specialists (a weed scientist

Table 2. Categories of information collected in integrated crop production survey and examples of information in each category

	Field-specific information	
1.	Field characteristics	- Soil type, texture, depth - Soil test data - Site data - topography, presence of trees - Location
2.	Cropping history of field	- Cropping rotation for previous two or more years - Practices in previous crop with potential carryover effect - Fertilizer history - Yield of previous crop
3.	Production practices for crop	- Operations performed - Timing of operation - Inputs applied - Method of application
4.	Agronomic and pest observations on crop	- Crop development - Plant stand at each growth stage - Weed and pest infestation - Nutrient deficiency symptoms - Soil moisture status
5.	Harvest data	- Grain yield - Biomass yield - Yield components - Lodging
	Farm-level information	
1.	Resource base	- Power source - Irrigation system - Farm size - Family labor - Livestock
2	System interactions	- Cropping patterns - Resource competition - Risk management - Crop-livestock - Off-farm labor
3.	Farmer characteristics	- Age, education, sex - Extension contact
	Village-level information	
1.	Climatic data	- Data rainfall - Daily temperature - Daily evaporation

for weeds or a plant pathologist for a disease) although survey enumerators can sometimes be trained and calibrated in subjective scoring methods. Even for experienced researchers, subjective scoring requires calibration across researchers (Kranz 1987). To obtain objective measures of pest populations requires the number of insect- or disease-damaged plants in a given area to be counted, and sometimes an assessment of the degree of loss for each damaged plant. Ruiz de Londoño et al. (1978) conducted detailed counts of the number of damaged plants for six diseases and insect species affecting bean yields. Although objective measurement eliminates biases possible in subjective methods, it is usually much more time-consuming and also requires adequate sampling methods.

Measurement of yields and yield components

The analysis of yield variability between fields in terms of various management, site, and soil variables and cropping history is often a major objective of the integrated crop production survey. Hence the measurement of yield is a crucial variable in the survey. This subject has been comprehensively reviewed by Poate (1988) and only some aspects are treated here.

First, field and sometimes subfield estimates of yield are required. Crop cutting techniques are often used for this purpose, although problems of adequately sampling within-field variability should be recognized (Poate 1988). If the crop production survey monitors specific subplots, within-field variability is less of a problem since the whole subplot can be harvested and related to management and soil and site variables in that subplot (Triomphe 1986).

Second, despite its problems, crop cutting has advantages. Although farmer estimates of yield may be appropriate for yield estimates at the farm level (Poate 1988), farmers may have more difficulty estimating field-specific yields. Moreover, crop cutting enables not only the estimation of yield but also yield components at harvest, which may be important in analyzing yield constraints (Sebillotte 1980). Some agronomic observations are best taken at harvest, including the incidence of diseases that attack the grain or ear, incidence of some weeds (e.g., grassy weeds in wheat), and crop lodging. Finally, the farmer is usually in the field during crop cutting, and it is easier to obtain data on management practices in a specific field when the interviewer and farmer are both there. When the objective is to provide a comprehensive analysis of crop production, crop cutting will usually be preferred to other methods of estimating yields.

Frequency of observations and interviews

Probably the most important factor influencing survey costs (as well as the costs of on-farm experiments) is the number of visits made to observe fields and interview farmers. In practice the number of visits in diagnostic surveys has ranged from daily visits to a single visit during the growing season. Most surveys with an agronomic orientation have used some type of multiple-visit method, since periodic assessments of soil moisture or pest incidence, for example, need to be made at different stages of the growth cycle. The number of visits depends on the particular problems under study, the resources available, and the cultural setting. Posting hired enumerators to sample villages reduces the cost of frequent visits. However, since many field observations require considerable technical skill and are best made by the researchers themselves, the most effective strategy is often for researchers to conduct the survey by making two to four well-timed visits over the growing season (e.g., post-emergence, flowering, grain-filling, or harvest).

Sampling

Sampling methods for integrated crop production surveys need not differ from methods usually used in farm surveys (e.g., Casley and Lury 1982). However, a major decision arises on whether to conduct an intensive survey of a small number of fields or a less intensive survey of a larger sample. Much depends on the main objectives of the diagnosis. A small clustered sample enables more visits, and more quantification of important agronomic variables, and hence is best for understanding factors influencing crop growth and performance in a relatively small homogeneous area. A larger sample, on the other hand, may be needed to explore variability over a wider area and to delineate more homogeneous research or recommendation domains. The French school has generally elected the intensive observation of a few fields, (often less than 20 in a small area such as a single village,[10] whereas most of the studies reviewed in this paper have used a sample size of 50 fields or more, over a somewhat larger area. The desirable strategy may be to combine intensive monitoring of a small sample of fields (to understand key agronomic relationships) with a less intensive survey of a larger sample (to verify these relationships over a wider area). However, in most developing countries research resources are limited and larger samples will be more useful in the initial stages of an OFR program.

Since one of the objectives of diagnostic crop production surveys is to sample variability between fields caused by environmental and management factors, sampling efficiency may be increased by stratifying the sample according to the major factors believed to cause the variability. These factors are identified through initial informal surveys or a review of secondary data. Sometimes discriminatory power may be increased by choosing extremes of the observed ranges, e.g., early sowing and late sowing to analyze critical factors. This may even involve the selection of good and poor fields to identify the major factors responsible for yield differences in a given area (Sebillotte 1975). However, when extremes alone are selected for diagnosis, care is needed in extrapolating to the wider population.

Creating management variability

One way of reducing sample size is to create more variability in the sample by asking a farmer to use a particular practice or practices on part of his or her field (Gras 1981). This technique may be especially useful where variability in farmers' management practices is sufficient to measure the response to critical practices, such as the use of a new variety. Clearly, in creating variability, the line between surveys and experiments is blurred in what is sometimes called a "controlled survey" (Hoffnar and Johnson 1966).

Examples of this approach are the use of four levels of practices for 25-30 maize farmers in Pakistan (Khan et al. 1986) and for a similar number of millet farmers in Niger (ICRISAT 1982). Farmers managed all practices while researchers provided the new inputs to be tested (in both cases improved seed and fertilizer) and monitored the fields. Controlled surveys of this type will generally provide more information than conventional surveys but may be somewhat expensive to administer. The close interaction with the farmer required by the controlled survey will also limit the sample size.

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10. Most studies have, however, monitored several plots within a field.

Estimation of a yield function

A major objective of most integrated crop production surveys is to estimate a yield function to analyze yield variability observed in farmers' fields. Yield variability can be analyzed by several methods. In the simplest case, fields are grouped to compare, say, the 25 percent lowest-yielding fields with the 25 percent highest-yielding fields and Chi-squared or t-tests are used to compare the differences observed. However, caution must be used in these simple comparisons, because of high correlation between several of the explanatory variables (e.g., between doses of nitrogenous and phosphatic fertilizers. For this reason, this method is used mainly to test hypotheses prior to conducting more in-depth analysis.

Multivariate techniques, usually Ordinary Least Squares regression analysis, are increasingly used to analyze yield variability between fields. Since decisions on production practices may be taken interdependently (as described by the technical itinerary), and yields are determined by a complex interaction of management practices, soil and climatic variables, and field history, two or more linked equations may express the decision-making situation better than single equations.

Most economists emphasize management practices as the independent variables (e.g., Moock 1981; Byerlee et al. 1984), although variables such as cropping history and agronomic measures are increasingly included in these yield functions. Linear models are more common since coefficients are directly interpreted as the contribution to yield of a given factor. Linear specifications can easily be extended, although at the expense of scarce degrees of freedom in the case of small samples, by including interaction terms and quadratic terms.

Agronomically oriented studies, on the other hand, such as Wiese (1982) and Martin et al. (1988), include only variables to measure the proximate influences on yield. Hence, herbicide phytotoxicity is included rather than the type, timing, and method of herbicide application, which are likely to cause the phytotoxicity. Although a few studies such as Bernsten (1977) successfully combine agronomic, input, and management variables in analyzing yields, considerable caution must be used in including agronomic variables measuring crop growth and condition in the same equation with management variables, because of simultaneity problems, e.g., where variables describing crop growth are a function of management practices. Hence it is important to have a well-specified model of yield determination based on agronomic principles.

A further refinement is to analyze determination in terms of its yield components (Boiffin et al. 1981; ICRISAT 1982). Because each component is determined within a specific period during crop growth, it is possible to consider the level of a given component as a function of (a) the level of the yield components determined in prior periods and (b) environmental conditions during the period in which the given component is determined. While this approach has several advantages, including simplicity and the ability to screen data showing a high degree of variability, it may lead to misinterpretation because of its inability to take account of compensating mechanisms between yield components.

In the future, computerized crop models will allow the possibility of modelling crop growth and development based on empirical estimates of parameters derived from integrated crop production surveys. Use of crop models is a logical extension of the French school, which emphasizes understanding the interaction between crop management and the environment in crop growth and development.

Concluding comments

On-farm research methods have evolved considerably in recent years. In particular, there is a trend toward more integration of disciplines at each stage of the research process. In the diagnostic stage, there are now a number of good examples of the integration of both agronomic and socioeconomic perspectives in diagnostic surveys. Clearly such integrated crop production surveys will have to be crop-specific and data must be collected at the level of specific fields or even subplots within a field. Such surveys can generate a considerable amount of data which require well-designed and sometimes more complex methods of analysis, especially if the objective of the survey is to analyze differences in yields between fields. A first step in such analysis is often some type of statistical yield function, but in time we expect to see increased emphasis on approaches that give more attention to analyzing crop performance in terms of agronomic principles, including the use of crop models and expert systems.

In many ways, the type of integrated crop production survey reviewed in this paper departs significantly from the standard diagnosis based on an informal or short, well-focused, formal survey of the system or its key enterprises. Although a range of methods can increase the precision and complexity of an integrated crop production survey, in general integrated surveys will require more resources than a standard, single-visit diagnostic survey. On the other hand, there may sometimes be considerable extra benefits from conducting an integrated survey. If the survey is done properly, researchers should have a much better understanding of the key problems, their causes, and their severity and extent in the research domain. Hence the integrated survey has the potential to partly substitute for exploratory trials aimed at better problem identification, "levels" trials to estimate optimum levels of inputs, and verification trials to validate solutions over a wider area. Researchers must weigh the potential benefits of conducting more in-depth diagnosis versus the extra costs in time and resources. In some cases, there may be justification for delaying the beginning of trials and using the first crop season of an OFR program to conduct only diagnostic activities. In other situations, the integrated survey can be conducted alongside an experimental program, either by monitoring fields around trial sites or even by monitoring simple trials, provided that they are truly managed by farmers and planted on a sufficient number of sites.

The appropriate combination of agronomic monitoring in diagnosis and formal experimentation will vary widely. However, we believe that in systems where factors limiting productivity are not readily apparent or understood, the better integration of agronomic variables into the diagnostic process can improve the efficiency of the OFR process. This is likely to be the case in areas which have already undergone considerable technological change or in more difficult environments. Also, as OFR programs give more attention to the longer-run sustainability of production systems, they will need to better integrate agronomic and socioeconomic variables in designing appropriate interventions and monitoring their impacts. Whatever the objective, the methods reviewed in this paper should be evaluated to identify approaches for conducting integrated crop production surveys that are simple and cost-effective, and that can be adopted readily in developing countries by national research programs, which often operate with limited resources.

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Single Site Design Considerations in On-Farm Experiments

Peter Walker

I do not propose to say much about the type of verification trial where a single plot using a package of improvements is established on the fields of several farmers. Although they often provide useful information over an area, I consider them to be little more than demonstration plots. Where we have several plots per site, on the other hand, we are forced towards experiments which may be loosely termed factorial (in that independent changes in several factors become necessary) if we want to know anything about the separate effects of several "interventions". There are four main ways of doing so and I propose first to analyze their pros and cons. They are:

1. Factorial designs;
2. Stepwise (either forward or backward), "one-plus" and "one-minus" designs;
3. Pure first-order designs (Plackett and Burman 1946); and
4. Response surface designs.

Factorial Designs

Factorial is used in the statistical sense, that is, with either all or a balanced subset of factor combinations represented. Sometimes there is fractional replication, and sometimes one or two extra treatments outside the factorial structure, as when an extra nutrient might be tried at only the high level of other nutrients, from a suspicion that only then will it be limiting to a crop. They will almost always be of the 2^N series, with levels equal to the farmer's and "improved" practice— there is hardly room for more (although a 3 x 2 factorial, and I suppose even a 3 x 2 x 2 could occasionally prove useful). The factors may be fertilizers, varieties, population density, planting date, weeding practices, and such. Although one of the advantages originally advanced for using factorial designs (as opposed to varying factors one at a time) was the possibility of estimating interactions, once we get off the research station we may be prepared to sacrifice some, or even all, the interactions by the procedures known as confounding and fractional replication. To illustrate these very simply, we note that:

4 plots can accommodate 1 rep of a 2^2 factorial
8 plots can accommodate 2 reps of a 2^2 or
1 rep of a 2^3 factorial
16 plots can accommodate 4 reps of a 2^2 or
or 2 reps of a 2^3 or
1 rep of a 2^4 factorial

We could confound the 2^4 design by arranging it, instead of in one large area of 16 plots, into two smaller (and hopefully more uniform) areas or blocks of 8 plots each. We sacrifice one interaction only (all other comparisons are estimable), and we should gain accuracy if the blocks are chosen carefully. But there will still be 16 plots per site. An example of fractional replication would occur if we only laid out 8 plots, i.e., only 1 of the 2 blocks just mentioned. This is more risky but— again provided the right 8 treatment combinations are used and that more sweeping assumptions are made about the interactions— the 4 main effects of the factors can be estimated from only 8 plots. This is a "half-replicate" of a 2^4 design. It is possible to go a little further in this direction and estimate the main effects of up to 6 factors in 8 plots— a one-eighth replicate of a 2^6 design:

	(A)	(B)	(C)	(D)	(E)	(F)
(1)	-1	-1	-1	-1	-1	-1
(2)	+1	+1	-1	-1	+1	+1
(3)	+1	-1	-1	+1	-1	+1
(4)	-1	+1	-1	+1	+1	-1
(5)	+1	-1	+1	-1	+1	-1
(6)	-1	+1	+1	-1	-1	+1
(7)	-1	-1	+1	+1	+1	+1
(8)	+1	+1	+1	+1	-1	-1

The great advantage of factorial designs is that all plots contribute to the estimates of all the effects (main effects and interactions). The same cannot be said of the stepwise designs described below. One or 2 extra treatments unrelated to the factorial structure can be included and do not really affect the basic utility of this class of design.

Stepwise Designs

In this case we have to make a judgement (anything from an inspired guess to a well-researched and well-documented conviction) about the order of importance of the factors (Mutsaers et al. 1986). The treatments for a trial of this sort might be:

(A) farmer's level of all inputs;
(B) as (A) but with an improved variety;
(C) as (B) but with more fertilizer;
(D) as (C) but with a higher plant population;
(E) as (D) but with improved weeding practice.

Here we are investigating 4 factors in only 5 plots, but note that if we have got the order of importance wildly wrong, no useful result will be obtained. Analysis would normally take the form of looking at the differences:

(B) - (A) the effect of improved variety;
(C) - (B) the additional effect of fertilizer;
(D) - (C) the additional effect of plant density;
(E) - (D) the additional effect of weeding;

over sites, or regions. Each of these effects makes use of only 2 plots per site, i.e., 2/5 of the information available. The use of polynomial regression, suggested in the handbook, relies on some rather heavy assumptions, and in the same publication I suggested a slightly superior way of defining the contrasts, namely:

	(A)	(B)	(C)	(D)	(E)
(1)	-1	+1	0	0	0
(2)	-1	-1	+2	0	0
(3)	-1	-1	-1	+3	0
(4)	-1	-1	-1	-1	+4

where at least we are dealing with orthogonal contrasts and better use is made of the available information. However, apart from the first, these contrasts only approximately estimate the additional benefit of each factor in turn. For example, the second contrast compares treatment C (baseline + variety + fertilizer) against the mean of treatments A (baseline) and B (baseline + variety). The effect of fertilizer is partially confounded with that of variety—unfortunate, since we are postulating that variety has the largest single effect of all the factors. From that point of view (provided again that our order is correct), it would be better to calculate the contrasts:

	(A)	(B)	(C)	(D)	(E)
(1)	0	0	0	-1	+1
(2)	0	0	+2	-1	-1
(3)	0	+3	-1	-1	-1
(4)	-4	+1	+1	+1	+1

where at least contrasts (2) and (3) stand a chance of being meaningful if the effects of the last 2 factors are relatively small.

The one-plus and one-minus designs are even simpler and would usually be an earlier stage of an experimental program aimed at finding the relative importance of the factors before proceeding to a stepwise trial. It is clear, though, that very misleading results could be obtained. To give only one obvious example, more frequent weeding will generally give a greater crop yield improvement once fertilizer has been applied (nutrients help weed growth as well as crop growth). For applications where there is high precision (e.g., industry) the one-minus is known to be superior to the one-plus for finding with minimum effort which of a set of variables (or any combination of 2 of them) is responsible for a system crash, but this is not the situation in agriculture.

In general it can be said that designs of this type need some luck before we can get decent estimates of even main effects independently. We prefer the Plackett and Burman designs (described next) because, as in factorial designs, the main effects are estimated over average conditions of all the other factors, and use all plots.

Plackett and Burman designs

These are the most purely first-order designs of all the categories considered (i.e., discarding interactions completely). The number of plots (N) must be a multiple of 4, and then (N-1) factors can be examined for their main effects. The example for 8 plots is:

	Factor						
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
Plot 1	+1	+1	+1	-1	+1	-1	-1
Plot 2	-1	+1	+1	+1	-1	+1	-1
Plot 3	-1	-1	+1	+1	+1	-1	+1
Plot 4	+1	-1	-1	+1	+1	+1	-1
Plot 5	-1	+1	-1	-1	+1	+1	+1
Plot 6	+1	-1	+1	-1	-1	+1	+1
Plot 7	+1	+1	-1	+1	-1	-1	+1
Plot 8	-1	-1	-1	-1	-1	-1	-1

This could perhaps be described as a weighing design; each factor is applied at its higher level on 4 plots, at its lower level on another 4 plots, and the estimates of the main effects of each factor are mutually orthogonal—(excellent for exploratory work in a new region). It is not necessary to hunt around for as many as seven factors, either (one or more of them can be dummies in the above). If as many as 12 plots per site can be managed, then up to 11 factors could be examined.

Response-surface designs

These deserve a brief mention where we are dealing with at least 3 factors. The case of only 2 factors turns out to be a mere rotation of a 3 x 3 factorial and as such was criticized by Yates (1967) because "for fertilizer components, and I suspect others, there are no grounds for reducing the range of one factor at the extremes of the others" and "exploration of a rectangular area of the response surface is more appropriate than a circular area". Three factors call for at least 15 plots (a basic 2^3 factorial plus 7 additional points), but allow examination of curvature in the response surface, and the calculation of an optimum for each site. They were originally developed for industrial research, where error is less and where work often proceeds sequentially, and, as such, have not found much favor in agricultural research. One series of more than 100 3-factor nutrient trials in the West Indies made use of a rotatable design of this sort, but the purpose there was more one of soil calibration than of on-farm research *per se*. There is, in any case, absolutely no point in replicating such a design. If as many as 30 plots were available, a single replicate of a 3^3 factorial would automatically be preferred.

Other designs

Within very wide limits almost any collection of treatments applied to a set of plots will give some information, and there can be no real objection, where land is hard to come by, to having (say) 3 plots per site with package treatments of (1) farmer's practice, (2) extension recommendation for the area, and (3) latest research findings. Even (1) might be dispensed with and an area of the farmer's own field harvested, although there are those who believe that there may be dangers in that. It seems to me to be hardly necessary to use the word "design" in such cases. Only when we can deal with a greater number of plots does this become meaningful, and my main contention has been that statistical considerations help in making the best use of the information available. This is obvious and yet needs to be said again and again. I am reminded of discovering, on a visit to the Philippines a few years back, that a considerable number of NPK trials had been laid out using the following set of treatments:

N	0	0	0	1	1	1	1	1	2	0	2	1
P	0	1	2	0	1	0	1	2	0	1	1	1
K	0	0	0	0	0	1	1	1	0	1	1	2

It was impossible for me to see why this precise set of 12 treatments from the full 27 of the 3 x 3 x 3 factorial were used. One can, it is true, derive 3-point response curves to N and P at the lower and at the middle levels of the other two nutrients, plus a response to K at the middle levels of N and P. But this is a poor return from as many as 12 plots, when either more factors could have been examined or at least part of the N x P interaction evaluated. Yet this was a replicated trial and genuinely off-station. The crop was a vegetable and plots were extremely small. One can do much better with 36 plots, or even with 24.

Across-site considerations

Although my main concern in this presentation has been with techniques at a single site, some mention should be made of the multi-site problems where the design is not the same at all sites.

A large series of 3^3 (NPK) factorials carried out in Bihar, India, in the late fifties illustrates the idea. As you will be aware, the 27 treatments of such an experiment can be divided into 3 sets of 9 (confounded), and the sets allocated to different blocks, in such a way that loss of information on the main effects of the factors and their first-order interactions is minimized. This is often done in the context of a single experiment, and by a slight extension the Bihari workers laid down many such sets, the 3 blocks being on neighboring farms within the same village.

McGuire and Walker (1982) advance the possibility of having the blocks of a balanced incomplete block (b.i.b) design distributed in such a way that one block lies on each of a number of chosen farms. This is, of course, a special case of the above example except that the treatments would not have a factorial structure.

Both these approaches suffer from the fact that one individual farmer will not necessarily have a control plot, (usually meaning a plot grown according to farmers' practices). It is normally thought desirable to have such a plot included at each site if only for demonstration purposes. However, I think this is to confuse the distinction between experimental and demonstration plots, and in any case there will be an area of the crop grown by the farmer in close proximity to a trial. More seriously, if the farmer shows an intelligent interest in the reason for these large differences within such a small area, it is almost impossible to explain to him what the research is trying to do. This is particularly so in the incomplete block case where the treatments may be completely different from those on a neighboring farmer's plots.

Finally, De Datta et al. (1978) came up with a different scheme, part experiment, part verification, and part survey, which has the merit that the loss of 1 or 2 entire sites does not have such serious effects. Briefly, they propose that sites be divided into 3 groups, the test factors being the same throughout the area.

In Group I, two replications of the full 2^N factorial are laid down, together (possibly) with 2 or 3 extra treatments representing management packages outside the factorial scheme. Normally N would be 2 or 3 and even that would lead to an experiment which could only be accommodated on a relatively large farm.

In Group II, sites are laid down to 2 replications in what the authors call a "mini-factorial" design, consisting of all factors at farmer's level, all at the presumed maximum level, and then the second of these with each factor in turn singly dropped to the farmer's level. This is a simple one-minus design plus a control.

In Group III (which I suppose is the survey part) a single plot is laid down at presumed optimum levels of the test factors, other cultural practices being at farmer's level. Farmer's yields are estimated by sampling the farmer's own crop. There may be an additional plot where the experimenter tries to optimize the other cultural practices also.

A complete investigation in an area would consist of these procedures in a ratio (i.e., the number of sites per Group) something like 4: 4: 12. Although the authors particularly recommend this plan for work on rice, I have encountered an example on faba beans in Egypt which gave very good results, from Groups I and II at least. Egypt is one of the finest locales in that respect, as the country is virtually one-dimensional: i.e., there is no topography to speak of, and altitude, soils (meaning quality of alluvial deposition), and climate, all change steadily as we proceed downstream.

Comparison of factorial and stepwise designs

Reference has already been made to a series of on-farm trials carried out in western Nigeria in 1986 and after. A maximum of only 6 plots could be accommodated on most of the farms, so a hybrid design was adopted, combining a confounded factorial and a stepwise. The factors investigated, in a cassava+maize intercrop, were, in presumed order of importance:

1. Improved maize variety (M);
2. Improved fertilizer application (F), and
3. Improved cassava variety (C).

There were 24 sites (farms) and different treatment sets were applied to the odd- and even-numbered sites, as follows:

Treatments			Odd sites	Even sites
M	F	C		
*0	0	0	xx	x
0	0	1		xx
0	1	0		xx
0	1	1	xx	
*1	0	0	x	xx
1	0	1	xx	
*1	1	0	xx	x
*1	1	1	x	xx

The four stepwise treatment combinations (*) appear at every site, and assume the order of importance (M) (F) (C). At the same time every pair (odd + even) of sites contains 1 replicate of a 2^3 factorial with the 3-factor interaction confounded between the sites (marked with xx). There were originally 24 sites, or 12 pairs, but in the event only 20 were harvested for maize, and the odds and evens were not equally represented in these. Also, it turned out that cassava variety had no effect on maize yields since maize was harvested after 4 months and cassava after anything up to 2 years. It is interesting to compare the results of restricting maize analysis to:

a. The factorial treatments only (79 plots, 1 missing).

$$SE\ (1\ \text{effect}) = \sqrt{\frac{2(0.3074)}{40}} = 0.12\ \text{t/ha}$$

b. The stepwise treatments only (79 plots).

$$SE\ (1\ \text{effect}) = \sqrt{\frac{2(1.005)}{20}} = 0.317\ \text{t/ha}$$

Preliminary work on this indicates another pitfall of intercropping work, however. Both maize variety and fertilizer had highly significant effects on maize yield, but when the cassava was harvested, the improved maize variety proved to have had a depressing effect on cassava yields. Assuming the relative value of the two crops as 5:1 (in weight), there was no eventual advantage in value from planting the improved maize.

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Farmer-Related Variables in On-Farm Trials: Their Measurement and Use in Statistical Analysis

H.J.W. Mutsaers

A common dilemma facing agronomists who conduct on-farm trials is the degree of control they wish to exercise over non-experimental or concomitant variables. One major difference from station trials is precisely this degree of control. In research station trials, all the non-treatment factors are set to a predetermined level. In order to obtain results which are relevant to farmers, they should represent "average farmers' conditions". If this requirement is not met, as is often the case, then the relevance to farmers is doubtful. The importance of realistic levels for non-experimental variables is even more obvious in on-farm trials. Whether these levels will be fixed or not depends on the type of trial one considers, which can vary from fully researcher-managed to fully farmer-managed.

Researcher-managed trials

Fully researcher-managed trials are not much different from station trials, except that they are conducted in farmers' fields. Experience shows that the need for such trials does not often arise. They may become necessary when the physical conditions in the research station are so different from those in farmers' fields that meaningful results can be obtained only outside the station.

An example is crop response to fertilizer. In researcher-managed on-farm trials, the primary objective would be to measure the effect of nutrient levels under representative physical conditions, such as different soil types. Fertilizer response will, of course, be influenced by management practices, but at this stage it is advisable to standardize management practices at a representative level. Otherwise the primary effects will be obscured and a large number of replicate farms will be required in determining them accurately.

Non-experimental factors in researcher-managed trials fall into two categories:

1. Those which are expected to have a direct effect on the treatments. Examples are soil type, previous cropping, and similar factors which are related to the fertility status of the soil.

2. Those which influence the treatment effects indirectly, such as management practices.

The first set of factors is used to stratify the replicates into homogeneous groups with each factor equally represented. This allows the researcher to estimate and test interaction between such factors and treatments. The second set of factors is fixed by the researcher at realistic levels, similar to average farmers' practices. The application of two or even more standardized management levels is sometimes recommended, e.g., one good and one average or below average. This, however, greatly complicates the trial and is not advisable. The effect of farmer management is better studied later in farmer-managed trials with a set of treatment combinations which have been chosen on the basis of results from researcher-managed trials.

Farmer-managed trials

Trials with a high degree of farmer involvement are sometimes subdivided into different categories. In practice this distinction is somewhat artificial. The degree of farmer involvement can vary along a continuous scale from "farmer only puts in the labor" to "farmer conducts the entire trial independently". How much is left to the farmers depends on the stage of the research. When testing new technology which is still unfamiliar to the farmers, the research team will apply or at least assist in the application of the experimental treatments. Also, when several treatments are being compared, extensive supervision by the research team is required. As the number of treatments narrows down, more will be left to farmers until, in the validation stage, farmers will carry out the (simple) trial independently.

A common characteristic of farmer-managed trials is that the researcher is not interested just in the mean treatment effects, but even more in how the effects are influenced by (a) differences in physical conditions and (b) farmer-related variables such as management practices. Some of the physical parameters characterizing a field may be measured before the trial and can be used to obtain a stratified sample of trial fields. This is obviously the best solution when the differences are clear-cut, e.g., with clearly distinguishable soil types, differences in hydrology, differences in altitude, and so on. It allows straightforward assessment of the interaction between treatments and the physical parameters. In many cases, however, parameters cannot be easily divided into homogeneous classes because they vary on a continuous scale; shade is an example. Even soil characteristics are sometimes not easily divided into meaningful classes. Other variables may only emerge during the season, e.g., the nature and degree of weed infestation or pest incidence.

Assessment of farmer-related variables is perhaps even more complicated. Stratification is, of course, possible for such obvious criteria as farmers' gender, but most of the farmers' management practices will only become apparent after the trial has started. Furthermore, there is a risk that farmers' practices in the trial are different from their usual practices. In order to minimize this effect, the researcher should superimpose the treatments on a normal farmer's field in such a way that the size of the trial is not much less than that of the whole field. This will only be acceptable to farmers if they have a favorable expectation of the trial results. In addition, the researcher should exercise a minimum of interference with those management practices which are not part of the experimental factors.

In summary, in trials with a high level of farmer involvement, it is advisable to stratify farmers' fields into a few, clearly distinct classes based on physical and socioeconomic characteristics, but otherwise to choose farmers randomly. Farmer- or field-related variables should be carefully measured or monitored while there should be as little interference as possible with those practices which are not part of the treatments.

Differences in non-treatment factors will occur not only between fields but also between plots within fields. Physical differences between plots may be in shade, weediness, pest incidence, and similar factors. Also, management practices may vary, e.g., farmers may not weed all the plots at the same time.

Which variables to measure?

The choice of variables to measure is a crucial decision in the planning of an experiment. The researcher should have a clear idea how each variable will be used in the analysis. It is quite common for many laborious plant measurements to be carried out which are never used, while other observations which could explain differences are not recorded. In the former category are details on 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 are rarely so 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— shade, if appropriate, soil texture and depth of profile, cropping history and weed incidence, for example. Another pitfall is an overemphasis on the 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. Experience has shown that a simple scoring system is often quite adequate for such factors. Some quantitative information on soils will always be needed, but a full soil analysis for each field is very expensive. The researcher should therefore select those soil parameters that are most required, and preferably that can be determined with simple methods.

The researcher must also decide which variables must be measured at the plot level and which can be measured at field level. The former are used as covariates or as regressors in the ANOVA to remove "noise" from the error term while the latter are used to explain differences between farmers' fields.

An example

I will briefly describe the measurement of nontreatment variables and the use of some of them in the analysis in a simple trial in southwest Nigeria. The target system was the farmers' maize + cassava intercrop, and the objective of the trial was to test the effect of fertilizer, weeding regime, and maize planting density on maize and cassava yield. The trial was a stepwise arrangement of the three test variables. The treatments and mean maize yields are shown in Table 1. The "improved weeding" intervention was only concerned with timeliness of weeding, i.e., at two and five weeks after planting.

Table 1. Treatments and mean maize yields, maize + cassava trial, Ayepe, 1988

Fertilizer	Weeding	Maize planting density	Maize yield (t/ha)
no fertilizer	farmers'	farmers'	1.75
300 kg/ha	farmers'	farmers'	2.44
300 kg/ha	improved	farmers'	2.50
300 kg/ha	improved	farmers' x 1.5	2.74
no fertilizer	farmers'	farmers' x 1.5	1.70

Based on previous experience the following non-experimental variables were measured.

Field level variables

1. *Soil analysis.* Standard soil analysis was carried out for each field. We found that the usefulness for the immediate trial interpretation was limited, most probably because of the fairly uniform soil conditions in the area. The cost of soil analysis was thus not justified. The data, however, were stored for possible future use and as a database on soil characteristics in the area.

2. *Topographical position.* This information was easily obtained. Topographical position is often associated with differences in soil texture and, in the case of low-lying fields, with hydrological conditions.

3. *Cropping history.* Cropping history reflects the intensity of land use. Accurate information can usually be elicited from farmers for up to six previous years. For use in the analysis, the recorded history can be translated in an intensity factor, e.g., a percentage of cropping years over the total number of years for which history was recorded or, in the case of crops with different resource needs, the weighting of cropping years according to crop.

4. *Method of land preparation.* The maize + cassava crop combination was planted directly on heaps or on the flat with heaping being done later.

5. *Planting dates.* They extended over a fairly long period. It is advisable to plant replicates over the same period as farmers plant their crops.

6. *Farmers' age and gender.* These were noted.

7. *Farmers' origin.* Whether they were indigenes of the area or immigrants was recorded.

Plot level variables

1. *Shade.* Differences in shade among plots were recorded. Initially a complicated method was used involving counting of trees of different types and sizes and deriving a tree competition factor. It turned out that simple scoring of shade on a scale of 0-3 was much easier and even more informative. However, the same person has to do the scoring in all fields.

2. *Planting density.* The trial involves minimum interference with farmers' practices and we recorded the density and planting pattern used by farmers after establishment, rather than impose a fixed planting density.

3. *Plant stand at mid-season and harvest.* These counts, combined with planting density, provide information on stand losses during the growing season. In this trial we actually sampled each plot at 2-weekly intervals in order to examine the causes of stand losses, because these losses seem to mediate the large yield differences between farmers. Such intensive sampling, however, may not always be possible or required.

4. *Weediness score (0 - 3).* We used fortnightly observations on weediness carried out at the same time as the stand loss assessment. A single-figure weediness score was derived by weighting each score according to time of

observation. The assumption was that weeds affect plants differently according to growth stage.

It should be noted that only repeated scoring for weediness gives useful information, and if this is not possible, it should be omitted. An inventory of the weed species is also useful since it may provide an indication of the fertility status of the soil.

5. *Cobs/stands harvested by farmers.* We requested farmers to inform us when they intended to harvest their trials, although they invariably harvest a few maize cobs or cassava stands early for consumption. We recorded these as missing cobs or stands and corrected the plot yields proportionally.

6. *Yield.* Yield sampling was done in three full rows per plot, usually equivalent to 30-50m^2 of harvested area. The same rows had been used for the counts and scores mentioned earlier.

Analysis

Analysis of variance. In the ANOVA (Table 2) three elements are noted:
– the usual mean squares for sites and treatments;
– the interaction between treatments and mean site yield;
– a number of measured variables (regressors) which remove "noise" from the residual term.

Treatment effects. The significant treatment effect was due to a significant yield increase by fertilizer and by increased density in the presence of fertilizer. The improved weeding treatment (in the presence of fertilizer) did not improve yield at all, as was already obvious from the mean yields (Table 1).

Table 2. Analysis of variance of maize yields in a farmer-managed on-farm trial, Ayepe, 1988

Source	DF	MS	P
Mean	1	909.19	
Sites	38	3.37	
Treatments	4	8.02	<.001
Treatments x site mean	4	0.63	0.020
Weediness	1	0.06	0.583
Shade	1	0.12	0.444
Stand at harvest	1	14.96	<.001
Residual	133	0.2069	

Note: CV = 20.4%

Interaction between treatments and mean site yield. It is now common practice to plot treatment yields against mean site yield in what is called "modified stability analysis". This is a useful technique for examining differences in treatment effects according to environment. The technique, introduced by Yates and Cochran (1938), was first adopted in the analysis of on-farm trials by Morris (1981), and later by Hildebrand (1984).

It is advisable to carry out a test for significance of differences in slope rather than to rely only on visual inspection of the plots. The treatment x site mean term in the ANOVA tests whether there are any significant differences among the slopes. The probability level in this trial was 0.02. If one tests for interaction between site-mean and the fertilizer contrast alone (treatment 2 versus 1 and 5), the interaction is significant at the 1 percent level: the effect of fertilizer was smaller as the mean yield was lower.

Measured variables. The measured variables, weediness, shade, and stand at harvest, were entered last in the analysis of Table 2. Some of the residual variability was explained by stand at harvest, not by differences in shade or weediness between plots within sites. This is probably caused by localized attacks by rodents, termites and other pests. The ANOVA carried out in this way is actually a regression analysis with dummy variables for factors, using the generalized linear model computer package STAN (Allen and Cady 1982). Covariance analysis should perhaps be preferred, particularly when accurate estimates of the treatment effects are required (see Mutsaers and Walker 1990), but calculations become quite complex with more than one covariate.

Analysis of site means. There were large differences in mean site yields (Table 2) and, according to the previous analysis, they influenced the treatment effects. This site mean x treatment interaction, while it is interesting, does not explain how the measured site variables interact with treatments. Interactions between individual measured variables and treatments should be tested, but they are often not strong enough to show significance.

The best we can do in such cases is to look at the regression of mean site yield on the available site variables, both those measured at the site level and the average site values of those measured at the plot level. This analysis is important to identify causes of the large yield differences among farmers and, hopefully, to identify production constraints.

In regression analysis it is important to decide on the order of inclusion of the explaining variables. In our analysis a logical order of inclusion was preferred to the mechanical decision procedures commonly applied in computerized regression. The order of inclusion was as follows:-

1. Physical factors beyond the farmers' immediate control (e.g., soil fertility, shade).

2. Physical factors controlled by farmers (e.g., weediness).

3. Non-physical factors (e.g., sex, age, origin).

4. Composite factors, i.e., factors which are the sum total of a number of unidentified causes.

Table 3 shows the analysis of mean maize yields using several measured variables, arranged in the way discussed above. For those measured at the plot-level, mean site values were used. The analysis shows that maize yield was significantly affected by shade and weediness. Also, immigrant aliens on average obtained higher maize yields than local farmers, due to factors over and above shade and weediness. After taking these variables into account, an important part of the variation in yields still remains unexplained. The highly significant effect of stand at harvest shows that an important part of the remaining yield differences was mediated by differences in final stand, with initial stand having no effect. Our fortnightly stand loss counts showed that grasscutters, termites and lodging (due to as yet unidentified causes) are among the major causal agents. Their direct effect remains to be analyzed.

Table 3. Analysis of mean site yield for maize; maize + cassava trial, Ayepe, 1988

Source	DF	MS	P
Mean	1	193.14	
Shade	1	2.48	<.001
Weediness	1	3.08	<.002
Sex	1	0.002	.95
Origin	1	1.87	.014
Stand at harvest	1	12.28	<.001
Residual	33	0.2769	

As stated earlier, the improved weeding intervention did not improve yield at all (Table 1). The analysis of site mean (Table 3) shows, however, that weediness is an important yield-depressing factor. This means that our improved weeding did not address the weed problem adequately.

Representativeness of trial farmers. Measurement of farmer-related variables also provides a way to assess the representativeness of the farmers participating in a trial, provided the distribution of the same variables in the wider population is known. Smith's paper addresses this issue from a methodological point of view and examines whether the farmers in this particular trial were representative for the population at large.

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Collecting Meaningful Data on Labor Use and Farm Size for Economic Analysis Associated with On-farm Trials in sub-Saharan Africa

Dunstan S.C. Spencer

On-farm research aims at examining the effects of physical, biological, and socioeconomic factors on the performance of different farming systems as well as testing the acceptability or adoptability of new technology by farmers. Gomez (1977) distinguished these aims as technology development and technology adoption research. Researcher-managed on-farm trials play a more significant role in technology development research, while in the case of technology adoption research, farmer-managed trials become more important.

In land-abundant economies, such as those found in most of sub-Saharan Africa, labor is the most important input in farming systems and the key to development of its agricultural economies (Mellor and Johnson 1984). An accurate estimation of labor productivity is, therefore, vital in the economic assessment of existing technologies as well as the adoption of new technologies in sub-Saharan Africa. In order to make such estimates one needs accurate measures of farm size, the actual labor input (e.g., man-hours/ha), as well as accurate estimates of crop yields.

Much of the literature on the design of on-farm experiments is dominated by agronomic features relevant to the estimation and measurement of yield. Most experiments are conducted on small plots, the data from which are extrapolated to the per hectare basis. Little attention is paid to the accurate estimates of farmers' labor use and farm sizes.

If we could accurately estimate labor use/ha for small experimental plots (usually less than 100m^2), we could theoretically obtain all the information necessary for the calculation of the economic profitability of a new technology. However, there are many difficulties involved in using small plots for estimation of labor use at the farm level. This paper discusses the need for estimating labor data from a range of plot sizes, and the accuracy of different methods of estimating farm/plot size in sub-Saharan Africa.

Measuring the labor input

The literature provides very few guidelines on the acceptable plot size for measuring resource inputs such as labor. Gomez (1977), for example, only stated that preliminary work at International Rice Research Institute (IRRI), in the Philippines, had indicated that labor input should be estimated from plots that are about 800 to 1,000 m^2. This is much larger than the normal plot size of 20 to 60m^2 used for measuring agronomic data. Zandstra et al. (1981) state that "cropping patterns are tested in large plots, 1,000m^2 if possible, to allow for measurements of labor and time required". Hildebrand and Poey (1985) state that in order to evaluate changes in labor requirements it is usually necessary in on-farm trials to have larger plots than are required for strictly agronomic evaluation, although the plots need not be of the full field size.

We expect that labor use per unit area (e.g., man-hours/ha) will vary depending on the cropping pattern, the soil conditions, the operation being performed, and so on. These are factors which depend on the farmer and his management practices, and can be controlled to a certain degree in on-farm experiments which compare the farmer's existing practices with new technology. However, in measuring labor inputs in on-farm trials, two other phenomena operate which are not often taken into consideration. These are the effects of memory bias and the economics of size in farm operations.

Where labor input is not obtained directly from farm records, labor use in a given operation can only be obtained by interviewing the farmer. We rely solely on his recall of what the amount of labor had been. The accuracy of recall is thus an important factor in data collection.

Recall largely depends on the time lapse (known as the reference period), and the characteristics of the activity in question. Generally, as the length of the reference period increases, recall becomes more blurred (Zarkovich 1964). However, this depends on whether the data are of a single point, are continuous, are registered or non-registered (Lipton and Moore 1972). Table 1, from Norman and Jones (1977), presents a classification of data for economic analysis according to the concept developed by Lipton and Moore.

Table 1. Classification of data for economic analysis of a cropping system

	Inputs		Products	
	Single point	Continuous	Single point	Continuous
Registered	Inorganic fertilizer	Money for hired labor	a. Cash crop sales b. Harvest of major food and cash crops harvested at one point in time	Sale of food crops
Non-registered	Seed	a. Family labor used b. Quantity of hired labor used c. Organic fertilizer	Harvest of minor crops	a. Harvest of crops that occur in small amounts over a long period of time b. Consumption of farm produced products

Note: This breakdown is based on a concept developed by Lipton and Moore (1972). Source: Norman and Jones 1977, Table 1.

The continuum, ranging from single point to continuous data, discriminates among activities according to how often they are repeated. The continuum, ranging from registered to non-registered, refers to the extent to which circumstances influence the respondent's ability to remember the time spent on an activity. Non-registered continuous data, such as family labor use, are subject to significant memory lapses over short recall periods and, therefore, need to be collected through frequent visits and surveys.

There is still much controversy and very little empirical evidence to help one arrive at the maximum recall compatible with accurate labor-use data collection in sub-Saharan Africa. In an analysis of the comprehensive rural consumption expenditure survey, conducted in Sierra Leone in 1974/75, Lynch (1980) showed that there was no advantage in using two interviews a month, instead of one, for estimating household expenditure. This, she claimed, resulted from the telescoping of data and the conditioning of respondents. Frequent visits also seemed to affect the recall due to the likelihood of respondent fatigue. Lynch found that there were significant recall lapses between one, two, three, and four day recalls used as reference periods during each interview. Expenditure estimates from the first day of recall were statistically different from, and consistently higher than, the figures given for the other three days.

Coleman (1983) also found evidence of significant recall bias in labor-use data collected in a survey of 129 farm households in Benue State in Nigeria during 1979/80. The data indicated that the mean number of hours of agricultural work for one day of recall was significantly lower than the means for two to seven days of recall. In this instance, the direction of the recall bias was in the opposite direction, and there seems to be no logical reason why farmers should consistently overestimate labor inputs for days farther removed from the activity.

If we accept that for inputs such as labor, which are continuous and unregistered, there is a significant lapse in recall, the question that arises for the design of on-farm trials is how often to interview farmers in farmer-managed trials to accurately measure the use of labor for a particular activity. If it were possible to fix a particular event in the farmer's memory, i.e., convert the unregistered to registered data, what is the maximum reference period possible? I conducted a small experiment in 1987 in an attempt to unravel some of these issues.

The experiment was an attempt to address the question of the minimum plot size and interview frequency that are necessary to collect labor-use data in on-farm trials. The design was a modified 5 x 5 Graeco Latin Square, with five plot sizes (350, 650, 950, and 1,250m^2 and five recall periods (1, 3, 7, 14, and 28 days). Twenty-five farmers were interviewed in the Ohosu area of Bendel State and 25 in the Ayepe area of Oyo State, Nigeria. Enumerators explained the study to each collaborating farmer, stressing that we only wanted to observe them at work on their farms on a particular day. On the agreed day, the enumerator went with the farmer to his farm and marked out and pegged a pair of adjacent plots of the same size using painted pegs. Each enumerator recorded the labor operation, cropping system and hours of work of the farmer, his family and/or hired laborers, using a stop-watch. It is important to note at this stage that by visiting the farm only once, pegging out the plot and observing the farmer at work, we were in fact fixing the day and the event in the farmer's memory. However, we did not tell the farmer at that stage that we would be returning later for another interview.

Depending on the days of recall that each farmer had been assigned, the enumerator went back and interviewed the farmer to determine the amount of labor and the operations that were performed on the day of the measurement. The results from analysis of variance showed that there was no statistically significant difference between measured figures and recalled figures from one to 28 days of recall. Our preliminary conclusion was that if we can fix an operation in the memory of cooperating farmers, we can use up to monthly interviews without any significant drop in accuracy of recall. However, this conclusion was only tentative and has to be treated with extreme caution. Since we lumped all operations together in this analysis, it is possible that the variability in labor use between operations performed in different farms might have affected the variation in accuracy of recall, thus rendering the differences non-significant. We may need to examine the effect of longer recall periods as well. It is hoped that the experiment can be repeated.

Even if we can use long periods of recall, what plot sizes should we use for accurate labor data estimation? The experiment reported above showed that the accuracy of memory recall was the same for small as well as large plots. If there were no economies of size in labor-use/ha, as shown in figure 1A, then we could use the smallest plot size possible and still expect to collect accurate data. However, we know that there are economies of size in labor-use/ha, and that the distribution is more like those shown in figure 1B. Plot sizes X and Y would give the minimum and maximum labor-use/ha. Shifts along the curve from X to Y would be due to the effect of economies of size.

The effect of technological change would be to shift the labor/ha curve (e.g., from a to b). If the new technology is size-neutral, i.e., if it does not affect the slope of the curve, both the small plot size Y and the large plot X could be used to measure the relative change in labor-use brought about by the new

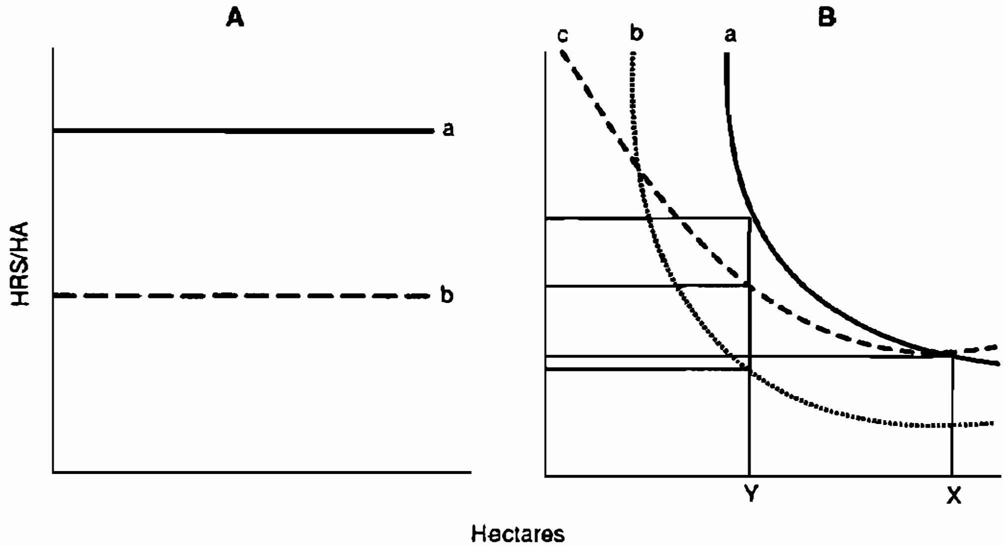

Figure 1. Effect of technological change on labor use without (b) and with (c) economies of size

technology. However, if the effect of the technology is not size-neutral and results in a new curve c, the relative effect of the technology measured by plot sizes X and Y would be different. In the latter case it would be much better to estimate the total distribution, i.e., to let farmers try the new technology over a range of plot sizes.

Collinson (1972) provides evidence of the effect of the size of plot and the rate of work which he called the scale effect. Table 2 contains data from the Niamey village studies of International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)[1], confirming that there is substantial size effect in labor-use/ha. The implication of this for the design of on-farm trials is that we could use small plots to conduct agronomic trials but in farmer-managed trials we need to use a range of plot sizes particularly to measure the labor use/ha associated with the new technology. This, of course, would not be necessary under farmers' conditions where the new technology is not expected to change the slope of the labor-use/ha curve.

Table 2. Average labor use by crop size class for planting millet in millet + cowpea intercropping system in Niger Republic, 1982 and 1983 crop seasons

Farm size (ha)	Hours/ha	SE
<2.0	27.4	4.98
2.0-3.9	15.1	3.37
4.0-5.9	14.3	2.58
6.0-7.9	14.2	4.20
8.0-9.9	11.5	4.83
10.0-9.9	11.5	0.83
>12.0	9.58	2.50

Source: Field survey

Measuring plot sizes

If the plots that farmers are to use in farmer-managed on-farm trials are marked out for them before the trials are planted, and a range of plot sizes is used, it would not be necessary to estimate plot sizes. However, if plot sizes are not marked out beforehand, either because farmers are allowed to plant whole fields with the new experiment, (a preferred approach), or because it was not possible to mark out the fields before the start of an experiment, then the actual plot or field sizes need to be measured.

Plot sizes can be obtained by asking knowledgeable individuals such as extension officers to make sight estimates, by asking farmers to report their farm or plot size, either in standard units of measures such as hectares, or in

1. The estimated equation for man-hours per hectare (Y) in sowing millet in millet+cowpea intercropping system was $Y = 2.95\ x\ {-0.32}$ (r = 0.36, t = 2.96 significant at 0.005), where X = field size in hectares.

their local units of measure, e.g., *igbas*, or the fields could be actually measured using tape and compass or similar methods.

Sight estimation, even by knowledgeable people, is notoriously inaccurate and can be discounted for all purposes. In a recent collaborative study undertaken by The World Bank, FAO, and UNICEF in 1987 in the Republic of Benin, Central African Republic, Kenya, Niger, and Zimbabwe, (Murphy 1988) a random sample of 100 cereal plots were selected in each participating area and the total harvest was estimated for each plot through three independent methods, namely;

a. total production was actually weighed at harvest time;

b. the crop cutting method was used to estimate production, and

c. farmers were asked to give their estimate of total production in their traditional units.

Estimates were obtained about one month before harvest and again shortly after harvest. The results showed that while farmer-estimates of total production before and after harvest were quite close to the actual output estimated by the harvesting of the total crop, their estimates of planted area were too systematically overestimated to be usable. Estimates based on the crop cutting method gave a systematic overestimation ranging from 15 to 40 percent with a 30 percent average. It is not clear why farmers should have been able to make such accurate estimates of their production and to have been unable to estimate the area planted.

The World Bank study provides yet another piece of supporting evidence of the inaccuracy of farmers' reported estimates of crop area when given in European units of measurement. Even where local standard units of measurement are used, the evidence is that the conversion of farmers' reported estimates to hectares leads to unacceptable levels of error. Much evidence for this exists in the literature. (See Kearl et al. 1976). More recent evidence has shown that standard conversion measures using farmers' units such as number of *igbas*/ha (Smith and Makinde 1989) or number of yam heaps/ha (Nweke et al. 1988), all lead to unacceptable estimates of farm size. Until better methods are developed, it is clear that the more expensive direct measurement methods using tape and compass, measuring wheels, triangulation, or aerial photography are the only options we have for measuring farmers' fields in Africa. However, the need to do field measurements every year, because crop boundaries continually change, makes land measurement an expensive activity. We need to continue to search for less expensive methods of direct measurement that would provide acceptable estimates. For now, however, there seems to be little alternative to the compass and tape method.

Conclusion

1. Where on-farm trials are aimed at collecting data on the physical, climatic, or biological conditions that determine the performance of particular technological innovations (e.g., variety x environment interactions), small plots could be used. In such agronomical trials we would collect all the data on the environment as well as the physical performance of the crop or system.

2. Where we need input/output data on the adoption potential of new technologies under farmers conditions, we should go to farmer-managed trials in which a range of plot sizes is utilized to collect the necessary input/ output data, particularly on labor use.

3. If by our actions we are able to get the farmer to fix an operation in his/her memory, e.g., by marking out plots and requesting farmers to remember the time they engage in particular activities, it is possible to use long recall periods for data collection.

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Measuring and Evaluating Pests of Millet in Semiarid Niger

John McIntire, Gemechu Degefa and E.W. Richardson

In the lists of ills that afflict African farming, pests are always mentioned. Pests typically include plant diseases, weeds, and insects. Mention of pests never fails to urge immediate action to reduce their impact and thereby to improve productivity and farmers' well-being.

Discussion of pests is often held without proof that they cause serious harm to farmers. Serious harm is, for the purpose of this paper, defined as an economic loss greater than the costs of control. One standard reference (Kowal and Kassam 1978) discusses pests in four important food crops (maize, millet, sorghum, rice), without citing a farm study in which serious harm occurred. A review article (Delassus 1977) admits that "the real effects of diseases on crop performance [are] often not known". Delassus' bibliography of 136 citations has fewer than 10 on the yield impacts of bacteria, fungi, or nematodes.

Mention of pests is also often made without any indication of how they can be measured on African farms. Defining how they can be measured is not easy, but a desirable measurement would satisfy at least the usual statistical properties— unbiasedness, repeatability, minimum variance for a given cost. The standard FAO handbook, in discussing sample sizes and sampling methods, concentrates largely on evidence from small grains in temperate countries (see the chapter by Richardson in Chiarappa 1981).

This paper presents evidence about pests of millet *(Pennisetum americanum)* in the semiarid tropics of Niger, collected in the 1982-1985 cropping seasons. It uses the evidence to estimate the probability of serious harm occurring, and to suggest on-farm measurement techniques. The pests studied are the fungus downy mildew *(Sclerospora graminicola)*, ear-head caterpillar *(Raghuva albipunctella)*, *Striga (Striga hermonthica)*, stemborers *(Acigona ignefusalis)*, and "chibras" (Hausa) millet, a wild relative of the cultivated plant.

Questions

1. What was the average pest incidence?
2. What was the impact of treatment, village, year on average incidence? If treatment affects incidence, then research and extension programs must consider that interaction. If village and year affect incidence, then the duration and location of surveys might need to be modified.
3. What were the costs of measuring incidence?
4. What are the best sample sizes for each pest? This question can be answered by examining the distributions with respect to an economic loss level of zero. The economic loss level is that at which the value of losses is greater than the costs of control, assuming that the costs of control are

not affected by incidence. If the economic loss level is zero— that is, if the pest should always be eliminated— then the optimal sample size would be much smaller because the probability of incurring it is greater. This question is relevant both for extension and field work.

5. If there is a positive economic loss level, what are optimal sample sizes? If the economic loss is high, then the probability of incurring it is smaller, and a larger sample size is required to identify it. If the sample size is large, then the cost of pest surveys might not justify them. This question is relevant both for extension and field work.

Materials and methods

It is necessary to consider three biases which typically occur in this work: sampling, excluded variable, and treatment. Sampling bias can happen in choosing the wrong sample size or in selectively choosing an unrepresentative sample. Lack of field data about pests makes it difficult to choose sample sizes efficiently because little is known about the underlying distributions, so sample sizes might be too small to capture extreme events. An example of selectivity bias is measuring a variable and yields at a "hot spot", and then correlating the two.

Excluded variable bias is latent in correlation analysis. If the pest variable measured is correlated with other variables, the estimate of the pest's impact is biased.

A typical station approach is to treat samples and to test for a treatment effect on yields as a means of screening for resistance. This method is unrepresentative of field attack levels, and cannot even serve to estimate representative station incidence because it uses treatments.

In the work reported here, we measured a comprehensive set of variables affecting millet production on randomly selected farms. With respect to the subset of pest variables, the choice of farms in a random sample eliminated, in principle, selectivity bias. The use of untreated plots meant that measured attacks represented field conditions and avoided treatment bias. Using multiple regression should, in principle, reduce excluded variable bias.

Data collection sites and methods

The data were collected on farms in four villages in western Niger from 1982 through 1985 (McIntire and Fussell 1989). All field operations were carried out by farmers on plots of their own choice. ICRISAT staff designed the protocols and took all technical observations, but the experiments were otherwise completely farmer-managed. Dates of crop operations, labor use, and soil type were all characteristic of the areas studied.

Experimental design

In 1982 and in 1983, the experiment was a randomized complete block with four treatments (Table 1). Treatment 1 is the local cultivar of millet, without chemical fertilizers and with a density of about 5000 pockets/ha. Treatment 2 is the local cultivar, with 30kg N/ha as urea (46-0-0), and 18kg P_2O_5 as single superphosphate (0-18-0), and a density of about 10,000 pockets. Treatment 3 is the same as treatment 2, except that an introduced millet cultivar replaces the local variety. Treatment 4 is the same as treatment 3, but with cowpea intercropped between every second row of millet.

In 1984 and 1985, the experiment was a randomized incomplete block with seven treatments (Table 1). Only the local cultivar was used. The control treatment (T1) used 30kg of N/ha as urea, so there was no control, as in 1982 and in 1983. Treatments 2 through 7 are combinations of P type (single super-phosphate [SSP] or partially accidulated phosphate rock [PAPR]) and level (12 or 24 or 36 kg/ha).

Table 1. Experimental treatments

	Treatment numbers			
	1	2	3	4
Plot size in m²				
1982	----------------------	500	----------------------	
1983	----------------------	1,000	----------------------	
1984	----------------------	250	----------------------	
1985	----------------------	250	----------------------	
Fertility, N-P				
1982	none	30-18	30-18	30-18
1983	none	30-18	30-18	30-18
1984	30-0	30-12	30-24	30-36
1985	--------------residual from 1984 trials------------			
Source of P				
1982	none	SSP*	SSP	SSP
1983	none	SSP	SSP	SSP
1984	none	SSP/PAPR	SSP/PAPR	SSP/PAPR
1985	--------------residual from 1984 trials------------			
Millet cultivar				
1982	local	local	test	test
1983	local	local	test	test
1984	local	local	local	local
1985	local	local	local	local
Recommended millet density, thousand pockets/ha				
1982	local	10,000	10,000	10,000
1983	local	10,000	10,000	10,000
1984	local	local	local	local
1985	local	local	local	local
Recommended intercrop				
1982	none	none	none	cowpea
1983	none	none	none	cowpea
1984	none	none	none	none
1985	none	none	none	cowpea

Notes: *SSP = single super-phosphate; PAPR = partially acidulated phosphate rock.

Yield plot observations

Grain and straw yield were measured in late August and early September of each year. In 1982 and in 1983, three yield plots were $30m^2$ in 1982 (18 percent of the treatment) and $50m^2$ in 1983 (15 percent of the treatment). In 1984 and in 1985, the entire plot of $250m^2$ was harvested.

Pest observations

We scored each pocket for "chibras" on a 0 to 4 scale: 1, one millet plant was chibras; 2, two millet plants were chibras; 3, three plants were chibras; 4, all plants were chibras. The variable in the analysis[1] is the average score per pocket in the three yield plots, multiplied by 100.

We scored each pocket for downy mildew on a 0 to 4 scale: 1, only axillary tillers infected; 2, less than 50 percent of main tillers infected; 3, between 50 and 99 percent of main tillers infected; 4, all tillers infected. The variable used in the analysis was the average score per pocket, multiplied by 100.

In 1982, we scored the 1kg threshing sample from each treatment for *Raghuva* damage on a 0 to 10 scale. After 1982, 10 ears from each 2kg threshing sample were chosen at random and scored with the same scale. In 1982, the variable for analysis was the total score, divided by the number of ears scored, multiplied by 100. In 1983, the variable was the total score as only 10 ears were scored. In 1984 and 1985, an average of 48 ears was scored per treatment.

To estimate stemborer incidence, a random sample of stalks was drawn from one of the three yield plots in each treatment. Field assistants split the stalks and counted total internodes, bored internodes, and larvae. The variable used was the number of bored internodes divided by the total number of internodes, multiplied by 100.[2]

We scored each pocket as 1, (*Striga* present) or 0, (*Striga* absent). The variable used in the analysis was the total score in the three yield plots divided by the number of pockets, multiplied by 100. We did not measure *Striga* intensity nor did we weight pockets by degree of attack as was done with the downy mildew and chibras scores.

Results

Crop conditions

Rainfall was generally below the expected annual amount from 1982 through 1985. Table 2 shows the expected rainfall and actual rainfall as a percentage of expected rainfall.

Crop yields were poor in all years. In 1984, which was exceptionally dry, the trials failed completely in Sadeize Koira and Samari, and did badly in Gobery and Fabidji.

1. Chibras and mildew can be measured by counting the numbers of pockets attacked (a measure of incidence and by scoring pockets by the degree of attack (a measure of intensity). The association between incidence and intensity of those variables has not yet been analyzed.

2. Analysis of the larvae counts is incomplete.

Table 2. Rainfall patterns of sites

	Sadeize Koira	Samari	Gobery	Fabidji
Expected annual rainfall, mm	500	500	600	600
Actual rainfall as percentage of expected rainfall				
1982	48	44	90	81
1983	81	67	66	72
1984	43	30	71	68
1985	47	70	71	70
1986	81	74	92	101

Incidence

Incidence was low except for chibras and stemborers (Table 3). Most observations on downy mildew and *Raghuva* were zero. The probability of a village/ year combination with 10 percent incidence was 2 in 12 for downy mildew, 3 in 12 for *Striga*, and 2 in 12 for *Raghuva*. The distributions were highly skewed. Incidence was higher and less skewed for chibras and stemborers. Probabilities of a village/year combination with 10 percent of its sample units attacked were 8 in 11 for chibras and 3 in 8 for stemborers.

Treatment effects on incidence

Estimating determinants of incidence is made difficult by variability in incidence and by changes in experimental design. High variability sometimes made statistical analysis unnecessary; in those instances, the data were plotted. A constant experimental design was not used, so it was impossible to pool the data to estimate year and village effects.[3]

The data for chibras, *Raghuva*, and stemborer were into quintiles, and a multinomial logit procedure was used to estimate determinants of quintile membership. Because of differences in data across villages and years, the estimates were made by year (Table 4). There were significant cultivar ($P<0.05$) effects on chibras and *Raghuva* in 1982, but none in 1983. There were significant village effects in all years ($P<0.05$), especially for *Raghuva* and stemborer. There was one significant fertilizer effect. While year effects could not be estimated statistically, year, via total rainfall, clearly had an effect.

The costs of measurement

The costs of pest measurement were labor, materials, and vehicle operation (Table 5). One driver, two field assistants, and one graduate technician

3. The design differed among years in response to information gained in previous experiments

Table 3. Distributions of yield loss variables, 1982-1985

	1982		1983				1984		1985			
	Sadelze Koira	Gobery	Sadelze Koira	Samari	Gobery	Fabidji	Gobery	Fabidji	Sadelze Koira	Samari	Gobery	Fabidji
Chibras score per pocket												
Valid observations	99	108	104	95	103	90	109	87	92	64	na	24
n of values <=1.0	4	2	4	4	2	1	1	0	2	0	na	0
mean	36***	38***	11***	9***	8***	10***	25***	30***	92***	55	na	24
standard deviation	27.3	30.8	10.5	6.4	5.2	7.8	18.9	24.8	79.8	25.1	na	27.6
median	34	30	8	8	7	7	20	22	84	54	na	8
Downy mildew score per pocket												
valid observations	99	108	104	95	103	90	109	87	95	64	40	48
n of values <=1.0	97	53	75	81	7	26	22	44	95	0	0	3
mean	2***	3***	0***	0***	3***	3***	7***	3***	0	0	10	12
standard deviation	14.1	7.9	0.4	0.3	2.0	3.3	7.7	4.3	0	0	5.0	11
median	1	1	0	0	2	2	5	2	0	0	10	9
Raghuva *score per head*												
valid observations	99	108	104	95	103	90	109	86	96	64	40	48
n of values <=1.0	50	10	32	52	60	6	20	20	84	63	34	17
mean	3***	17***	3***	1***	1***	5***	4***	3***	1***	0***	1***	10***
standard deviation	4.5	12.3	3.2	0.1	0.9	3.7	2.6	1.7	1.4	0.3	2.3	14.5
median	0	14	1	0	0	5	3	3	0	0	0	3
Stemborers score per stalk												
Valid observations	99	108	104	96	103	90	108	87	na	na	na	na
n of values <=1.0	0	1	0	0	0	1	1	0	na	na	na	na
mean	23***	21***	13***	12***	25***	23***	28***	18***	na	na	na	na
standard deviation	11.7	9.7	4.2	5.8	8.8	11.3	16.7	4.5	na	na	na	na
median	22	21	13	12	25	21	25	17	na	na	na	na
Striga score per pocket												
valid observations	99	108	104	95	103	90	109	87	96	64	40	48
n of values <=1.0	83	97	72	52	81	37	101	72	0	28	36	20
mean	1***	1***	2***	12***	2***	10***	0.3***	0***	1	11	0***	4***
standard deviation	2.9	2.8	5.1	2.0	9.6	15.2	1.1	1.9	0	10.3	0.5	9.8
median	0	0	0	0	0	3	0	0	0	15	0	2

Notes: na means not available *** indicates the skewness was significant at P< 0.01

Table 4. Determinants of incidence

	Maximum likelihood parameter estimates					
Source	DF	Chi Sq	DF	Chi Sq	DF	Chi Sq
1982						
Intercept	4	23.09***	2	7.56**	3	33.86***
Village	4	4.06	2	24.26***	3	0.45
Cultivar	4	10.21**	2	7.78**	3	2.07
Fertilizer	4	2.31	2	3.94	3	0.27
Likelihood ratio	8	25.92***	4	9.65**	6	9.89
1983						
Intercept	2	94.75***	2	19.79***	4	44.13***
Village	6	10.38	6	91.07***	12	105.20***
Cultivar	2	3.40	2	2.07	4	4.75
Fertilizer	2	2.36	2	6.61**	4	4.73
Likelihood ratio	12	8.74	16	6.49	24	8.76
1984						
Intercept	4	64.02***	2	75.39***	3	14.30***
Village	4	4.38	2	6.14**	3	8.27**
Quantity of P	12	15.09	6	12.97**	9	11.65
Type of P	2	0.13	3	1.38		
Likelihood ratio	12	7.08	16	11.45	24	16.20
1985						
Intercept	4	3.31	2	45.67***		
Village	8	32.20***	6	31.51***		
Quantity of P	12	18.68*	6	5.87		
Type of P	2	1.90				
Likelihood ratio	24	21.83	40	25.17		

provided field labor, for which they received their normal salaries plus overtime in view of the speed with which the work had to be done. International and local professional time were also counted. Material costs were such things as bags, knives, scales, and paper. Vehicle costs were the variable costs of a four-wheel drive vehicle. Capital costs such as houses, vehicles, and computers were excluded because they were fixed costs unaffected by the pest survey.

Additional labor costs had to be calculated for stemborer and *Raghuva*. For stemborer, on the assumption that 20 stalks were scored per treatment, the time to split and count 20 stalks was 2 hours. An enumerator could score four treatments in a day, and a sample of 30 farmers and four treatments per farmer would take 30 days. Assuming 22 days per month at $200 per month of enumerator cost, the incremental cost to count stemborer in addition to the costs of harvesting the yield plots was approximately $275.

Table 5. Survey costs in Niger 1983

Cost items	$17,368
Capital	$122,363
Variable	$139,731
Survey units	
Households	107
Area	1328
Population	1132
Annual working days	261
Total cost	
Cost/household	$1,306
Cost/ha	$105
Cost/person	$123
Cost/working day	$536
Variable cost	
Variable cost/household	$1,144
Variable cost/ha	$92
Variable cost/person	$108
Variable cost/working day	$469

Source: McIntire 1984
Note: In 1983, $1 was roughly equal to 350 CFA francs

For *Raghuva*, approximately 200 heads could be scored in a day. An enumerator could score 20 treatments in a day, i.e., 20 treatments of 10 heads each. A sample of 30 farmers and 4 treatments per farmer would take 6 days. Assuming 22 days per month at $200 per month of enumerator cost means that the incremental cost to count *Raghuva* in addition to the costs of harvesting the yield plot was approximately $55.

It took roughly five days to harvest the yield plots in a village. With 25 households per village, and four treatments per household, this gives five treatments per man/day. At that rate, the total variable cost of a sample of 100 plots, each 100 m^2, was the sum of the items in the last row of Table 6. It was about $2050 in 1983 dollars. While that figure did not include costs to enter, clean, and analyze data, it does show that sampling costs alone were small.

Yield impacts of the pests

Yield impacts were estimated with regression analysis (McIntire 1989). The strongest results from the 1982 and 1983 estimations are summarized in Table 7. The values given in Table 7 are the marginal yield impacts (in kg of millet grain/ha) of a 1 unit change in the pest variable. Most of the estimated pest coefficients were not statistically different from zero.[4]

Economic impact was calculated for each plot. This was done by multiplying each plot's observed score on a variable by the regression

4. The regression analysis showed no significant coefficients for downy mildew. It also showed no significant interactions between any pest variables and added fertility, or introduced cultivars.

coefficient for the specified year and village. The product is the plot-specific yield effect of the variable. If the coefficient was not significantly different from zero, then the economic impact was set to zero. The plot-specific yield effect was multiplied by the 1983 millet grain price to give a plot-specific economic loss.[5]

Table 6. Sample units measured in 1983

	Chibras, *Striga*, and downy mildew	*Raghuva* Incremental)	Stemborer
Sample units measured			
Number of farms	107	107	107
Number of plots	428	428	428
Number of yield plots	1,284	1,284	428
Area, hectares	6.42	6.42	2.14
Heads	na	4,280	na
Stalks	na	na	8,560
Time to measure, days			
Specified area	21	na	na
Specified heads	na	21	na
Specified stalks	na	na	107
Summary of variable costs			
Variable cost/working day	$469	$9	$9
Total variable costs	$10,042	$197	$985
Variable cost/yield plot	$8	$0	$2
Variable cost/hectare	$1,564	$31	$460
Total variable cost/hectare	$2,055		

Note: In 1983, $1 was roughly equal to 350 CFA francs.

Frequency distributions of the plot-specific economic losses were produced (Figs. 1 and 2). The distributions of losses were positively skewed, with many zeroes. Roughly 60 percent of the distribution had no loss, another 35 percent lost between 0 and 15,000 CFA francs/ha, and the last 5 percent lost between 15,000 and 60,000 francs/ha. Chibras accounted for the greatest share of losses.

Sampling strategies

A sampling strategy is often designed to detect differences between samples so as to make inferences about populations. An efficient strategy usually depends on four things: the inherent variability in the population sampled; the size of the difference to be detected; the confidence level at which inferences are to be made; and the cost of sampling.

5. Losses attributed to straw yield effects are ignored.

Table 7. Estimated yield impacts of the pests, 1982 and 1983

	Regression coefficients			
	Sadeize Koira	Samari	Gobery	Fabidji
Chibras				
1982			2.09	
1983				6.94
Raghuva				
1982			1.759	
1983				
Striga				
1982				
1983		5.53		
Stemborer				
1982				
1983				2.552

Note: No significant estimates were obtained for downy mildew. Otherwise, blanks indicate no estimate significant from zero ($P<0.05$)

The design of a sampling strategy for these pests has a slightly different purpose. It is to find a sample size which is efficient in that it maximizes the probability of finding a target value for given sampling costs. Here we estimate the probability of observing a mean incidence at a specified sample size. This is done by:

a. defining a target value for each pest;

b. simulating the distributions of the pests for different sample sizes;

c. plotting the distributions; and

d. calculating the costs of each sample size.

Target values

The target value is usually defined by the cost of control (Walters et al. 1986). Because the costs of control are unknown, arbitrary targets were chosen between 1 and 20 percent incidence.

Simulating different sample sizes

A simulation technique (Walters et al. 1986) generated frequency distributions of the pest indicators. First, we pooled all valid observations of the five variables across the four years and four villages. Then we drew 300 repeated random samples of specified sizes—20, 30, 50, and 100—for each variable from the pooled data.[6] In sum, there were five variables, four sample sizes,

6. The indices were all standardized on a one acre ($100m^2$) basis. One acre is easy to mark in the field, corresponds to a 1 x 1 crop spacing, and simplifies conversion to percentages and to hectare equivalents.

and 300 samples of each variable/size combination, making 6,000 simulated samples.

For each group of 300 samples, we calculated the mean, the standard deviation, the minimum, and the maximum, and plotted a histogram. This

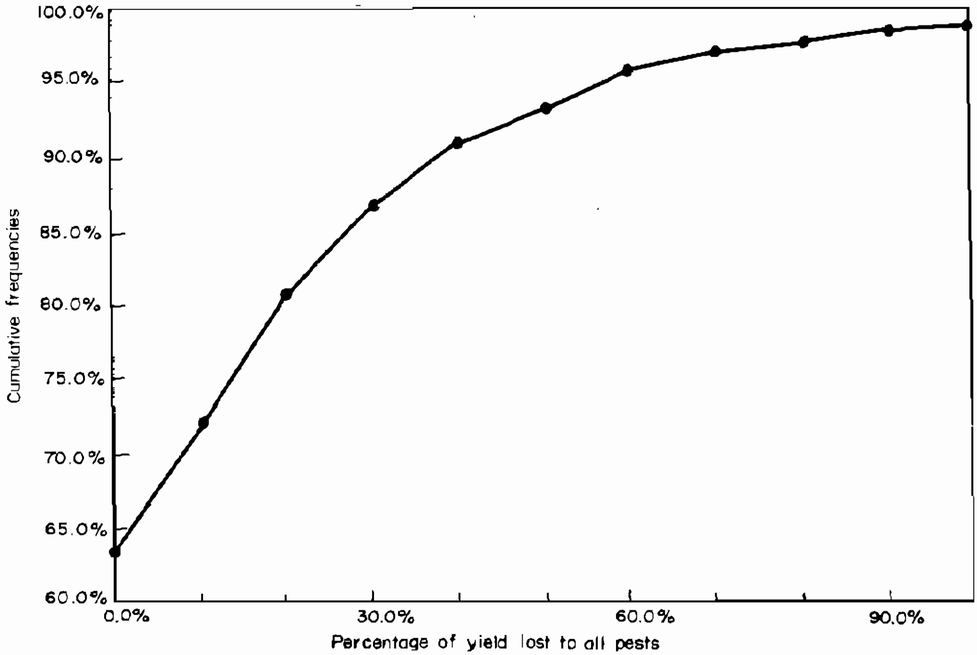

Figure 1. Frequencies of relative losses to pests, 1982 and 1983

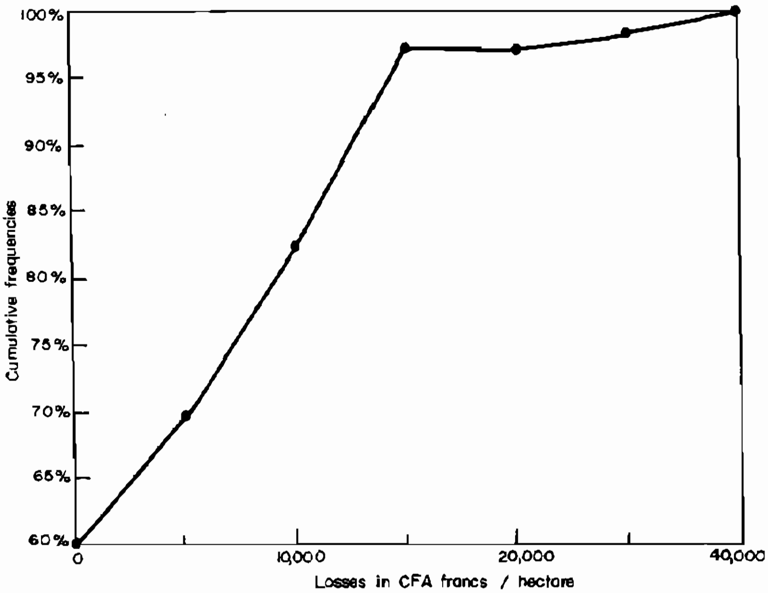

Figure 2. Cumulative frequencies of losses to pests, 1982 and 1983

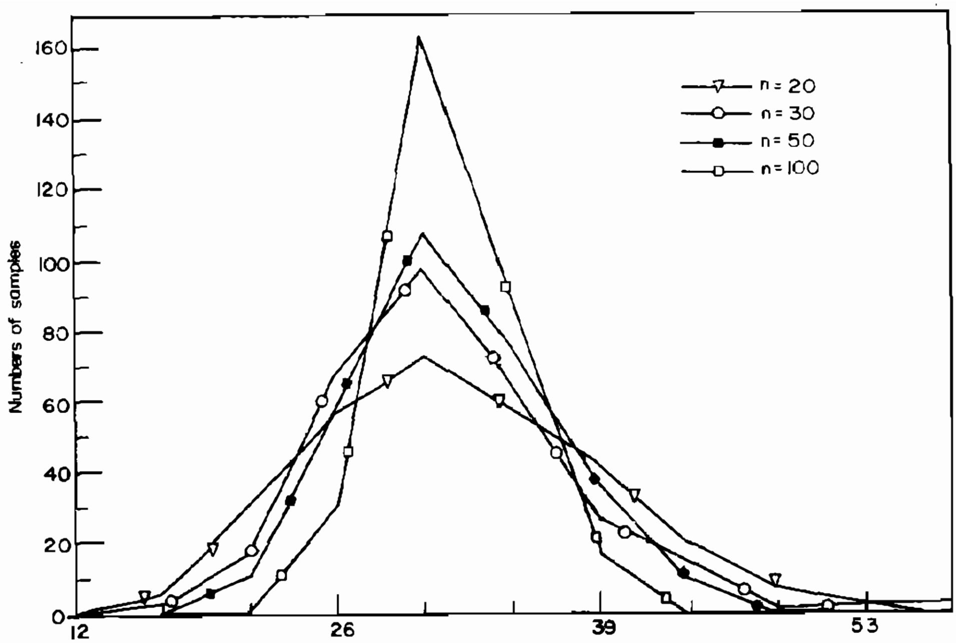

Figure 3. Chibras means

generated 20 means, 20 standard deviations, and 20 histograms. The 20 histograms were reduced to five by plotting the distributions of the four sample sizes for a given variable on one page.

Plotting the simulated distributions

Figures 3-7 illustrate the distributions of each pest by sample size. What is of interest to sampling strategists is the probability of detecting a larger mean for a larger sample size. This would appear as a rightward shift of the distribution with a larger sample. Such a rightward shift is seen in the mildew (Fig. 4) and *Striga* (Fig. 7) distributions, but not in the chibras (Fig. 3) or stemborer (Fig. 6) distributions, and perhaps in the *Raghuva* distributions (Fig. 5).

The sampling effects in the simulated mildew and *Striga* distributions are caused by their low means (Table 8). Because those distributions are like chi-square distributions with many zeroes, larger samples are necessary to detect higher mean incidence. The simulated distributions of chibras and stemborer are more normal, and a sample size effect was not found.

Sampling costs

Sampling costs are as shown in the section on the cost of measurement. The approximate variable cost of sampling a hectare for the five pests was $2050, in 1983 dollars (Table 6).

Discussion

In general, there are two types of pest surveys: surveys to estimate critical levels to recommend control measures (control surveys); and surveys to determine research priorities (research surveys).

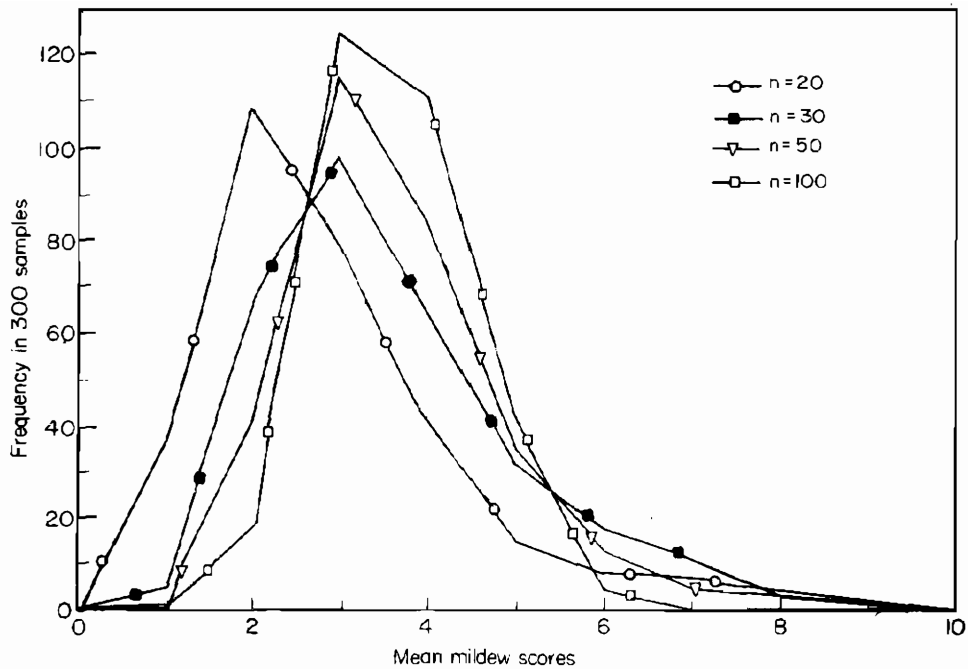

Figure 4. Mildew means

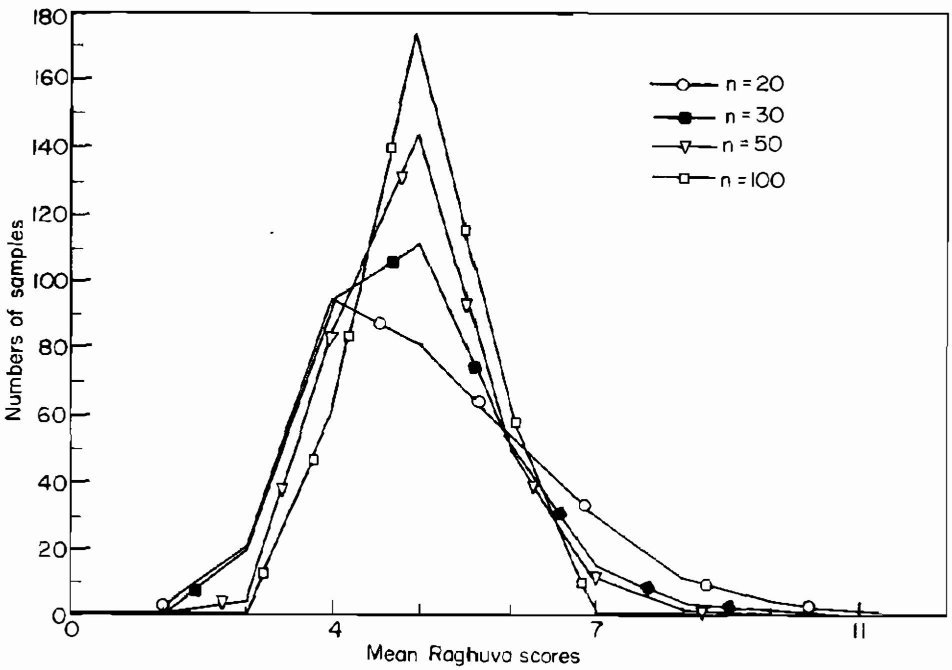

Figure 5. *Raghuva* means

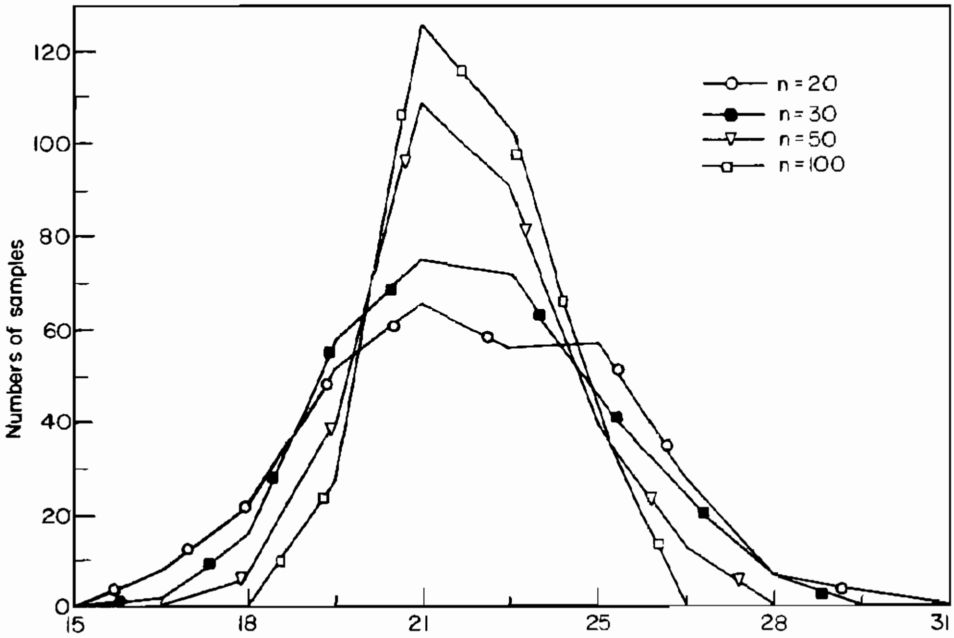

Figure 6. Stemborer means

The incidence results and the low yield impact of these pests suggest that control surveys would not be profitable for mildew, *Striga*, and *Raghuva*, and perhaps stemborer. For mildew, *Striga*, and *Raghuva*, incidence was usually quite low; incidence of stemborer was greater, but its yield effect was weak and usually not statistically significant. Control surveys of chibras would be profitable, in principle, because losses to chibras are high. The main control techniques, however, are plant breeding and seed cleaning, which do not require control surveys.

The audience is crucial in research surveys. To simplify, audiences are of two types: national programs with little money, and international programs with some money. Several arguments can be made against research surveys in national programs.

The distributions vary across year and site. Estimating national parameters would impose a major effort for several years. In a single year, taking 100 samples of 20 one-acre plots would cost $41,000, without data analysis costs, and would cover less than 0.001 percent of Niger's millet-growing area.

The yield impact of the pests was usually zero and was low on average. The payoff to reducing incidence would also be low.

One reason for low yield impact is the use of local cultivars, or of test cultivars derived from local parents, in which pest tolerance or resistance is better than in exotic cultivars. If one assumes that evaluation of exotic cultivars is the role of international programs and not that of national programs, research pest surveys are better done in international programs.

How should research surveys be done by international programs?

Many small samples are preferable for pests known to occur generally, such as chibras and stemborer. Sample size did not really affect mean incidence, but year and village did. For pests which occur generally, survey resources would, therefore, be used more efficiently in more sites, with fewer observations per site.

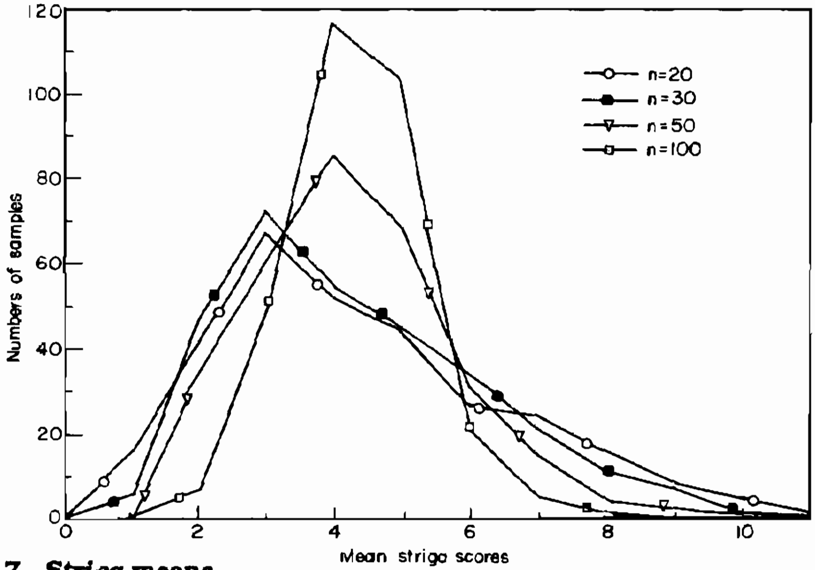

Figure 7. ***Striga*** **means**

Table 8. Probabilities of exceeding target incidence (1, 5, 10 or 20)

	1	5	10	20
Chibras				
n=20	100	100	100	92
n=30	100	100	100	96
n=50	100	100	100	98
n=100	100	100	100	100
Mildew				
n=20	87	6	0	0
n=30	98	11	0	0
n=50	100	7	0	0
n=100	100	2	0	0
Raghuva				
n=20	99	34	0	0
n=30	100	24	0	0
n=50	100	22	0	0
n=100	100	21	0	0
Striga				
n=20	95	26	2	0
n=30	98	25	0	0
n=50	100	17	0	0
n=100	100	9	0	0
Stemborer				
n=20	100	100	100	73
n=30	100	100	100	75
n=50	100	100	100	84
n=100	100	100	100	91

Fewer large samples are preferable for pests which occur in isolated hot spots, such as mildew, *Raghuva*, and *Striga*. Only in such spots could the true yield impact of these pests be estimated. A general survey would simply produce many samples with no or light incidence, in which yield impact would be trivial.

Such surveys must be done continuously. While our statistical evidence on year effects was weak, it is obvious that they exist.

The low yield impact of these pests means that surveys ought not to be a major part of the work of internationally-recruited scientists. Such scientists are, by far, the most expensive element in research, and should not be allocated to something which has a low expected return.

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Methodological and Analytical Issues in On-Farm Alley Farming Research

J. Cobbina and A.N. Atta-Krah

In this paper we introduce alley farming as an example of a composite technology, and we discuss the objectives and methodology for the conduct of on-farm research on the system. We also look at the usefulness of on-farm trials in problem identification for on-station research designed to fine-tune the technology. Finally we present conclusions on methodologies for on-farm alley farming research.

The alley farming technology

Alley farming is an agroforestry system in which arable crops are grown in 4-5m alleys between rows of frequently pruned leguminous trees (Kang et al. 1981; Wilson and Kang 1981). The nitrogen-rich foliage can be applied as green manure for the maintenance of soil fertility, or can be fed to livestock as a high-protein feed supplement (Sumberg 1985; Atta-Krah et al. 1986). The two tree species commonly used in alley farming in West Africa are leucaena *(Leucaena leucocephala* [Lam] de Wit) and gliricidia *(Gliricidia sepium* [Jacq] Steud).

Alley farming is a multiple-component technology in that it involves a number of farm enterprises. These include the planting and management of trees, the planting and cultivation of arable crops, the management of land to maintain soil fertility and productivity, and cut-and-carry management of trees to provide fodder for livestock.

In the humid areas of West Africa the dominant ruminant livestock species are sheep and goats. These animals are kept as a secondary farm activity, and provide roughly 5-10 percent of the total farm income. It was hypothesized early in the work of the Humid Zone Program of the Inter-national Livestock Centre for Africa (ILCA) that reduced mortalities following better disease control and improvement in management would invariably lead to a shortage in animal feed. After about three years of on-station research, ILCA embarked on a pilot on-farm research and extension project with a view to fine-tuning the alley farming technology to facilitate low-cost feed production, and also provide material to improve and maintain high soil fertility status. This project was a collaborative on-farm research activity between ILCA and the Nigerian Livestock Projects Unit (NLPU).

The methodological and analytical issues discussed in this paper evolved from this on-farm activity. The research sites were two adjacent villages, Owu-Ile and Iwo-Ate, which are about 20km northeast of Oyo, in Oyo State, Nigeria.

Methodology for on-farm research on alley farming

Two kinds of information can be obtained from on-farm trials on any specific agricultural technology. These have been described as type-1 and type-2 information. With composite technology such as alley farming, two different types of experiments are required to collect the two types of data. Atta-Krah and Francis (1987) have described these two types as developmental and experimental. These are described below.

Developmental trials

These trials provide type-2 information on the workability, relevance, and acceptability of the technology to the farmers in a particular recommendation domain. In conducting developmental trials, there is a need to ensure that farmers are in absolute control of the management and utilization of the technology. This is achieved gradually, starting with a few farmers, and with a high level of research assistance. With time, more farmers are introduced and correspondingly reseacher involvement in the management of the trials is also decreased. Farmers are made to see the farms as their own and are free to make modifications in their management. The final stage of this developmental phase is when a pilot project is implemented at the community level to test the acceptability of the technology. Extension involvement is critical in this phase.

During the execution of developmental trials, an experienced technician should visit all farms every two weeks. During these visits, the technician should collect data on the condition of the trees, the various types of food crops planted, activities carried out by the farmer since the last visit, the general condition of the farm, the incidence of the use of tree prunings either as manure/mulch or as cut-and-carry feed for livestock, and farmer perceptions of the system.

The establishment, growth and performance of the trees in various farms is evaluated periodically, for example, every six months, by a team of researchers. During such evaluations a scoring scheme is used to rate the performance of the trees in various farms. The scores will range from 1 (poor) to 4 (excellent). The scoring could be done by three or four persons and a mean score calculated later. The data collected during these evaluation missions are analyzed using simple descriptive statistics. Correlations are then established between the regular descriptive information collected during the fortnightly visits and the evaluation scores.

In the ILCA on-farm alley farming pilot project area, marked differences exist among communities in the quality of alley farms. Table 1 shows the number of alley farms under each of four ratings in six villages in the pilot project area in 1987. The survival of trees, and hence successful establishment of alley farms, are determined by the level of management. The two tree species, leucaena and gliricidia, have low growth rates early in the growth cycles and are easily suppressed by fast-growing weeds. Regular weeding in the early stages of tree establishment is essential. Table 2 gives the mean evaluation score of farms against number of weedings carried out on the various farms.

Although maize is usually the arable crop planted on-station in alley farm experiments, on farmers' fields, a large variety of other crops is found. The most commonly planted crops in farmers' alley farms in the ILCA pilot project area are yam, cassava, maize, and combinations of these. In an evaluation conducted in 1987, out of a total of 116 alley farmers, 53 (45 percent) had planted only cassava, since as a major staple the crop is found to dominate many farms. This is a demonstration of the flexibility and adaptability of the alley farming technology.

Table 1. **Number of alley farms under each of four ratings in different villages in 1987**

Village	Farm rating				Total in villages
	Poor	Fair	Good	Excellent	
Owu-Ile	11	9	8	4	32
Iwo-Ate	12	16	7	10	45
Alebiosu	4	1	2	-	7
Olori	3	5	5	3	16
Aba-Oku	3	2	3	2	10
Emi-Abata	2	2	2	-	6
Total	35	35	27	19	116

Table 2. **Mean evaluation scores against number of weedings**

Number of weedings observed	Owu-Ile		Iwo-Ate	
	Number of farms	Mean score	Number of farms	Mean score
1	5	2.2	0	—
2	6	2.0	3	2.0
3	9	2.6	11	2.3
4	11	2.8	6	2.9
5	2	3.4	8	3.6
Total	33	2.5	28	2.8

Experimental trials

Once an agricultural technology has been defined, developed and tested through developmental trials, a more technical approach is needed to get data on production and other coefficients under farmer conditions. Experimental on-farm trials provide this type of information about technical and biological coefficients on the system. In these trials, experimental treatments are superimposed on farms established under farmer conditions. Standard research methods are used, such as those described by Hildebrand and Poey (1985) but the design should be simple and flexible. In order not to confuse farmers, a few treatments must be tested on any occasion. At ILCA we have used two or three treatments in any one trial. The treatments are usually not replicated. The various farms then become the replications.

At the ILCA on-farm alley farming pilot project sites, a number of experimental trials have been undertaken to gather information on technical and biological coefficients. Labor requirements for planting seeds of leucaena and gliricidia, using family labor, have been measured. Table 3 presents sizes of various farms, and time expended to plant seeds per-farm and per-hectare. In general, it takes about 15 hours to plant a hectare of land with leucaena and gliricidia in alternate rows spaced 4-5m apart.

Table 3. Time taken to plant leucaena and gliricidia direct from seeds in alley farm using farm labor

Farm number	Farm size (ha)	Time/farm (hours)	Time/ha (hours)
1	0.088	1.60	18.18
2	0.156	1.60	9.18
3	0.058	1.10	18.97
4	0.128	2.22	17.34
5	0.234	3.17	13.55
Mean	0.133	1.92	15.57
SE	0.068	0.80	3.83

Tree growth and productivity, as represented by height and dry-matter yield per unit land area, have been measured. Often, depending on the farm size, a 5m or 10m single tree-row plot is used to estimate height growth and wood and leaf dry-matter yields. These trials were basically researcher-managed, replicated twice on each farm. Data collected were analyzed as completely randomized designs using analysis-of-variance procedures, with the various farms as replications. Data collected on height-growth indicated that at 12 months after planting, leucaena is always taller than gliricidia. The leaf and leaf-plus-wood dry-matter yields/ha are presented in Table 4. Generally, leucaena is a more vigorous and productive tree species than gliricidia.

The soil chemical characteristics of individual alley farms have also been described. Since ILCA recommends alternate rows of leucaena and gliricidia on every farm, two 5m x 4m sampling plots (one grown with leucaena and the other with gliricidia) are selected. A tree hedgerow of 5m length runs through the centre of the sampling plot. Composite surface soil (0-15cm) samples are taken from each farm and analyzed. Data collected revealed large variability in soil chemical properties of farmers' alley farms with nitrogen and phosphorus being generally low.

Experimental on-farm trials have been conducted to obtain information on the quantity and frequency with which leucaena and gliricidia from alley farms are offered to village small ruminants. Households were selected and daily visits were made to each of them. The weight was recorded of fresh browse on offer, and that of left-overs from the browse offered the previous day. The number of animals of each household was also noted to allow calculation of mean quantity/animal. Table 5 gives the frequency of feeding leucaena and gliricidia to animals, and the quantity consumed. There is wide variability in these parameters. The mean length of browse coppice was only 0.77m, suggesting that even when browse is offered only 8.8 days per month, the trees are still being pruned prematurely. The recommendation is that coppice

Table 4. Leaf and wood dry-matter yield of leucaena and gliricidia in alley farms at 12 months after planting

Farm No.	Leucaena Leaf and wood	Leucaena Leaf only	Gliricidia Leaf and wood	Gliricidia Leaf only
1	6.3	3.3	2.0	1.0
2	2.8	1.5	2.8	1.5
3	5.4	2.4	1.6	0.8
4	4.8	1.8	3.3	1.6
5	3.8	1.8	2.4	1.2
6	2.4	1.2	3.0	1.4
7	3.2	1.6	1.5	1.0
Mean	4.1	1.9	2.4	1.2
SE	1.4	0.7	0.7	0.3

Table 5. Leucaena and gliricidia browse from alley farms offered to village small ruminants

Farm No.	Number of animals	Length of browse (cm)	Frequency offered browse (days/month)	Browse consumed (gDM/animal/feeding)
1	2	72	8.3	246
2	4	70	8.8	147
3	6	79	7.5	94
4	5	86	13.8	180
5	26	71	10.5	33
6	8	83	3.7	69
Mean	8.5	77	8.8	128
SE	8.8	6.8	3.3	78.2

regrowth should reach 1.5m in length before pruning. This length is attained in 6-8 weeks during the rainy season and in 10-12 weeks during the dry season.

Since improved agricultural technologies are disseminated to farmers within the recommendation domain through extension agents, it is advisable that extension personnel be involved in the on-farm testing. For a composite technology, such as alley farming, extension agents should be involved in the conduct of the developmental as well as the experimental trials. In this manner extension personnel will become knowledgeable about the characteristics of the improved technology, become aware of farmers' responses to it, and have some investment in disseminating it (Sands 1985, Winkelmann 1984).

Links between on-farm and on-station research

On-farm research methodology, outlined above, provides the focus for on-station research work and increases its relevance to farmers' needs. Farmers' observations and evaluations of the technology gleaned through developmental trials are carried back to the research station. This helps the formulation of more realistic and relevant research priorities to fine-tune the technology to farmers' needs and circumstances. Input on relevant problem areas and constraints from experimental trials is incorporated in the objectives and design of on-station research to make the technology workable.

ILCA has learnt a lot about the establishment and management of leguminous multipurpose trees under diverse environments, and their suitability to farmers with varying resources, through the on-farm testing of alley farming technology. For instance, on-station research designed on the basis of results from on-farm trials has revealed that low P status of soils restricts nodulation and N acquisition through symbiotic N-fixation by leucaena. In soils with low available N, initial growth is hampered. Trees show stunted height-growth and chlorosis in leaves. Therefore, ILCA now recommends the application of fertilizer P about the time of planting leucaena to enhance rapid growth and nodulation early in the growth cycle.

Another on-station trial is designed to test the hypothesis that the most essential mulch application is that from the first pruning just prior to planting the maize crop. Preliminary results indicate that within leucaena alleys, with no fertilizer application, preplanting prunings applied as mulch increased maize yield by 35 percent over zero mulch. When additional foliage from subsequent prunings was utilized as mulch, there were no significant increases in maize yields. These results suggest that subsequent prunings could be fed to livestock without sacrificing maize yields. Yet another study is evaluating the effect of providing mixed leucaena and gliricidia fodder as protein supplements at strategic periods in the productive cycle, since at the village level, farmers often lack continuous sufficient quantities of browse. Preliminary results indicate higher survival rates to weaning of offspring from females who had received such supplements.

Conclusions

It has been emphasized that for a multiple component technology such as alley farming, farmers should be involved in the on-farm testing. Type-2 data which provide information on workability and relevance to farmers are important in the development and evaluation of the technology. Therefore, we recommend that the development of a composite technology should involve on-farm assessment by farmers at an early stage through the developmental on-farm research process. On-farm experimental trials designed to define technical and production parameters of the system under farmer conditions should be implemented thereafter. Extension agents should be involved in the on-farm testing from its earliest stages. If there is effective collaboration, by the time recommendations have been worked out, extension should already be aware of the characteristics of the technology.

A number of on-station experiments have been designed, based on experience from developmental and experimental on-farm trials. The findings should, in due course, enable us to refine and fashion alley farming technology to suit its ultimate clients, i.e., smallholder arable crop farmers who also rear sheep and goats as minor enterprises.

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Representativeness of Farmers and Sites in On-Farm Trials

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In the Farming Systems approach to technology development, trials are carried out on a limited number of farmers' fields. Results of these trials are extrapolated to the entire target area and used either to identify directions for further research or to develop recommendations for farmers. Extrapolation is obviously not valid if farmers and fields are not representative of the target area. In practice, however, it is difficult to select a sample of farmers according to predetermined criteria. Researchers are constrained by farmers' misgivings about the efficacy of the technologies being tested. As a result, trials are carried out on fields of farmers who volunteer or are persuaded to participate. This paper examines the type of bias that is likely to occur in this situation and reasons for its occurrence. This is illustrated with data from on-farm trials in southwest Nigeria. The interpretation of data in situations where bias exists is discussed, and procedures which may reduce bias in future trials are presented.

Aspects of representativeness

The representativeness of three factors—farmers, fields, and management practices—is examined. Representativeness of fields is important for biophysical reasons such as soil fertility and topography. Representativeness of farmers is required because socioeconomic factors, such as access to cash, labor, and size of farm, may affect the feasibility and attractiveness of new technologies. Management practices need to reflect normal practice if new technologies are to be properly evaluated.

Two propositions are put forward. Firstly, the relative importance of the representativeness of each of the three criteria discussed above depends on the objective of the trial, and the degree of farmer participation in the trial. Secondly, the representativeness of farmers need not necessarily result in representativeness of fields or management practices.

Types of trials and the importance of representativeness

Trials are usually carried out with one of the following objectives, diagnosis of constraints to increased productivity, development of recommendations for farmers.

Representativeness is important in diagnostic trials, because the results are used to guide the direction of future on-station and on-farm research. Unrepresentativeness could, therefore, result in future research being focused on constraints which are applicable to only a minority of farmers in the target area. If diagnosis correctly reflects constraints important to the majority of farmers, and trials have moved to the stage where precise recommendations are being developed, lack of representativeness is less serious. This is because recommendations are, at best, rough guidelines which farmers adapt to their individual biophysical and socioeconomic circumstances, which in any case vary from year to year. Also if recommendations have been mistakenly based on trials from an unrepresentative sample, the cost of repeating the trials on a more representative sample is lower than undoing the consequences of diagnosis based on an unrepresentative sample, which may distort the focus of the research program.

Even for diagnostic trials, the relative importance of the different elements of representativeness depends on the degree of farmer participation. In researcher-managed trials, representativeness of fields is important. Representativeness of farmers and management practices is irrelevant since trials are designed, implemented and usually evaluated by researchers.

Representativeness of farmers and management practices become important in farmer-managed trials, where trials are implemented by farmers. Management of test factors is specified and sometimes implemented by researchers. All other practices are left to the discretion of the farmers. Evaluation of results usually takes the farmers' views into consideration. In this case, representativeness of all three factors— fields, farmers and management practices— becomes important if results are to be extrapolated to the rest of the target area.

Pleas for an even higher degree of farmer participation are now being heard (Ashby 1985). Trials which are designed as well as managed by farmers are being advocated. Farmers' criteria play a key role in the evaluation of results in this approach. The importance of representativeness is more complex in this case. While involvement of representative farmers and fields is as important as in farmer-managed trials, if results are to be extrapolated and used to guide research priorities, the methodology works best with farmers who are innovative and habitually carry out informal experiments on their own initiative. How common this practice is and, therefore, how feasible it is to have a representative sample, are issues which require further investigation.

In summary, representativeness is more important for diagnostic trials than for trials designed to develop specific recommendations. Representativeness of fields is required in researcher-managed trials. In trials where farmers are involved in design and/or implementation, representativeness of farmers and management practices is also important if results are to be extrapolated to the rest of the target area.

Causes of unrepresentativeness

The normal practice in Farming Systems Research is to carry out an informal survey of the target area, consisting of discussions with farmers and key informants, and visits to fields. This is used to select a representative site where farmer-managed trials are carried out on fields of volunteers. Unrepresentativeness occurs because farmers who volunteer or are persuaded to participate, may not have the sociocultural attributes such as gender and ethnic origin representative of the area. In fact the volunteers are often more similar to the researchers than to the farmers of the area.

Representativeness of trial participants can be increased by selecting a stratified sample of farmers, instead of volunteers. A formal survey is carried out prior to the trial to obtain data on the proportion of farmers of the key sociocultural, economic, and other characteristics. Gender differences are also included. This is used to select a sampling scheme for trial participants. Alternatively, if volunteers are to be used, representativeness can be increased by ensuring that researchers solicit volunteers who are as similar as possible to the farmer population. Factors such as gender and ethnic background may be particularly important. Special efforts can also be made to recruit farmers from categories likely to be underrepresented in a group of volunteers, due to the ethnic or gender characteristics of the team of researchers. A formal survey can be carried out concurrently with the trial to test for the representativeness of trial participants, and analysis and interpretation of results modified to accommodate unrepresentativeness, if it exists.

Fields will not necessarily be representative even if the sample of farmers is representative. Since the outcome of the trials is unknown, farmers are most often unlikely to risk their most productive fields. This effect increases with the size of the plot required for experimental purposes, and is strongest in the early stages of on-farm experimentation, when farmers have yet to witness any notable improvements over current practice.

Although management practices are a result of field and farmer characteristics, a sample of representative farmers and fields need not ensure representative management practices on the experimental plots. Farmers are likely to neglect trial plots particularly when plot sizes are small. Even where experimental plots comprise a substantial portion of the farmers' holdings, the farmers may choose to favor plots that are not involved in the experiment, since the experiment may in his or her view be more risky than normal practice. On the other hand, the demonstration effect may prevail. Advanced management practices being tested by researchers may be imitated by farmers on control plots, even when they deviate from normal practice. This is most likely to happen when implementation of the management practices being tested requires additional use of resources that are relatively abundant. In a similar vein, Ashby (1985) has shown that farmers tend to deviate from normal practice in control plots in cases where recommendations are significantly different from practices normally followed by farmers. These effects can be reduced by having experimental plots which are large, relative to the farmers' total holding. This may make it more difficult for farmers to deviate from normal practice. Unrepresentativeness of fields and management practices may also decrease in farmer-designed trials (Ashby 1985). This would occur because farmers would be involved in choosing the treatments to be tested, and should, therefore, be interested in the outcome. If the experimental procedure is adequately explained to them, they may appreciate the importance of representative fields and management practices.

In summary, the representativeness of farmers can be increased if researchers who solicit volunteers are more closely matched with the farmers' backgrounds. The representativeness of farmers does not, however, guarantee the representativeness of fields and management, practices. This can be improved by involving farmers more fully in the design, management, and evaluation of trials.

An example from a trial in southwest Nigeria

This was a farmer-managed trial carried out in 1988 in Ayepe, a village in the forest fringe cocoa belt of southwest Nigeria. The trial tested the effect of fertilizer, earlier weeding, and increased planting density on intercropped maize + cassava fields. The purpose of the trial was diagnostic, i.e., to identify promising areas requiring further on-station or on-farm research. It was important, therefore, to ensure representativeness of fields, farmers, and management practices. Further details of trial design, analyses and results are given in Mutsaers' paper in this volume.

An informal survey had been carried out in Ayepe in 1985. On-farm farmer-managed trials had been held every year, 1986-1988. Group discussions with farmers had been held every year to elicit farmers' assessment of the previous season's trials, their suggestions, and reaction to proposed future trials. In 1988, a detailed multiple visit survey on farmer characteristics, management practices, and input and output data was conducted concurrently with the trial we are now analyzing. The survey covered two other villages (Bamidele and Onikoko) in addition to Ayepe. These were spread out over the Egbeda soil association in the region. The objective was to cover the target area to which results of the trial could be extrapolated.

Researchers in the Ayepe area were well known to local farmers and the normal practice was to obtain volunteers to participate in trials. Special efforts were made to recruit female farmers. Volunteer farmers then indicated the field to be used for the trial. Inputs used for test factors were supplied by researchers. All other inputs were supplied by farmers who were free to follow any management practices they desired on the control plot and non-test factors on other plots.

Representativeness of plots, farmers, and management practices was tested by comparing (a) trial farmers with randomly selected farmers included in the three-village survey, (b) trial control plots with plots of survey farmers.

Testing for representativeness

Representativeness of farmers. As mentioned earlier, unrepresentative farmers could lead to atypical fields or management practices on the control plot. The farmers' economic position, such as access to cash, is likely to influence the use of inputs such as fertilizer, and also the timing of operations due to the ability to hire labor. The farmers' sociocultural background could also be a determinant.

No data on income and assets of trial farmers were available to act as an indicator of financial position. Informal observation, however, indicated relative homogeneity of farmers as far as wealth was concerned. Educational levels of trial and survey farmers were compared, as a proxy for wealth. In addition, the positions of the individuals in the households (i.e., household head, spouse) were compared. This was done because household heads were expected to be better able to mobilize resources. Farmers were also classified by main occupation. Those for whom farming was a secondary occupation would be expected to commit fewer resources to crop cultivation. Sociocultural factors compared were religion, gender, and whether the farmer was a native of the area or a migrant.

The proportion of women farmers in the trial (28 percent) was significantly higher than for the survey as a whole (10 percent). This occurred because special efforts were made to involve as many women as possible, at a time when information on the extent of women's participation in farming was not available.

Chi square tests of the proportion of farmers in each category showed significant differences between trial and survey farmers in three aspects: gender, education, and primary occupation (Table 1). There were no significant differences among villages in any of these characteristics. Data from the three villages were, therefore, combined and compared with data on trial farmers.

Table 1. Differences in personal characteristics: trial and survey farmers (in percentages)

	Trial farmers		Survey farmers
No. of observations	32		42
Gender			
Female	28		10
Male	72		90
Chi Square (DF=1)		5.62*	
Education			
No schooling	84		45
Primary	16		48
Secondary or higher	0		7
Chi Square (DF=2)		12.26**	
Primary occupation			
Farming	72		93
Other	28		7
Chi Square (DF=1)		5.96*	

Notes: ** Significant at 0.01 level, * Significant at 0.05 level

Trial participants had significantly lower levels of education. The proportion of those for whom farming was a secondary occupation was also significantly higher in the trial (28 percent) than in the survey (7 percent). These differences occured to some extent because of the higher participation of women farmers in the trial. Women have lower levels of education than men and fewer have farming as their main occupation. When gender is held constant, the differences in occupation between trial and survey are no longer significant. Trial participants, however, remain relatively less educated, even when the effect of gender is removed (Table 2). We have no explanation for this. The critical question is the extent to which these differences affect management practices. This is discussed in a later section.

In summary there appears to be an over-representation of females, uneducated farmers, and those for whom farming is a secondary occupation. The latter two characteristics appear partly to be a result of the overrepresentation of women.

Representativeness of fields. The choice of trial fields with atypical biophysical characteristics could result in erroneous assessment of the agronomic performance of the technology being tested. Relevant variables in this category include soil type, topography, and cropping history. Many food-crop fields in the area were located in degenerated cocoa groves, which were converted to food-crop farming, as the incentives for cocoa production declined during the oil boom. These fields were likely to have heavier soils than fields which had always been used for food crops. Fields were, therefore, differentiated according to whether they had previously been cocoa fields. This variable was used as a proxy for soil type, because data on soil characteristics were not available.

Table 2. Gender differences in education and occupation; in percentages

	Trial farmers		Survey farmers
Male farmers			
Total number	(23)		(38)
Without schooling	78		42
With schooling	22		58
Chi Square		8.8*(1 DF)	
Female farmers			
Total number	(9)		(4)
Without schooling	100		75
With schooling	0		25
Chi Square		2.44 (1 DF)	
Other primary occupation			
Males	9		5
Chi Square		1.11 (1 DF)	
Females	67		25
Chi Square		1.99 (1 DF)	

Trial plots were significantly different from survey plots in two aspects. There were fewer trial plots in old cocoa groves and secondly, trial plots had been continuously cropped for a longer period than typical fields in the target area (Table 3). An examination of differences among villages shows that this unrepresentativeness occured because the village in which the trials were located (Ayepe) was unpresentative in these aspects when compared with other villages in the target area as a whole.

Other plot characteristics could affect management practices for socio-economic reasons. Differences in tenure status, size of plot, and travel time between the plot and the farm homestead were analyzed. The only significant difference between trial and survey plots was in travel time: trial plots were located further away. This may have occurred because fields in Ayepe were located further away from homesteads than in other villages. There were no significant differences in travel time between trial and survey fields in Ayepe.

In summary, trial plot characteristics were significantly different from food-crop plots in the target area as a whole in a number of aspects. These differences apparently occurred because plots in Ayepe were significantly different from plots in other villages. It should be pointed out that because of data collection problems, the sample of fields from Ayepe was smaller than from other villages. It was, however, obvious that Ayepe was less remote than the majority of villages in the target area. It had its own market, good access to larger markets in the area, and a higher population density. The differences between Ayepe and other villages are consistent with theoretical prediction of

Table 3. Differences in plot characteristics: trial and survey farmers; in percentages

	Trial plots	Survey plots: All villages	Ayepe	Bamidele	Onikoko
No. of observations	32	68	9	30	29
1. *Years Cropped* Continuously					
1-2	41	85	56	97	83
3-4	44	7	11	3	10
5 and over	16	7	33	0	7
Chi Squares:					
Trial vs combined villages (DF=2)			22.01**		
Among villages (DF=4)			13.07*		
Trial vs Ayepe (DF=2)			3.959		
2. *Farmer cocoa plot*	56	81	56	70	100
Chi Squares:					
Trial vs combined villages (DF=1)			6.43*		
Among villages (DF=2)			12.89**		
Trial vs Ayepe (DF=1)			0		
3. *Travel Time*					
5 minutes or less	19	78	56	83	79
6-60 minutes	78	18	44	10	17
More than 60 minutes	3	3	0	7	0
Chi Squares:					
Trial vs combined villages (DF=3)[a]			34.91**		
Among villages (DF=6)[a]			9.23		
Trial vs Ayepe (DF=2)			4.95		

Notes: ** Significant at 0.01 level
* Significant at 0.05 level
a. 1 missing value

the effect of higher population density and better access to markets (Binswanger and McIntire 1985).

Representativeness of management practices. The management practices analyzed were either test factors or factors expected to interact with the treatments in the trial. There were no significant differences between the trial and survey for the following factors:

i. Time of planting: maize and cassava;

ii. Use of hired labor for operations other than land clearing.

The proportion of farmers applying fertilizer was lower in the trial (13 percent) than in the survey (29 percent). The difference was not, however, statistically significant (Table 4). Among villages, there were no significant differences in fertilizer use.

Table 4. Differences in management practices: trial control plots vs survey plots; percentages

	Trial plots		Survey plots
No. of observations	32		52
1. *Fertilizer applied*	13		29
Chi Square (DF=1)		3.22	
2. *Labor hiring for land clearing*	81		56
Chi Square (DF=1)		5.99*	
	Weeks after maize planting		
3. *Time of weeding*			
First weeding	6		10
F (DF=1.82)			
Second weeding	11	28.10**	16
F(1,66)		32.08**	
Third weeding	16		20
F(1,21)		19.94**	
4. *No. of weedings*			
1	3		29
Chi Square (DF=1)		21.17**	
2	56		52
Chi Square (DF=1)		0.15	
3	41		19
Chi Square (DF=1)		8.08**	

Notes: ** Significant at 0.01 level
* Significant at 0.05 level.

More trial farmers used hired labor for land clearing than for the survey as a whole. This occurred because labor hiring was more widespread in Ayepe compared with the other village clusters.

The most significant and consistent difference between trial and survey farmers related to weed control. Control plots in the trial were weeded significantly earlier than in the survey area as a whole. On an average, trial control plots were weeded for the first time just under six weeks after maize planting, while survey plots were weeded at just under ten weeks after planting. The same pattern was repeated in the case of the second and the third weedings. In addition, the frequency of weeding was higher on control plots than on survey fields (Table 4). No significant differences could be detected among villages for the timing of the first and third weedings. The second weeding was carried out earlier in Ayepe relative to other villages, but later than on trial control plots.

To investigate whether these differences were caused by the unrepresentativeness of the sample, differences in management practices were analyzed by education and occupation. No significant effect of education or occupation emerged. When education and occupation were held constant, weeding on trial plots still remained significantly earlier than on survey farms, thus indicating that earlier weeding on trial plots was not caused by the unrepresentativeness of the sample of trial farmers (Table 5). Control plots may have been weeded earlier than normal because of the demonstration effect of treatment plots, where the effect of early weeding was being tested. Apparently farmers managed to achieve early weeding without hiring extra labor, as there were no significant differences in labor hiring for weeding between trial and survey plots. This may have occurred because researchers weeded test plots, thus releasing farm labor for earlier and more frequent weeding by farmers on control plots. In the case of fertilizer, the demonstration effect was not visible as the number of farmers applying fertilizer was not significantly different between the trial and the population as a whole. Presumably this occurred because farmers were unwilling to risk cash expenditure in a risky trial situation. The implication appears to be that whether or not the demonstration effect occurs depends on the scarcity of the type of resource required. In the trial under discussion, the demonstration effect occurred for weeding where the nature of the trial released weeding labor. It did not occur for fertilizer where additional use of a scarce resource (cash) would have been required.

Implications of unrepresentativeness

Unrepresentativeness of farmers. The sample of trial farmers was unrepresentative in that there were more women farmers in the trial than in the population as a whole. This in turn resulted in overrepresentation of those without schooling and those for whom farming was a subsidiary occupation.

In this situation, trial data should be analyzed to detect differences due to these farmer characteristics. Mutsaers' analysis in this volume showed that gender had no effect on yield. Since gender was closely correlated to the other two unrepresentative characteristics, it is likely that they too would not significantly affect yield. This is consistent with the analysis in this paper which showed that occupation and education had no effect on management practices. If, however, the analysis revealed that these characteristics significantly affected trial results, it would no longer be valid to interpret the results as representative of the target area. Attention would then be focused on why these personal characteristics affected yield, with the objective of investigating how constraints differed among different categories of farmers. An unrepresentative sample of trial participants need not be undesirable as long as (a) unrepresentativeness is recognized, (b) the overrepresented categories belong to groups which are of particular interest to researchers and (c) the data are analyzed to identify the impact of unrepresentativeness.

Unrepresentativeness of fields. Fields were unrepresentative in that they had been cropped continuously for a longer period, there were fewer fields in old cocoa groves and they were located further away from the homestead. Some of these factors could affect trial results. For instance, fertilizer response may

Table 5. Differences in time of weeding: trial and survey plots

	Trial plots		Survey plots
	Weeks after maize planting		
1. *Farmers without schooling*			
Time of first weeding	6		10
t(DF44)		17.11***	
Time of second weeding	11		16
t(DF36)		27.41**	
Time of third weeding	16		25
t(DF14)		105.24**	
2. *Farmers with schooling*			
Time of first weeding	5		10
t(DF36)		7.64**	
Time of second weeding	10		16
t(DF28)		5.63*	
Time of third weeding	13		17
t(DF5)		3.91	
3. *Main occupation: farming*			
Time of first weeding	6		10
t(DF69)		19.22**	
Time of second weeding	11		16
t(DF54)		19.48**	
Time of third weeding	15		20
t(DF16)		16.58**	
4. *Main occupation: other*			
Time of first weeding	6		8
t(DF11)		13.03**	
Time of second weeding	10		16
t(DF10)		12.12**	
Time of third weeding	16		17
t(DF3)		0.35	

Notes: ** Significant at 0.01 level
* Significant at 0.05 level.

be overestimated if there is overrepresentation of fields which have been cropped for longer periods. It would be important, therefore, to analyze the impact of field cropping history on fertilizer response, and to identify the types of farms to which trial results could be extrapolated. If this is not done, the result may indicate that fertilizer use would be attractive and research might move onto the next stage of identifying optimal levels of fertilizer use. If, however, fertilizer response is far lower on fields with a shorter cropping history, further research should probably be directed towards other methods of increasing productivity. This illustrates the way in which an unrepresentative sample in a diagnostic trial could distort future directions for research.

The analyses earlier in the paper showed that unrepresentativeness of fields occurred because the village in which the trial was located was not typical of the target area as a whole. This underlines the importance of selecting experimental sites which are representative of the range of conditions in the target area.

Unrepresentativeness of management practices. The most significant result was the demonstration effect in the earlier weeding treatment, which caused farmers in the trial to weed control plots earlier and more often than they usually did. It is not surprising, therefore, that the trial results showed that earlier weeding had no significant effect on yield. This result would lead researchers to investigate other ways of controlling weeds. On the other hand, if control plots had been weeded according to normal practice, a significant effect of earlier weeding may have been detected. Research would then be directed towards understanding the constraints that prevented farmers from weeding earlier.

Conclusions

The objective of this paper was to illustrate the importance of representativeness in on-farm farmer-managed diagnostic trials. Three types of representativeness were discussed: representativeness of trial participants, fields, and management practices.

Representativeness can be increased through careful selection of experimental sites to reflect the range of biophysical and socioeconomic conditions in the area. Once a site has been selected, the representativeness of trial farmers can be increased if researchers are closely matched with representative farmers in the area in sociocultural and other attributes. Factors such as gender and ethnic background are, at times, particularly important.

Choosing representative farmers does not ensure representative trial fields or representative management practices on control plots. This is because farmers may regard trials as risky, may not be interested in them or understand their purpose. This situation can be improved by involving farmers more closely not only in trial management (as is commonly done), but also in trial design. Experimental plots which are usually larger than most farmers' total holdings also compel farmers to take a more active interest in the trial.

In spite of these devices, representativeness may not be achieved. It is important, therefore, to test for representativeness of farmers, fields, and management practices. If unrepresentativeness exists, trial results should be analyzed to investigate the impact of overrepresented categories, and extrapolation to other parts of the target area limited accordingly. If this is not done, particularly in diagnostic trials, the direction which future research takes could be seriously distorted, and researchers could end up in a situation where years of effort result in a finished technology which is attractive only to a small segment of the population in the target area.

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Extrapolation of Experimental Results from a Series of On-Farm Trials

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Agrotechnology extrapolation is the transfer of experimental information from a known set of on-farm trial environments to other known but different environments. The term interpolation more accurately connotes the situation since the non-trial environments are assumed to occur within the range of the experimental environments; however, extrapolation is the commonly used term. Two general approaches for agrotechnology transfer are extrapolation by (i) deductive logic and (ii) inference.

Using the deductive approach, it is presumed that a cropping system will demonstrate a given response to a given trial environment. Non-trial farmers' fields which have analogous soil, socioeconomic, and climatic environments should respond similarly. Analog extrapolation assumes that the variables chosen to define the analogs are also the determinants for the system to be extrapolated. However, crops interact with the biotic environment of a farmer's field and with seasonal variability of weather, and the natural and man-made (past management) variability of the soil. As a result the deductive logic approach may not be practical for making yield predictions.

Soil, socioeconomic, and climatic information play important roles in the definition of a geographic area or areas in which technology recommendations will be valid. Extrapolation by inference starts with a well-defined recommendation domain; basic units of inference within the area are farmers' fields. These may vary in size and shape, but are defined as parcels of land which will be handled as working units by the farmer. A random sample of units is selected and experiments are carried out. Based on an analysis of the experimental data, extrapolation by inductive reasoning is made to other farmers' fields in the recommendation domain. The strategy of a random sampling of fields for the experiments ensures the validity of the inferential procedure, while the precision of the yield predictions depends upon replication and number of fields selected for the experiment. Ideally, the selected fields are randomly selected from stratifications of the most important physical and socioeconomic determinant gradients. In practice, random sampling is difficult to achieve and the effect on inferences is unknown.

Field selection

Recommendation domains are based on known soil, socioeconomic, and bioclimatic information. After the area has been bounded, the experimental framework is a series of on-farm trials carried out within the recommendation domain. Invariably, the combined analysis of data will show an interaction between the treatments used in each experiment and the fields. In other words, the differences among treatments are not the same for all fields. In analyzing the results, it is usually necessary to characterize each trial field by measuring several weather, soil, and socioeconomic variables.

Recommendations to non-trial fields are based on knowledge of differences between management practices and how these differences vary from field to field. A prediction equation, estimated from a series of on-farm trial yields and field environmental data, is one mode for extrapolation to non-trial environments. Terms in the model will include

i. contrasts among the treatment means for transfer of average treatment differences, and

ii. additional interaction terms to modify the average predictions.

A more difficult problem is predicting absolute yields, which requires more complex modeling.

An interpretation of important interactions depends on a careful selection of environment variables. Nevertheless, problems can arise if:

a. a sufficient range of values for the variable does not exist in the recommendation domain,

b. a range exists but most trial values are beyond the "critical" value, or

c. the variable cannot be measured sufficiently well under field conditions.

The number of fields selected within each target area depends on the precision needed in the extrapolation and the number of significant environmental gradients. If rainfall is the only gradient of primary importance, the area can be stratified into several subgroups of increasing levels of expected rainfall, based on long-term recordings, and fields selected from each subgroup. If rainfall and soil texture, for example, are the major gradients of importance, then the area can be divided into subgroups, each one being a different combination of rainfall and soil texture, and fields selected within each stratification.

Selection of the villages, farmers, and fields ideally is at random and in reality, the selection should be as random as practically possible.

Treatment and experimental design

An experimental treatment is a term used in comparative trials to describe an effect of a procedure (agent or intervention). Treatments can be physically applied, as with fertilizer applications, or definitional, as with planting dates. Each type of treatment is commonly called a treatment factor. Examples of factors are cropping patterns, fertilizer nutrients, genetic material, and planting arrangements.

A treatment design is a structural arrangement of treatments. A single factor treatment design will usually have two or more categorical states, as with varieties, or three to five quantitative levels, as with applied nitrogen levels. The number of treatments is the number of qualitative states or the number of quantitative levels.

A two-factor treatment design is a factorial arrangement of treatments where the possible number of treatments is the product of the number of levels (states) for each of two factors. Each treatment is a factorial combination of one level of one factor with one level of the second factor.

The selection of the treatments will usually be based on modifications of farmer practices, yielding specific information for recommended technology packages. Factors of possible importance are listed and then ranked in order of potential and degree of change from existing farmer practice. Usually, the selected treatments represent relatively minor changes in farmer management, with a potential for increasing production or returns. Each level of a factor should be expected to give a minimum of a preselected percentage increase in yield over the farmer practice before inclusion in the experiment.

An experimental design is a set of rules for assigning treatments to experimental plots. The choice of an experimental design is usually based on experimental variability. If trial-to-trial variability is large, relative to within-trial variability, and the total number of plots for the network of trials is fixed, each treatment is usually replicated once in a trial. No measure of within-trial error, for intrasite analyses, or pooled-experimental-error in the intersite analysis of trial data are then available. If two or more replications are not warranted, a compromise is to replicate one of the treatments at each trial.

Data analysis

The general pattern of the data analysis will include three stages.

Yield-environmental correlation analysis

Yield data from control plots of each experiment are plotted against each of the field-measured environmental variables. These plots serve as a check on the range and distribution of points for each environmental characteristic. The magnitude of the correlations, along with plots of one environmental variable against another, assists in the selection of environmental variables to be included in the combined analysis of variance.

Analysis of variance

Replicated data from each site is analyzed by an analysis of variance (ANOVA) procedure for calculation of the coefficient of variation and estimation of the experimental error. But the differences among the treatments, calculated for each trial, do not remain the same from one trial site to another. The magnitude of this treatment by trial interaction can be evaluated graphically or from the ANOVA of the data combined over the trials. Degrees of freedom for the interaction can be subdivided into components to evaluate the value of the measured field characterization variables to account for the major part of the interaction sum of squares. The remainder of the interaction sum of squares is sometimes used as an approximation of the experimental error for single replication trials.

Regression analysis and prediction

Using all the experimental data from the on-farm trials and the measured environmental variables, regression methodology is employed to estimate a prediction equation. In general, form yield can be modeled as a function of two general groups,

$$Y = f(M, E)$$

where M are trial treatment factors managed by the farmer, and E are the environment variables that can be measured at each trial site but that cannot be managed.

If the combined ANOVA shows interaction between the treatments and the fields, then interaction variables between the treatments and the environmental factors will need to be included in the prediction equation. The regression methodology at this stage also includes goodness-of-fit statistics and analysis of residuals.

Extrapolation methodology

Extrapolation has been practiced for many years, first by trial and error, and more recently by environment analogs. Extrapolation by modeling is not as well developed. One output of current on-farm research trials is the development of extrapolation methodology and methods for validating estimated extrapolation models. Systematic development of procedures for determining the weight of evidence for successful prediction to fields which have not been part of the experimentation has not been finalized. This section outlines a possible approach and starts with overly simplified examples to illustrate the general nature of the proposed strategy.

The simplest of extrapolation models would be the average of treatment data across the on-farm trials. The value of extrapolating the same average value to all non-trial fields would be limited unless all trial and non-trial sites are truly replications. If the same average yield within statistical limits was measured for all the fields, then the mechanism for extrapolation would be the overall mean. No other information would be needed and the average over all the experimental fields would be the predictor for other fields not in the series of experiments.

Now suppose the individual field means are different but they correlate well with measured soil moisture-holding capacity. The extrapolation mechanism is the estimated straight line relationship between yield and holding capacity, namely the intercept and the slope of the regression line. Based on this estimated model, predictions can be made to other fields by knowing the soil moisture-holding capacity for the new field.

The next step is to impose two treatments at each trial, e.g., farmer and improved technology levels. Again, assume that a straight line adequately fits the data, resulting in two straight lines. If there is no interaction between technology level and soil moisture-holding capacity, the two lines will be parallel and the extrapolation mechanism will be the two parallel straight lines, i.e., the prediction equation will include estimated parameters for the two intercepts (means) and one slope. As indicated in a previous section, extrapolation of the difference between farmer and improved technologies (the slope of the line) is easier to transfer than the slope and two means.

As other treatment differences and environmental variables need to be considered, the extrapolation models become more complicated but the basic outline remains the same. More options in the extrapolation analysis can be exercised. For example, treatment differences plotted against environmental variables can reflect stability of cropping patterns as the nature of the regression slopes (or curves) is examined.

An extrapolation example

A major assumption in a series of on-farm trials is that information from the experimental trials may be extrapolated to other fields within the same recommendation domain. Extrapolation is based upon a model estimated from the experimental data. For example, if applied nitrogen (N) is the factor of interest and trials are carried out with two or more N levels, the extrapolation (prediction) model is:

$$YHAT = b_0 + b_1N + b_2N^2$$

where YHAT is the predicted yield and the b values are the estimated intercept, linear and quadratic terms of the quadratic polynomial curve between yield and applied nitrogen.

A problem arises in using the model, estimated from the experimental fields, to predict yields on nonexperimental fields. Environmental variables vary from field to field in a series of on-farm trials. These field variables are factors believed to affect crop yields but cannot be controlled at a constant level across the series of on-farm trials. Neither is it desired to control these field variables at a constant level since the effect of field variables on the relationship between yield and the controlled factors is one of the major reasons for the series of trials. However, farm variables can be measured and incorporated into the estimated extrapolation model.

For example, field soil-moisture during a critical period of plant development can be estimated by forming a drought index from measured rainfall and soil texture. The effect of a field variable on the analysis and interpretation of a series of trials is shown using a soil-moisture index, denoted as "m". Suppose trials were carried out on two fields and the difference between the two fields is due only to the main effect of moisture. Then:

$$YHAT = b_0 + b_1N + b_2N^2 + b_3m$$

The estimated b_3 coefficient reflects the difference between field mean yields and is estimated from soil-moisture information at the two fields. If the soil-moisture index is coded +1 and -1 for convenience, then:

$$YHAT = (b_0 + b_3) + b_1N + b_2N^2 \text{ for field 1, and:}$$

$$YHAT = (b_0 - b_3) + b_1N + b_2N^2 \text{ for field 2.}$$

It can be seen from this example that any field variable measured at the two fields will explain the difference in the mean yields of the two fields. In practice, more than two fields will be needed to evaluate a measured field variable. Also note from the equations that the applied nitrogen response curve is the same for both fields but the curves have different intercepts. It then follows that the economic optimum calculated by equating the term, $b_1 + 2b_2N$, the derivative of Y with respect to N, to the price-cost ratio is not affected by the field soil moisture index.

The situation changes if the field variable interacts with the controlled factor, e.g., the difference between two levels of applied nitrogen depends on the level of the soil-moisture index. Now the extrapolation model is:

$$YHAT = b_0 + b_1N + b_2N^2 + b_3m + b_4Nm$$

and the derivative of yield with respect to applied nitrogen is:

$$(b_1 + b_4m) + 2b_2N$$

showing that the economic optimum now depends on the level of the soil-moisture index.

From a series of on-farm trials the estimated extrapolation model including the b^3 and b^4 coefficients can be calculated. A plot of the predicted response curves for different levels of the soil-moisture index, or several levels of rainfall at two or three soil textures is a valuable graphic to show the extrapolation model.

Yield for additional applied nitrogen experiments on new fields during the next growing season (verification experiments) can be predicted using the estimated extrapolation model and soil-moisture index values from the new fields. Evaluation of the extrapolation methodology is then based on the statistical analysis of the differences between the predicted yields and the actual yields from the new fields.

Evaluation of the extrapolation methodology

After estimation of an extrapolation model, its predictive value needs assessment. Selection of a "goodness" measure depends on the chronological stage of the experimentation, the trials' experimental design, and the availability of measured environmental variables.

After one growing season with no measured environmental variables, the classic combined analysis of variance table would include sums of squares for

- Environments (fields),
- Blocks within fields (assuming replication and blocking),
- Treatments,
- Fields by treatments interaction, and
- Experimental error (assuming replication).

The (t-1) treatment degrees of freedom and sum of squares would usually be subdivided into single degree of freedom comparisons (contrasts estimating meaningful differences among the treatment means) labelled C1, C2, ...C(t-1). Extrapolation of contrast estimates to non-trial fields is justified if the interaction is judged not important by comparing interaction and experimental error mean squares (F statistic) and the widths of calculated confidence intervals are satisfactory.

With measured environmental variables, e.g., E1, E2 and E3, and assuming that plots between treatment contrasts and E variables reflect straight line fits, an important interaction degrees of freedom and sum of squares would also be subdivided into 3(t-1) C*E components. The three E variables would usually be correlated, the magnitude of the C*E sum of squares would be order dependent, and the researcher's subject matter knowledge would determine a reasonable order for interpretation. The remaining degrees of freedom and sum of squares would be a term labeled "remainder". Extrapolation of contrast estimates modified by inclusion of the C*E interaction terms in the estimated extrapolation model is justified if the remainder and experimental error mean squares are judged not to be different by an F statistic evaluation. If judged to be different, problems in extrapolation are to be expected. For nonreplicated trials the researcher has to subjectively judge the relative magnitudes of the remainder and experimental error mean squares.

Inclusion of additional environmental variables will account for an increasing proportion of the interaction sum of squares but does not necessarily improve extrapolation. With f fields, the inclusion of (f-1) environmental variables will account for the total interaction sum of squares even if the environmental variables have been computer-generated from a random number table. Few environmental variables, relative to the number of fields and selected on both statistical and subject matter considerations, should be utilized in the extrapolation model.

Verification trial analysis

Verification trials are additional on-farm trials, usually starting in the second growing season with on-farm measurement of the extrapolation model environmental variables. Verification trials need to include some of the same treatments as the original trials but the trial design could be more appropriate for demonstration trials with larger plot sizes. Replication and randomization could be compromised.

Based on the extrapolation model, estimated from the experimental sites, yields are predicted for the verification trial plots. Plots of observed versus predicted should show most points close to a 45° line through the origin. The observed minus predicted differences are then subjectively evaluated by a standard, e.g., the average absolute difference should be no greater than a predetermined percentage of the observed. The differences can also be plotted against the predicted and various environmental variables to expose patterns of poor extrapolation. Finally analysis of variance tables are calculated for each verification trial using the observed minus predicted differences. Estimates of each treatment contrast should not be statistically different from zero.

If verification experiments cannot be carried out or the number is limited, an alternative validation measure can be calculated from the original trials with replication. This goodness-of-prediction test statistic is based on the ratio of the sum of squares of the observed minus predicted differences when the predictions are made to new fields (called the prediction sum of squares) compared with the usual residual sum of squares. Specifically, the extrapolation model, estimated by using the data from all the on-farm trial sites except for one field, is used to predict plot yields for the remaining field. This is then repeated for each of the f fields based on the extrapolation model estimated from the other (f-1) fields. The observed minus predicted sum of squares, calculated for each new site and then summed over the f fields, is then compared with the sum of the individual field residual sums of squares calculated in the usual way. The ratio of the prediction sum of squares to the residual sum of squares provides a statistical test for validating an extrapolation model. The statistical distribution of the statistic is known (Wood and Cady 1981). Chi-square tables can be used to determine significance levels (Wood, Cady and Chan, 1985). A worked example is given by Cady et al., in University of Hawaii College of Tropical Agriculture and Human Resources Research Series 15, (1982).

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An Assessment of the Design and Analysis of On-Farm Trials in Nigeria's Agricultural Development Projects (ADPs)

S.W. Eremie, P.S.O. Okoli and H.R. Chheda

The Agricultural Development Projects (ADPs) were started in Nigeria in the mid-1970s primarily to increase the productivity and income of small-scale farmers. In order to achieve this objective, agricultural research activities were incorporated in their programs. The research focus was on on-farm trials. These trials represent an attempt to develop technologies that are relevant to the farmers' needs and capabilities and to shorten the period between the development and the adoption of relevant technologies.

The research program involves the collaboration of the national agricultural research institutes (NARI), universities, the ADPs, and the Federal Agricultural Coordinating Unit (FACU) in the planning, design, conduct, and review of on-farm trials. From the experience gained in the various zones of the country in the past few years, some lessons have emerged that can be used to improve the utility of these trials. This paper highlights the current arrangements and processes for on-farm trials in the ADPs and discusses the issues that have arisen along the way. Some of these issues are common to on-farm research activities in other parts of the world, while some are peculiar to Nigeria's circumstances and stage of development in on-farm research. The paper finally offers recommendations to resolve some of the issues raised.

Arrangements for on-farm trials

Over the last few years, a number of institutions were brought together to conduct on-farm trials in various agricultural development projects. The roles and responsibilities of each of these institutions are briefly highlighted below:

National agricultural research institutes (NARI) and universities

a. Provide the zonal coordination for all on-farm research activities in the zone, as well as some members of individual ADP on-farm research teams;

b. Provide technical support and back-up training for subject-matter specialists of the ADPs;

c. In collaboration with FACU and ADPs, design, implement, and monitor on-farm trials of the ADPs.

Agricultural Development Projects (ADPs)

a. Provide the financial resources for on-farm research as agreed in the budget;

b. Provide transportation for the successful implementation of the research project;

c. Provide facilitating assistance to the research team in the form of farmer and site selection;

d. Provide some staff for the conduct and supervision of trials.

Federal Agricultural Coordinating Unit (FACU)

a. Links up the collaborating institutions in on-farm research and facilitate the implementation of agreed activities;

b. Arranges meetings and workshops to plan and review on-farm research activities in collaboration with NARI and ADPs.

c. Assists in the publication of reports and information generated through on-farm research activities.

The processes currently followed in on-farm trials in the ADPs are listed in Table 1.

Issues in on-farm trials in the ADPs

This section reviews the issues that have arisen in connection with on-farm trials in Nigeria's ADPs. The issues center on the processes of on-farm trials indicated earlier, and include planning, trial design, conduct of trials, data analysis and review of trial results, and formulation of recommendations.

Planning

Team formation. On-farm research activities within NARI are the responsibility of the staff in the Farming Systems Program of the institutes. Scientists in other programs are generally excluded from these activities. As a result, in some cases, qualified and knowledgeable staff of the coordinating NARI are not involved in on-farm research activities. The exclusion of staff from programs other than the Farming Systems Program introduces some bias in team composition. Similarly, very little consideration is given to using the expertise of scientists in similar neighboring research institutes and universities. The exclusion of scientists in fisheries and livestock institutes in some on-farm research teams is of particular concern.

Solutions to identified problems. The search for solutions to identified problems is often limited to the technology generated by the coordinating NARI, little conscious effort being made to seek appropriate technologies in other research institutes and universities. This has serious implications for the relevance of trials. In the first place, there may not be enough or even any innovation within the concerned NARI to address the most serious technological production constraints in the area. What is eventually taken to the field for testing represents primarily the coordinating NARI's current interests and recommendations. In some cases, the trials do not attempt to address the most pressing production problems. For instance, in a part of the country, an analysis of the results of the diagnostic survey of farming systems clearly showed that poor storage and processing constituted the most serious bottlenecks in food production. These problems were not addressed in the subsequent on-farm trials because there were no suitable technologies developed by the coordinating NARI. A little more effort in the search for

Table 1. Processes in on-farm research in Nigeria's ADPs

Process		Institution responsible
1.	*Planning*	
a.	Planning meetings	NARI/FACU/ADPs
b.	Team formation	NARI/FACU/ university/ADPs
c.	Identification, definition and prioritization of problems and opportunities through diagnostic surveys, Monthly Technology Review Meetings (MTRM) and field visits.	NARI/university/ FACU/ADPs
d.	Identification and listing of probable and possible solutions to commonly defined problems	NARI/university
2.	*Trial design*	
a.	Choice of trials and experimental design, including data to be collected, through Review and Planning Workshops	NARI/university/ FACU/ADPs
b.	Costing of trials and preparation of implementation schedule	NARI/university/ FACU/ADPs
3.	*Conduct of trials*	
a.	Farmer and site selection	NARI/university/ ADPs/farmers
b.	Management of trials	NARI/university/ ADPs/farmers
c.	Data collection	NARI/university/ ADPs
d.	Monitoring of trials through joint supervisory visits	NARI/university/ FACU/ADPs
4.	*Data analysis*	NARI/university
5.	*Review of trial results and formulation of recommendations through Annual Review and Planning Workshops*	NARI/university/ FACU/ADPs

solutions to the storage and processing problems would have yielded fruitful results, had at least one other research institute in the vicinity been contacted.

Trial design

Choice of trials. The choice of on-farm trials often does not reflect the clientele's real needs and objectives. Focus has often been on maximizing yields, with little or no consideration for yield stability, risk minimization, and optimum utilization of available farm resources.

Biases. There is certainly a professional or specialist bias in the choice of trials. In several review meetings, entomologists who have previously worked exclusively on cereals have tried to tailor trials towards cereal insect problems when insect problems of legumes have been more prominent. Similar biases have been readily observed in the choice of trials by the coordinating commodity-based NARIs.

Experimental design. Considerable variation has been observed in site replication in the design of on-farm experimentation in different parts of the country. This ranges from heavy reliance on on-site replication to excessive reliance on across-site replication without taking into consideration the ecological differences in the areas. Too many treatments (as many as six) have often been included in farmer-managed trials. In some of these trials, appropriate controls have not been incorporated. The line between researcher-managed and farmer-managed trials does not appear to be very clear. Little or no attention is paid explicitly in the designs to available or needed data on soils, climatic factors such as rainfall and temperatures, and certain economic variables. Instead, a heavy emphasis is placed on yield data.

Farmer and site selection. On-farm trials often end up on poor sites because the researchers have inadequate knowledge of the history of the sites, and sometimes because good sites are lost due to delays in establishing trials. The orientation of selected farmers on their expected responsibilities, on the data that will be required from them, and on the object of trials, is generally inadequate. Many farmers have consequently regarded on-farm trials as the concern of government ADPs.

Management of trials. Closely linked with the lack of orientation of the farmers is the degree of farmer involvement in the management of the trials. In researcher-managed trials, the farmer often contributed only his land. Farmers in these cases often complained of the late establishment of trials by researchers. A classic example of a late start of on-farm trials was a rice variety trial that was devastated by birds because all other rice farms had been harvested before the rice in the trial plot matured. In farmer-managed trials, the demands on the farmer's labor are usually not clearly understood before the commencement of the trials. In parts of the country where several replications have been carried out on an individual farmer's field, the farmer has often been unable to employ labor for the weeding of the large experimental plot, leading to discarded trials or confusing results.

Data collection. What data should be collected, who collects them, who keeps the logbooks, and timeliness of collection are all issues that have plagued on-farm trials in almost all ADPs. Some of the research institutes do not have confidence in the ability of ADP research officers and subject matter specialists to collect good data on the trials and prefer to post their own technical assistants to do so. The ADPs, on the other hand, are suspicious of the quality and timeliness of collection of data by research institute technicians. Arguments have also raged over who should maintain the logbooks for on-farm trials. While some institutes allow duplicate logbooks to be kept by the ADPs, others insist that only the institute should maintain the logbooks.

Monitoring. Joint visits by scientists and ADP staff to monitor on-farm trials often do not correspond with the established schedule. As a result, important stages of the trials are not monitored. Often farmers' reactions to the trials are ignored by scientists anxious to reinforce their assumptions. Trials are prolonged that, according to the farmers, should be discontinued or modified. For instance, monitoring farmers' reactions to a trial evaluating cassava+maize intercropping would have dictated the need to consider treatments involving the intercropping of local cassava and improved maize, or improved cassava and local maize, rather than trials using local cassava with local maize as the control.

Data analysis. Analyses of variance and sometimes mere calculations of treatment means (without any test for significant differences) are the analytical methods most often used for on-farm trials in the ADPs. Ordinary analyses of variance are often used, even in researcher-managed on-farm trials involving crop associations (some of which could be better handled with split plot design), and in multilocational trials involving strong interactions of sites with treatments which could benefit from combined analyses of variance. The implicit assumption here is the homogeneity of the domain with respect to the treatments considered.

Economic analysis is often ignored or carried out only after all other analyses have been completed. Economic costs are usually downplayed. Little attention is given to a scientific analysis of the farmers' reactions, to the likely effect of the proposed technology on other enterprises on the farm, the effects on farm labor and other inputs, and the potential risks to the farmer which are involved.

Finally, the exclusion of ADP staff in the analysis of data from on-farm trials has resulted in considerable apathy on the part of ADP staff towards the results.

Review of trial results and formulation of recommendations. In the review of on-farm trials results, many research teams come to the review workshops with incomplete analyses and supporting data on soil and climatic conditions. Their presentations are often handicapped by the absence of audiovisual aids. The absence of scientists conversant with issues such as fisheries and livestock from these workshops puts limitations on the evaluation of some of the results, while the absence of subject matter specialists and research officers of the ADPs limits communication and the exchange of ideas. These subject matter specialists and research officers who were involved in the trials would have brought with them valuable insights. Furthermore, the very limited time given the review workshops results in hurried recommendations and trial proposals.

Funding. The level of funding has had considerable impact on the on-farm trial activities. In the design of trials, such items as the number of treatments, number of sites or replications, and the quantum of data to be collected have had to be considerably modified because of a scarcity of funds. Joint supervisory visits and the effectiveness of review workshops have also been limited by funding constraints. However, it is hoped that progressive involvement of the existing research institutes and universities in the ADP area will, to some extent, reduce funding and mobility problems.

Recommendations

The following recommendations to improve the output of the trials are based on our experience.

Planning

1. On-farm trials should be regarded as an institute activity rather than a Farming Systems Program activity and therefore draw on all available scientific resources within the coordinating institutes.

2. Collaborating universities and institutes should have greater responsibility in conducting trials. (This is now happening in one zone).

3. The National Farming Systems Research Network should work out ways of integrating other institutions into the network in on-farm trials. This must be seriously pursued in each zone.

4. Conscious attempts should be made by the on-farm research teams to tap all available resources, locally and abroad. Budgets for on-farm research should provide for local travel by scientists and for the participation of at least one outside resource person at each monthly technology review meeting.

Trial design

1. Thematic diagnostic surveys will result in more clearly defined problems and constraints. Along with information obtained at monthly technology review meetings, this can lead to a better choice of trials.

2. On-farm research team members need further orientation through training workshops on the holistic nature of on-farm problems and in the design of on-farm trials.

3. On-farm trial designs should have an ecological focus and incorporate clear ecological disparities in the recommendation domain.

4. Better use should be made of available soil and climatic data in the design of trials.

Conduct of trials

1. Team members should fully brief farmers on their involvement in trials, the demands on their labor and other inputs, the risks involved, and the expected benefits.

2. Early review workshops will ensure prompt finalization of trials and budgets, encourage early release of funds, and the procurement of trial materials, thereby reducing the chances of the late establishment of trials.

3. On-farm research teams should consciously aim at making subject matter specialists and research officers fully responsible for all aspects of on-farm trials, especially those which are farmer-managed.

4. Monitoring schedules for trials should be prepared and ADPs should provide the necessary facilities and assistance required by scientists.

5. Farmers' reactions should be noted during monitoring and an analysis of their reactions presented during review workshops. Each ADP should invite and bear the expenses of one or two farmers to the review workshop to improve the planning of trials.

Data analysis

1. There is a need to selectively utilize appropriate analytical tools in the analysis of on-farm trial data. The involvement of statisticians in the design and analysis of the trials would be very helpful.

2. Properly designed and maintained logbooks will facilitate analysis. The ADPs should also maintain copies of the logbooks as is the practice in the northwest zone.

Review of results and recommendation formulation

1. The two-tier review system, started on a pilot basis in the southwest zone late in 1988, can help to make up for many of the deficiencies identified in review workshops. Under this system, the research team works with ADP staff to analyze the results and prepare trial proposals before the review workshop.

2. Two subject matter specialists/research officers of each ADP should attend the zonal on-farm trial review workshops.

Conclusion

After five years of collaboration among NARI, universities, FACU, and ADPs in the planning, design, conduct, and review of on-farm trials, much has been achieved. A favorable climate for interaction between research and extension agencies in the country has been developed. The interaction has mutually benefited all the participating agencies. Moreover, the farmer who is the end-user of the results of these collaborative efforts has benefited from these efforts.

The efforts of the dedicated core of agricultural scientists who have worked to improve the lot of the small farmer through on-farm experimentation are fully appreciated. The issues raised in this paper are directed towards recognizing the intricacies and requirements for even better on-farm experimentation.

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II

Case studies

Trial Design and Analysis for On-farm Adaptive Research: A 1988 Maize Trial in the Mono Province of the Republic of Benin

M.N. Versteeg and A. Huijsman

On-farm Adaptive Research (OFAR) in an alfisol area in Southern Benin (Mono Province) started in 1986 with the introduction of a collaborative project of the Direction de la Recherche Agronomique (DRA) of Benin, the Royal Tropical Institute (KIT) Amsterdam, and the International Institute of Tropical Agriculture (IITA) Nigeria. Major constraints to agricultural development are:

- declining soil fertility caused by shorter fallows;
- reduction in average farm size because of the increase in rural population;
- low resource productivity in food crop production due to the predominant use of manual labor (seasonal shortages) and the non-utilization of inputs such as fertilizers and pesticides; and
- low risk-bearing capacity of farmers who are confronted with highly variable incomes from agriculture.

The principal aim of the OFAR project was to intensify crop production through the introduction of new crop technologies while maintaining and/or improving the sustainability of agriculture.

Initial on-farm testing and adaptation of techologies focused on the introduction of new plant material (maize, cowpea, groundnut), row planting, higher plant densities, and the application of chemical fertilizers. The results of 1986 and 1987 trials showed that the replacement of the first season local variety with the improved TZSR-W variety was economically viable. It outyielded the local variety at about 700 kg/ha, which was sufficient to cover the additional seed cost. Although farmers were impressed by this yield increase, they had doubts about the storage quality of the cobs. This observation was confirmed by results of a storage trial showing storage losses about twice as high as those in the local maize variety. The same trials indicated a significant fertilizer response to maize, but given the existing maize/fertilizer price ratio, the application of fertilizer was for most farmers not economically attractive.[1] However, when fertilizer application was combined with the improved variety, the overall package was economically viable.

1. To calculate the maize/fertilizer price ratio the following prices were used: the farmgate price of maize for the period shortly after the first season maize harvest and the prince of fertilizer supplied through official government channels (the extension service is the sole officially recognized supplier of fertilizer in Benin). This results in a rather conservative maize/fertilizer price ratio. On the parallel market, farmers are able to obtain illegally imported fertilizers at prices substantially below the official price, whereas maize prices increase considerably 3-4 months after the first harvest.

This is an important finding, given the necessity to replenish the soil using fertilizer as a way of preventing further mineral exhaustion of the alfisols in the region. Fertilizer application should concentrate on the replenishment of phosphorus and potassium extracted with each harvest. The need for nitrogen fertilizers can be reduced by introducing nitrogen-fixing leguminous species in alley cropping, and as covercrops and rotation crops. In combining organic and commercial fertilizers it is expected that the financial risk of applying commercial fertilizer alone is acceptable to farmers. The loss of cash investments after bad years (generally due to drought) is offset by the retention of minerals in the soil due to a reduced harvest. Hence there is no necessity for fertilizer application the following season.

Objectives of the 1988 maize trial

The objectives of the trial were:

i. to compare two improved maize genotypes with a local maize variety, under a management package of a minimum replacement fertilization and recommended plant spacing and

ii. to test the effectiveness and attractiveness for farmers of a maize/pigeonpea (*Cajanus cajan*) association (where the pigeonpea replaces a second season crop as a short season fallow) as a soil fertility improvement measure.

The improved genotypes are the TZSR-W selection SEKOU-TZSR-W and the hybrid 8321-18. The SEKOU variety has been selected in collaboration with Beninois researchers and is expected to be more in line with farmer preferences as far as storage and grain quality is concerned. As a second treatment, pigeonpea was planted with every other maize row. Based on experiences elsewhere in Benin, it is expected that the interplanted pigeonpea will not affect the yield of the first season maize crop. It is further expected that the next year's pigeonpea will produce a substantial amount of litter and fresh leaves during the preceding short rainy season and the harmattan period. In previous trials under controlled conditions, this organic matter resulted in an extra maize yield of 500-1000 kg/ha.

Trial design

In farmers' fields, blocks of about 30m x 20m were divided into three main plots for the maize genotypes (local variety, SEKOU and hybrid 8321-18), which were sown in rows at a spacing of 0.80m x 0.40m. The distribution of the varieties among the three plots was determined at random. The plots were further divided in two. After emergence of the maize, in one half of the plot (randomly chosen), pigeonpea was sown between every other maize row, resulting in a plant spacing of 1.60m x 0.40m. This design, where treatments are arranged in strips across each farmers' block, was chosen to facilitate the interpretation by the farmers and hence to increase their participation. Such lay-out is sometimes termed a split-block design (LeClerq et al. 1982), or a "criss-cross design" (P. Walker, personal communication) and is, in fact, a variant of the often used split-plot design. Compared with completely randomized blocks, less information becomes available as regards the main treatment effects, but this statistical flaw was compensated by a relatively large number of repetitions (participating farmers). An additional advantage of many repetitions is that it diminishes the possibility of too strong a supervision of farmers by field assistants, thus avoiding the creation of demonstration fields.

The whole block received a first weeding and 100 kg/ha cotton fertilizer (14-23-14). The trial was farmer-managed as far as maintenance, planting- and harvesting-dates, etc., were concerned. To avoid treatment errors, the field assistants helped farmers in delimiting the plots, planting the field, applying fertilizer, and harvesting the trial. In principle, no special crop care was requested of farmers. However, like most agricultural credit programs, farmers only received fertilizer after the first weeding was properly carried out. Furthermore, in case farmers' maintenance favored particular plots, farmers were requested to correct such practices in order to decrease within-block variability.

Monitoring farmers' trials

Monitoring of farmers' fields by field assistants (two per village), was facilitated by using a separate work sheet for each field, where dates of planting, weeding, etc., were recorded. Schematic field plans, tables for harvest and interim evaluations were also recorded. After the first weeding, field assistants laid out an observation sub-plot of 25 m^2 where the number of plants were recorded and pest and disease incidence were monitored. These sub-plots were selected in such a way that growing conditions (shade, soil variability) were for the most part similar. The sub-plot is mainly a tool for a systematic monitoring procedure until harvest time. Field staff made weekly visits to the sites. During the period that field assistants were not busy supervising planting and harvesting operations, fields were systematically visited. For the purpose of such visits, all trials around the village were grouped according to their location into three tours of an equal number of fields. One such tour was made with the field assistant during each weekly visit to the site. As a result every field was visited once every three weeks. Impressions during these visits were recorded on the corresponding work sheets. Such tours are essential to remain in touch with farmers and trial development and to assist in the interpretation of final results.

At harvest, plants and cobs within the observation sub-plots were counted and the cobs weighed. These cobs were then threshed and grain weight recorded. Subsamples were taken and put in double plastic bags for later humidity determination. The cobs in the remainder of the plot were separately harvested and weighed. Grain yield was calculated on the basis of total cob weight and the grain/cob conversion factor derived from the sub-plot measurements. A second yield calculation can be derived from the sub-plot grain weight alone for verification. In this way we were able to trace and correct errors.

The field harvest results were ordered according to treatment and were compared and discussed with the farmer. His impressions and opinions were recorded on the worksheet.

Data processing and technical assessment

For data analyses the Lotus 123 electronic spreadsheet for IBM compatible computers was used. Yield calculation, statistical analysis, and stability analysis (including linear regression and graph plotting) were carried out.

Statistical analysis

Grain yields of different treatments of 25 farmers are presented in Table 1. Analysis of variance of these data according to the used crisscross design (Table 2) resembles the analysis of a split-plot design. Calculations of the correction factor (CF) as well as the sum of squares (SS) and mean square (MS) for farms (= replications), varieties, association (= treatment with/without pigeonpea association) and the interaction (varieties x associations) are the same as for the most commonly used randomized block design.

Table 1. Data/plot (t/ha) of the 25 farmers who participated in the maize/pigeonpea trial, first season, 1988

	Local variety		TZSR-W		Hybrid 8321-18	
Farm	Sole	Mixed with pigeonpea	Sole	Mixed with pigeonpea	Sole	Mixed with pigeonpea
1	2.375	2.363	2.078	2.444	3.544	1.566
2	1.814	2.435	1.697	2.684	2.984	3.758
3	3.065	2.110	3.081	3.760	4.130	3.520
4	2.085	1.958	1.205	1.194	2.062	2.350
5	1.493	1.479	2.205	2.273	2.044	2.291
6	1.128	1.524	1.240	1.651	1.268	1.817
7	2.334	1.658	2.573	3.129	4.155	3.845
8	1.459	0.830	1.842	0.578	1.798	0.978
9	1.990	2.283	2.408	1.647	2.570	2.746
10	1.320	0.991	1.686	0.712	2.324	1.998
11	1.777	1.701	1.648	2.225	2.054	2.094
12	1.084	1.197	1.545	1.796	1.583	1.558
13	1.387	1.142	2.096	2.802	1.454	3.066
14	1.245	1.229	1.675	1.942	1.990	2.045
15	2.601	2.949	3.474	3.023	4.564	3.525
16	1.925	1.759	3.081	3.551	2.800	3.115
17	0.194	0.192	0.048	0.159	0.785	0.558
18	2.318	1.924	2.628	1.990	2.970	2.555
19	0.646	0.918	1.909	2.450	0.810	1.134
20	1.620	0.994	1.429	0.661	1.632	0.968
21	1.462	1.511	2.216	1.901	2.794	1.324
22	1.317	0.887	1.921	2.282	0.486	0.711
23	0.730	0.480	0.790	0.722	0.583	0.110
24	1.617	1.306	1.490	1.497	2.226	2.379
25	1.458	0.476	1.031	1.327	0.879	1.531

The particularity of the crisscross design is that the effects of varieties, association, and the varieties x association interaction are measured on plots of different sizes and shapes and that, therefore, each will have its own error term for testing its significance.

The first error term for testing the significance of varieties, is obtained after calculation of the sum of squares of the plots of varieties and subtracting the sum of squares of farms and varieties. These calculations are the same as for the main plot error in a split-plot design with varieties as the main treatment. The result shows a very significant varietal effect (Table 2).

The same procedure is now followed to obtain the second error term for testing the effect of association, hence first the calculation of plots of association and then subtraction of the sum of squares of farms and association. Again, the calculations are the same as for the main plot error in a split-plot design, but now with association as the main treatment. This test indicates no significant influence of the pigeonpea association on maize yields.

Finally, the third error term for testing the significance of the varieties x association interaction is found after calculation of the sum of squares of the grand total and then subtraction of the sum of square of farms, varieties, error 1 association and error 2. The corresponding test of significance does not indicate any interaction effect either.

Table 2. Tables of sums, averages and ANOVA (crisscross design)

	Table of sums				Table of averages		
	Pure	+pigeon-pea	Total		Pure	+pigeon-pea	Average
Local	40.45	36.30	76.765	Local	1.618	1.452	1.535
TZSR-W	47.00	48.39	95.401	TZSR-W	1.880	1.935	1.908
Hybrid	54.50	51.55	106.055	Hybrid	2.180	2.062	2.121
Total	141.95	136.24	278.221		1.892	1.816	1.854

ANOVA

Source	DF	SS	MS	F	
CF	1	516.046			
Farms	24	83.701	3.488	10.18	***
Varieties	2	8.791	4.396	12.82	***
Error 1	48	16.441	0.343		
(Plots of varieties	74	108.933)			
Associations	1	0.217	0.217	0.83	ns
Error 2	24	6.308	0.263		
(Plots of associations	49	90.225)			
Varieties x associations	3	0.340	0.170	1.27	ns
Error 3	48	6.409	0.134		
Grand total	149	122.206			

CV = 19.56%

Stability analysis

Table 1 shows that the variability between farms was very large due to factors such as soil fertility, field history, influence of rainfall of individual fields (often related to sowing date), farmer's management, etc. It can be assumed that the mean yield over all treatments reflects the accumulated effect of all these factors. In the stability analysis, the mean yield of each field is used as a compound index for the environment and therefore often indicated as the Environmental Index (EI) of that field. This EI is then used as the x variable for the calculation of the linear regression for the yields of each variety separately.

The means (EI) of individual fields are shown in Table 2 together with the yields of the three varieties. The calculated regression lines of each variety on EI are given in the left part of Table 2. In Figure 1, for every field the corresponding EI is plotted against the yield of each variety of that field. Next, for each variety, the corresponding regression lines have been drawn. The graph shows that the line of the local variety has the smallest slope, hence is less influenced by the environment. It can, therefore, be considered more stable. Also the stability of SEKOU appears fairly similar. The hybrid is less stable and there is a significant advantage over SEKOU only in favorable environments.

The differences in stability can be tested on significance, using the ANOVA on the varietal means (Table 3) and the calculations as described by Mutsaers et al. (1986). First the sum of squares (SS) for the regression on EI for each variety is calculated. The sum of these three values (which are 8.148, 12.665 and 22.960 for the SS of local variety, SEKOU and Hybrid respectively) should, however, in this case be multiplied by a factor 2 (because the varietal means of Table 3 are on the basis of two values), before subtracting the SS term for Farms, in order to get the SS due to differences in regression, REi-1 (3.845). This is incorporated in the first part of the ANOVA table and the corresponding MS and F values are calculated (Table 4). In our example it shows clear significance, indicating that the observed varietal differences in stability are real. An additional advantage is that the error 1 term of the original ANOVA became smaller, resulting in a higher precision in the significance tests on varieties.

In the same way, the SS due to differences in regression of the pigeonpea treatments on EI (REi-2) is calculated on the basis of the means of these treatments (to be deduced from Table 1).

Economic assessment

The economic assessment of a new technology is commonly based on a partial analysis of costs and benefits. Partial budget analysis is used to compare additional costs related to the new technology with additional returns. Costs and benefits are calculated on the basis of farmgate prices for cash inputs and outputs and imputed prices for non-cash inputs such as family labor. If there is an interaction with other parts of the cropping or farming system, increased or diminished costs and/or benefits should be taken into account. The economic attractiveness is then evaluated on the basis of the incremental benefit/cost ratio (B/C). An innovation is economically attractive in case of an incremental B/C ratio higher than 1, indicating that additional returns are higher than additional costs. To take into account interest cost and farmers'

Table 3. Regression of varietal means/farm on environmental index (EI= mean of all treatments per farm) (stability analysis)

Farm	EI	Local	TZSR-W	Hybrid	Regression Output: EI/Local
1	2.395	2.369	2.261	2.556	
2	2.562	2.125	2.190	3.371	Regression equation of mean yields
3	3.278	2.588	3.421	3.826	of local variety on environmental
4	1.809	2.022	1.199	2.207	index (EI):
5	1.964	1.486	2.239	2.168	
6	1.438	1.326	1.445	1.543	
7	2.949	1.996	2.851	4.000	Local = 0.117 + 0.764 EI; r = 0.93
8	1.247	1.144	1.210	1.388	
9	2.274	2.137	2.028	2.658	
10	1.505	1.156	1.199	2.162	Regression equation of mean yields
11	1.916	1.739	1.936	2.075	of variety SEKOU TZSR-W on
12	1.461	1.141	1.670	1.571	environmental (EI):
13	1.991	1.264	2.449	2.260	
14	1.688	1.237	1.808	2.018	
15	3.356	2.775	3.249	4.045	TZSR-W = 0.140 + 0.952 EI; r = 0.90
16	2.705	1.842	3.316	2.958	
17	0.323	0.193	0.104	0.672	
18	2.398	2.121	2.309	2.763	Regression equation of mean yields
19	1.311	0.782	2.180	0.973	of hybrid 8321-18 on environmental
20	1.217	1.307	1.045	1.301	index (EI):
21	1.868	1.486	2.059	2.060	
22	1.267	1.102	2.101	0.599	
23	0.569	0.605	0.756	0.347	Hybrid = -0.250 + 1.282 EI; r = 0.96
24	1.749	1.461	1.484	2.302	
25	1.116	0.967	1.179	1.205	

risk considerations, it is usually assumed that for a technology to be attractive to farmers, returns should at least cover twice the costs, hence a B/C ratio higher than 2 is required. If the new technology requires a substantial increase in labor use, it is further useful to compare alternatives on the basis of the incremental benefit/man-day ratio, instead of using imputed prices for labor.

For the present example of introducing a new maize variety with similar growing characteristics as the existing variety, the B/C analysis is relatively straightforward. The additional costs are solely related to the increased seed cost, whereas the additional benefits are due to the yield increase of the new variety. The additional seed cost of the SEKOU variety is calculated on the basis of the actual price difference of 100 CFA/kg between improved seed sold by the extension service and local seed obtained at the market.[2] The extra cost

2. The price difference of 100 CFA/kg between improved and local seed does not reflect the real cost of producing open pollinated improved maize seed, i.e., the extension service supplies improved seed at heavily subsidized rates. Unfortunately, data on the real cost of production are presently not available.

of 30 kg/ha improved seed is CFA 3000. Given a farmgate price of maize of 50 CFA/kg during the period shortly after the first harvest, this is equivalent to 60kg maize. Thus, assuming a minimum incremental B/C ratio of 2, the yield increase of the SEKOU variety should be at least 120 kg/ha in order to be attractive to farmers.

Table 4. Incorporation of regression on environmental index (RE_i-1, -2) in ANOVA of Table 2

Source	DF	SS	MS	F	
CF	1	516.046			
Farms	24	83.701	3.488	12.73	***
Varieties	2	8.791	4.396	16.05	***
RE_i-1	2	3.846	1.923	7.024	***
ERROR 1	46	12.594	0.274		
(Plots of varieties	74	108.933)			
Associations	1	0.217	0.217	0.791	ns
RE_i-2	1	0.004	0.004	0.016	ns
ERROR 2	23	6.303	0.274		
(Plots of association	49	90.225)			
Varieties x association	2	0.340	0.170	1.271	ns
ERROR 3	48	6.409	0.134		
Grand total	149	122.206			
	CV	19.56%			

Using the graph resulting from the stability analysis (Fig. 1), it can be easily demonstrated that for the majority of farmers the replacement of the local variety with the improved variety is economically attractive. By drawing a line parallel to the regression line of the SEKOU variety in Figure 1 but at a 0.120 t/ha lower level, we obtain a line indicating the yield of the improved variety minus twice the additional cost incurred with this variety (Fig. 2). For farmers with an EI higher than the EI where the two lines intersect (EI = 0.5 t/ha), the incremental B/C ratio is higher than 2. It should be noted that the above assessment is conservative in the sense that the cost of purchasing seed of an open pollinating variety should be considered an investment rather than a variable cost that can be tied to a single crop.

To assess the economic attractiveness of introducing the hybrid maize variety, a comparison is made with the SEKOU variety which was shown to be economically superior to the local variety. Assuming a price difference of 150 CFA/kg seed between the hybrid and the SEKOU variety, the replacement of SEKOU by the hybrid variety requires an extra cost of 4500 CFA/ha which is equivalent to 90 kg/ha maize. Employing the method described above, i.e., lowering the regression line for the hybrid variety in Figure 1 with 180kg maize, it can be demonstrated that for about half the number of farmers the introduction of hybrid seeds is not economically attractive. Only for farmers with an EI higher than 1.7 t/ha is the incremental B/C ratio higher than 2.

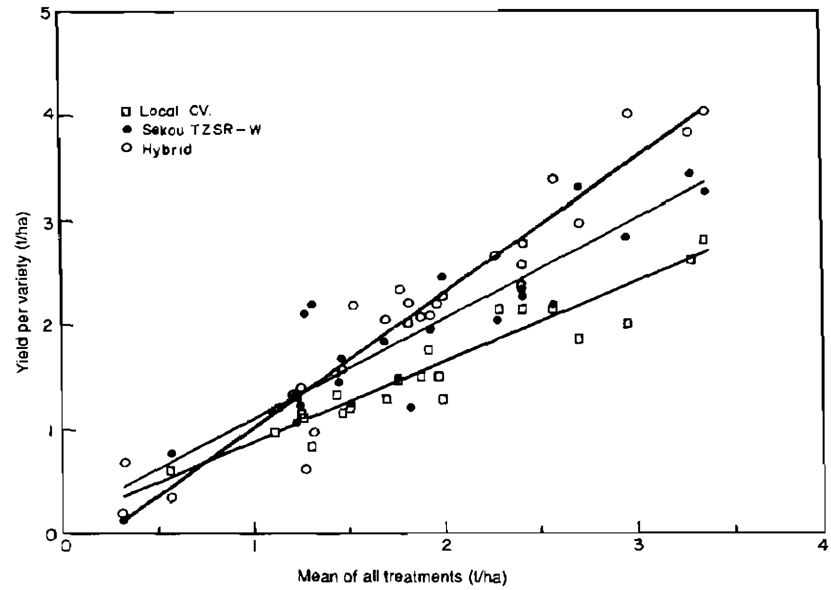

Figure 1. Stability analysis of maize grain yield as influenced by variety in 1988, first season

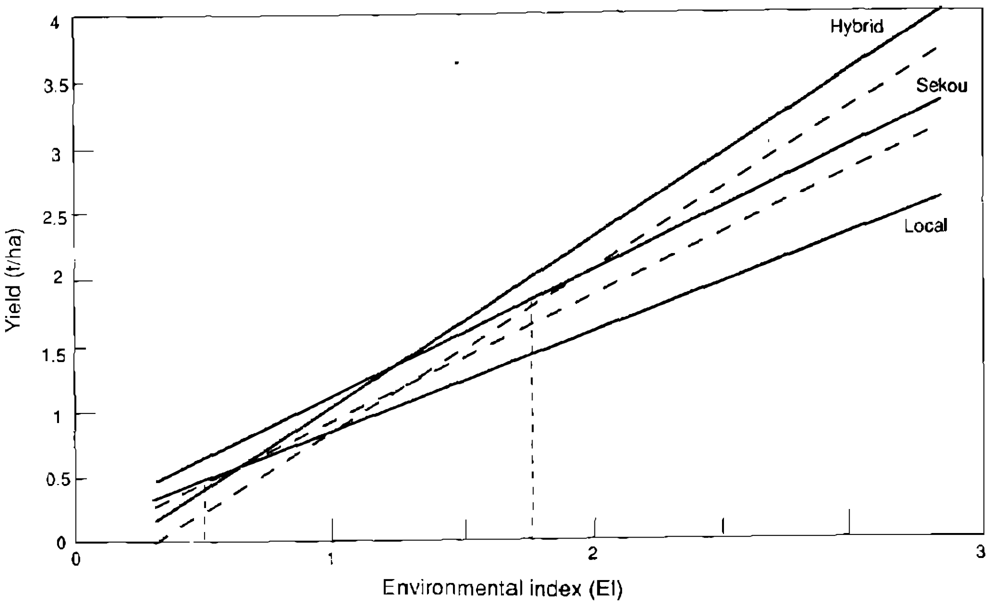

Figure 2. Comparative yield analysis for economic assessment of improved varieties. Continuous lines: relation between environmental index (EI) and yield of local variety, SEKOU and hybrid, respectively (copied from Fig. 1). Broken lines: yield minus 2 x additional costs for replacement of local variety by SEKOU and for replacement of SEKOU by the hybrid. Further explanation: see text

Combined with the necessity to purchase seeds every year, investment in hybrid seed production or importation does not appear to be economically viable.

Farmers' opinions

Farmers' opinions obtained in the field were complemented by farmers' observations obtained during village meetings after trial results had been analyzed. There was no consensus among farmers about the behavior of the hybrid variety and several farmers were aware that the yield difference with SEKOU in many fields was absent or not impressive. SEKOU was further considered to give a better quality of *pate* (a local maize dish) than the hybrid variety. Expectations with respect to the storage quality of both varieties were lower, compared with the local variety. Farmers who knew Ikenne-TZSR-W from last year and from the pre-extension test preferred SEKOU because of better husk cover and *pate* quality.

Continuation of trial

The above analysis relates only to the first stage of the trial. To determine the viability of the pigeonpea intercrop as a source of organic fertilizer, data will be collected on the soil fertility improvement and its effect on the performance of next year's maize crops. Presently, most pigeonpea blocks have formed closed canopies and litter production has started. After the pods mature (around the end of January) the pod and grain production will be determined. In areas where maize only was sown, farmers planted cotton, cowpea, maize or sometimes left the area fallow. The history of these plantings and the pigeonpea was monitored with another worksheet. For the continuation of the trial several possibilities are open, among others:

- One maize variety is chosen for all fields by the researcher, during the first as well as the second season.
- One maize variety is chosen per farmer's block, but the choice of the variety is left to the farmers. This provides an indication of the farmers' opinion of the introduced varieties, while for the significance of the fertility effect it will probably not have much influence. On the other hand, the choice of variety will influence the environmental indices which may confound environmental effects with genetic factors.
- 2-3 maize varieties are again randomly planted, leaving the block again to a comparison of maize genotypes.
- The trial is planted with one maize variety but a cassava association is incorporated to explore the possibility of using cassava organic matter to improve soil fertility.

The economic analysis will take into account the costs and benefits of replacing a second season maize crop with a short season fallow of pigeonpea. Also the effect on weeding labor of interplanting pigeonpea in the first season maize crop will be analyzed in more detail in the future using larger plot sizes.

Aspects of trial follow-up

To follow up on the storage problem, a maize storage trial was started with three treatments:

i. local control– according to farmers' practice;

ii. improved traditional storage– by trying to increase husk protection a more careful selection of cobs showing signs of insect penetration together with Kaothrin™ applications (during establishment of the storage structure and periodically afterwards); and

iii. an improved storage method as in (ii).

In the latter case, cobs were de-husked and threshed and after treatment with a mixture of Actellic™ and Kaothrin™ powder, the grains were stored in bags (this was included because of the presence of the larger grain borer (*Prostephanus rostratus*) which could not be controlled efficiently when maize was stored as cobs). The cobs of the different introduced varieties were color-marked and mixed with cobs of the local variety within every treatment. Grain storage was in separate bags for each variety. Results of the storage trial would be evaluated when prices were attractive.

Feed-back to station researchers on the behavior of technologies in OFAR trials may lead to special research programs. An example of such feed-back concerns the better storage characteristics of the local maize variety. This observation led to a joint effort of the IITA's maize breeding program and a researcher of the Faculty of Agriculture in Benin to study the mechanism of the better storage quality of these local varieties and to screen the total TZSR-W population for its best storable maize families.

Finally, in case a technology has proved to be viable in farmers' trials, a pre-extension test is executed with a larger number of farmers in other villages in collaboration with the extension service. The aim is to test the technology in a real situation using existing extension channels, which include information transfer to farmers, input supply, and credit. Based on results with Ikenne-TZSR-W in 1987, the extension service executed a pre-extension test of a package of TZSR-W, including a minimum fertilizer rate and line sowing at recommended density, in 1989.

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A Maize and Groundnuts Stepwise Trial in the Ndop Plain, Cameroon (1987)

Dermot McHugh

The Ndop Plain is a fertile valley, lying between 1150m and 1300m above sea level in the northwest province of Cameroon. The plain covers an area of 1117 km^2, with a population density of about 100 per km^2 (SEDA 1983).

Eighty-five percent of the planted area is in food crops. The mean farm size is 1.5ha, while the average family size is six. Maize, the principal food crop, is almost universally intercropped with groundnuts, cocoyams or beans (SEDA 1983).

The Testing and Liaison Unit (TLU) has been carrying out on-farm trials in the plain since 1982. Beginning with maize variety trials, the TLU progressed to fertilizer and planting rate trials (National Cereal Research Extension Program, 1982-86), and finally to maize+groundnuts stepwise trials.

Objectives

This trial was designed to estimate the successive contributions of four production factors, applied in a logical sequence, to yields of a maize + groundnut intercrop; and to evaluate their effects on the economics of production. It was an attempt to synthesize the results of five years of testing the various factors individually and in pairs.

Materials and methods

The trial was set out on 21 farms in the Ndop Plain. The production factors, in the order added, were:

1. an improved maize variety (V);
2. nitrogen (N);
3. phosphorus (P); and
4. increased maize plant density (D).

The five treatments were set out in a Randomized Complete Block Design (RCBD), with $48m^2$/experimental unit and two replications/farm. The treatment levels were as follows:

Treatment	*Variety*	*Nitrogen* (kg/ha)	*Phosphorus* (kg/ha)	*Density* (no./ha)
1	Local	0	0	20,000
2	Kasai 1	0	0	20,000
3	Kasai 1	50	0	20,000
4	Kasai 1	50	25	20,000
5	Kasai 1	50	25	40,000

The maize was planted in single rows in the middle of 1.5m ridges, with two plants per hill and intra-row spacing varied to control the density. Both nitrogen and phosphorus were applied to the side and below the maize seed at planting. Groundnuts were planted in single lines on either side of the maize at the rate of 88,888 plants/ha.

Western Cameroon experienced near drought conditions during the early months of the 1987 cropping season. Three weeks of normal rainfall, beginning in mid-March, were followed by six weeks of very little rain. The rains returned in mid-May, however, just prior to the flowering stage. This helped the recovery of the crops to some extent, but it did have some negative effects on maize yields. Groundnut yields were also adversely affected, as a result of poor pegging.

Results and discussion

The data from the 21 sites were pooled for analysis of variance across locations. The large number of trials facilitated the estimation of treatment effects under a wide range of soil fertility and management conditions. Replication within locations permitted estimation of location by treatment effects, and the possible identification of sub-zones with differing response patterns, which warranted different recommendations.

The three variables used in the statistical analysis were maize-grain yield, groundnut-grain yield, and total revenue. An economic (net benefit) analysis was also conducted.

Maize yields demonstrated significant location, treatment, and location x treatment effects (P=0.05). Each stepwise treatment increased grain yield with the exception of phosphorus (Table 1). The complete package (treatment 5) yielded 184 percent of the local check; whereas treatments which only involved a varietal change in maize increased yields by 14 percent.

Table 1. Effect of maize variety, nitrogen, phosphorus, and increased maize plant density on maize and groundnut grain yields (kg/ha) and total revenue (TR) in the Ndop Plain, 1987

Treatment	Maize mean		Groundnut mean		TR* mean	
1. Local Check	2620	d**	190	a	1.70	d
2. Kasai 1 variety	2980	c	200	a	1.90	c
3. plus nitrogen	3610	b	180	a	2.10	b
4. plus phosphorus	3680	b	190	b	2.20	a
5. plus high density	4810	a	160	b	2.40	a
SE	90		7		0.04	
CV%	16		23		13	

Notes: * A value of 1.00 indicates a total revenue of 100,000 CFA/ha

** Duncan's multiple range test: values not sharing the same letter are different (P=0.05)

A modified stability analysis (Hildebrand and Poey 1985) shows a treatment by environment interaction (intersecting treatment lines), which suggests the partitioning of the trial farms into sub-groups in the analyses (Fig. 1).

Using the mean maize-grain yield for each location (i.e., environmental index) as a criterion, the 21 farms can be divided into three groups, where means within a group are not significantly different (with the exception of one farm), but means between groups are different (Table 2).

This grouping follows a geographic pattern. All of the farms in group 1 are located in the south of the plain, where infertile red soils are dominant. Six of the seven farms showing high yield potential (group 3) are in the north, where the more fertile brown/black soils are common.

Maize yield response to nitrogen and increased plant density were similar for all three groups. However, only the highest yield group showed a significant response to variety alone (P=0.05), and only the lowest yield group showed a response to phosphorus (Fig. 2).

Groundnut yields were low (mean=187), and responded negatively to maize density (Table 1). The pattern was the same for the three farm groups. No residual effects were detected on beans which were planted after the maize+groundnut harvest (mean bean yield = 321 kg/ha).

Total revenue (TR) was affected mostly by the maize component of the intercrop. The market value for the mean maize yield was 1.7 times that for groundnuts. TR correlated very closely with maize yields, the difference being a subdued response to increased maize density because of the offsetting reduction in groundnut yield (Table 1).

Because of low market prices, the total revenue/ha for maize was low for 1987. Nevertheless, economic returns to tested factors were sufficient to warrant their recommendation. The net benefit curves for the three groups of farms, and for all the farms, are presented in Figure 3 (a-d).

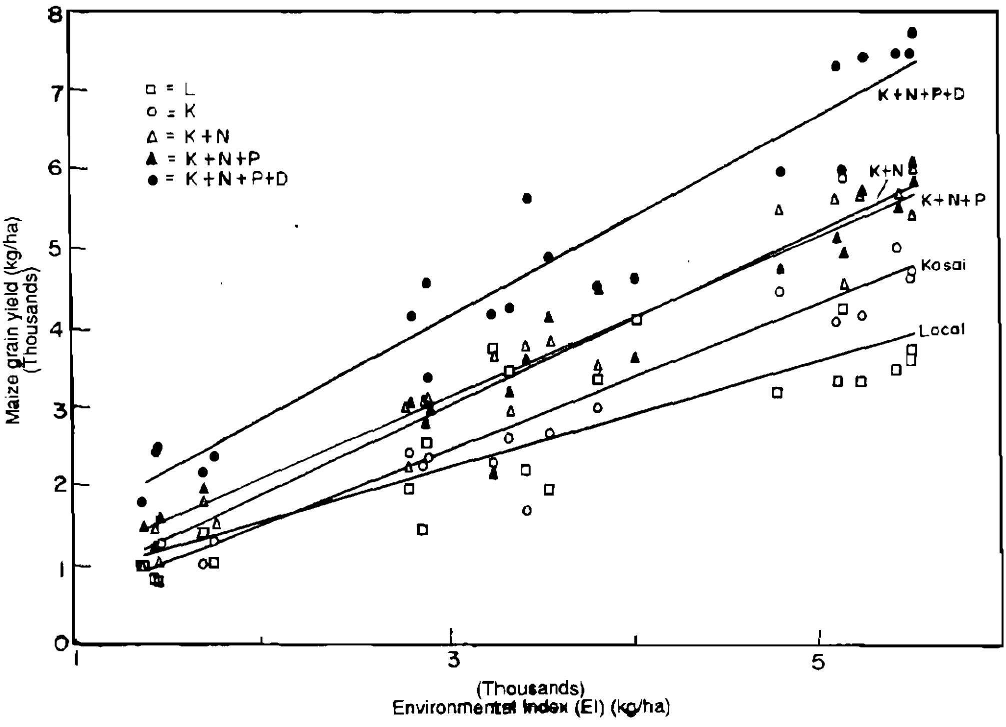

Figure 1. Maize yield constraints (Ndop, 1987)

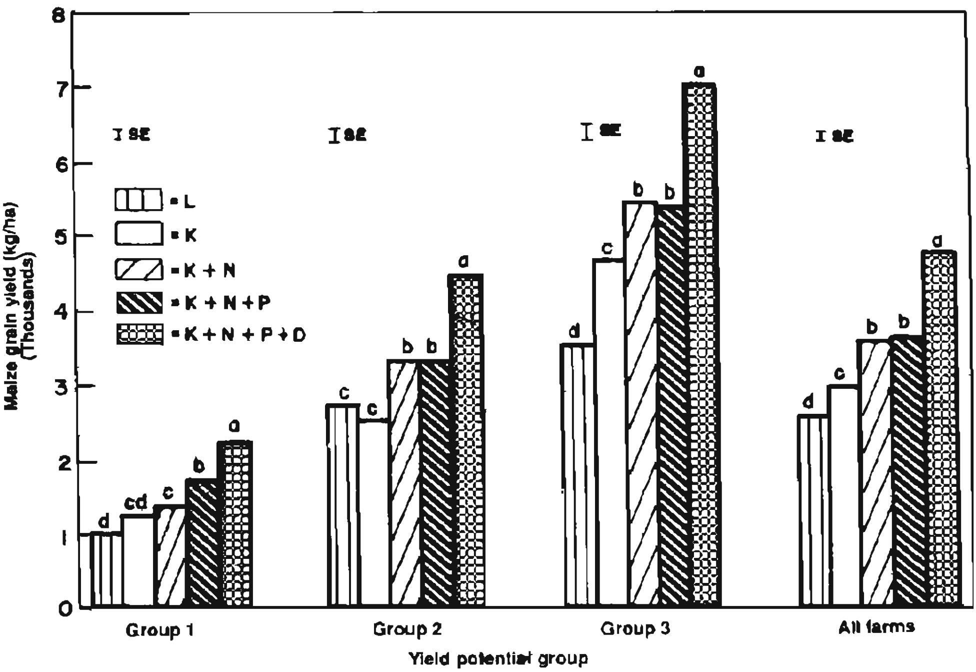

Figure 2. Maize yield constraints trial (Ndop, 1987)

Table 2. Mean maize grain yield (kg/ha) by location, Ndop Plain, 1987

Location	Mean yield		Location	Mean yield	
Group 3			Bangolan	3400	cd
Babessi	5530	a	Babungo	3300	cd
Babessi	5520	a	Babessi	3240	cd
Balikumbat	5440	a	Babanki	2880	d
Babessi	5240	a	Babanki	2870	d
Babessi	5140	a	Bamali	2790	d
Babessi	5100	a	*Group 1*		
Babessi	4800	ab	Bambalang	1750	e
Group 2			Bambalang	1690	e
Babessi	4010	bc	Balikumbat	1450	e
Babungo	3800	cd	Bangolan	1440	e
Bamali	3520	cd	Wasi-Ber	1360	e
	SE	± 310	CV (%)	16	

For group 1 (low yield potential) a slight increase in maize yield (P=0.10), and an equally slight increase in groundnut yield gave these farmers a marginal rate of return (MRR) of 751 percent for planting the improved maize variety (Fig. 3a). Although applying phosphorus and doubling the maize

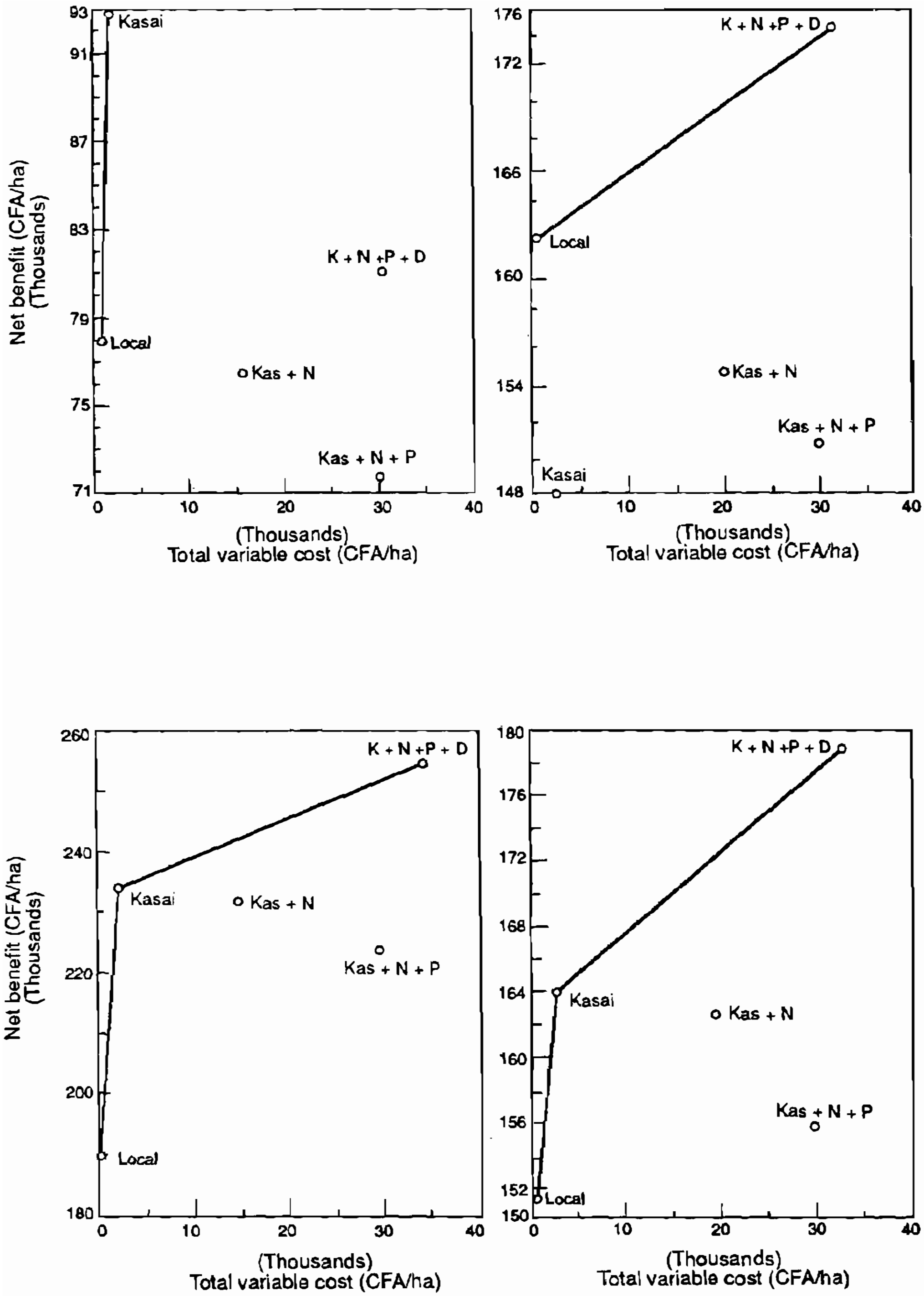

Figure 3. Net benefit curves

density increased maize yields by almost one ton, reductions in groundnut yield plus the additional fertilizer costs (using non-subsidized prices) left the farmers with a lower net benefit.

In group 2 (medium-yield potential), only the complete package treatment was slightly profitable (MRR = 41 percent, Fig. 3b). Despite a maize yield increase of 600kg, low maize prices, high fertilizer prices, and diminished groundnut yields made the application of nitrogen with low plant density unprofitable.

Group 3 farms (high-yield potential) responded strongly to all factors but phosphorus. Changing the maize variety gave an MRR of 2151 percent. Moving from there to a complete package yielded an MRR of 61 percent. The relatively low return to the complete package is due to inclusion of phosphorus, which was costly but had marginal effects. The exclusion of phosphorus boosts the MRR to 95 percent.

These results seem to argue for the partitioning of the Ndop plain into two recommendation domains with the following characteristics and recommendations.

Domain 1: Low-yield potential farms on the red soils in the south of the plain. *Recommendation:* none yet. There is a need for further soil fertility studies.

Domain 2: Medium- to high-yield potential farms in the north of the plain. *Recommendation:* Kasai 1 (or COCA) maize variety, planted at 40,000 plants/ha, plus 50kg N/ha. Twenty-four farmer-managed production plots in 1988 showed a 68 percent maize yield increase over the farmers' practices for Kasai 1 maize variety with a low rate of fertilizer [30kg N] and medium maize plant density (26,000/ha).

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Maize Response to Fertilizer in the Center Province, Cameroon; A Methodological Case Study

John Poku and Doyle Baker

The Nkolbisson Testing and Liaison Unit (TLU) was created in June 1986 with the major goal of increasing the productivity and income of family farmers in the Southern provinces of Cameroon through the development of appropriate farming systems packages. Although the team is mandated to cover this region, its activities have been restricted to five villages in the Center Province.[1] However, conditions in these villages broadly reflect the general features of the region as a whole. The villages were selected through exploratory field visits. Informal farming systems diagnoses were conducted to identify researchable production problems and constraints.

The efforts of the team were concentrated on joint researcher/farmer-managed trials involving the introduction of improved maize and cassava varieties, maize response to fertilizer, cropping patterns, and weed control. Two socioeconomic surveys were carried out. Some farmer-managed trials with improved cassava and maize varieties were also conducted. The team's other activities include training extension agents, setting up demonstration plots on farmers' fields, and performing liaison activities with agricultural development parastatals in the region.

The purpose of this paper is to illustrate the team's primary approach to trial design and analysis, using as an example maize fertilizer response trials conducted in 1987 and 1988 in five villages in the Center Province.

Background

Study area

Agricultural production in the Center Province follows a cropping-fallow rotation. Cocoa farms, mainly owned by men, are the major cash earners. Coffee *(robusta)* and oil palm are also of economic importance. Cassava is the most important food crop, grown in association with groundnut, maize and vegetables. Other crops include plantain and cocoyam.

Maize is a major and minor food crop in the transition and forest zones, respectively, but has important potential as a cash crop. It is a relatively new crop in the forest zone, and there is a growing interest in its cultivation by both men and women farmers, for consumption as well as for cash. Fresh maize is in high demand in markets around Yaoundé. The major maize production constraints in the region include:

- High incidence of stem borers, particularly during the second season

1. Team activities will encompass the other provinces as resources and linkages to relevant agricultural development agencies are built over time.

(August-November). Consequently, most farmers will normally not grow maize during the second season.

- Low soil fertility, especially nitrogen, because of shortened fallow periods.
- Lack of cultivars adapted to farmers' conditions and consumption patterns.

The primary locations for research in 1987 were two villages in the Ntui Sub-Division (Mbam Division). Ntui is in the transition zone of forest and savanna, and therefore offers a wide variation of systems. Baseline data on Ntui Sub-Division were available from an earlier survey, and an IRA (Institute of Agronomic Research) experiment station for the forest-savanna transition zone is located in Ntui. The main cropping sequences are groundnut/maize+cassava; yam/maize+cassava. Groundnut usually opens up the fallow, intercropped with maize and cassava. Cassava is normally planted flat in groundnut fields, but if planted after yam, it appears on the heaps previously prepared for yam.

Before the end of 1987, a decision was taken to shift to villages located in the forest zone closer to Yaoundé. This was primarily prompted by logistical considerations. The new villages are located in Obala and Soa Sub-Divisions. The cropping pattern is cassava-based followed by groundnuts and plantain. Yam is of less importance. Rainfall is bimodal (first season, March-July, second season, August-November) and averages approximately 1600 mm/year.

Village selection

The team's research domain encompassed forest and derived savanna zones. Attempts were made to select villages that broadly represent those two zones based upon ecology, production practices, sociocultural considerations, and farmer interest. In Ntui, informal field visits were made to areas having these representative characteristics. Contact was established with the agricultural delegate of the area and the team's objectives and activities were explained. The delegate then put the team in touch with field staff who took them to representative villages. In Obala and Soa Sub-Divisions, the villages were selected through personal contact with farmers through seminars, field days, administration of socioeconomic surveys and training activities.

In both years, the final decision on each village was made after team discussions. Once a village had been chosen, arrangements were made to meet the chief and a date was set for a meeting with the farmers.

Trial design

Selection of farmer cooperators

In each village a meeting was held with the farmers, with the chief presiding over the meeting. The objectives and activities of the team were explained; the importance of working in partnership was stressed. The team emphasized that the farmers were regarded as co-researchers in the attempt to find solutions to some of their production problems and constraints.

During the village meetings, the farmers' perceptions of production problems were discussed, and technologies were proposed for addressing the problems. The farmers' cooperation was then solicited on a voluntary basis.

An effort was made to recruit female farmer participants for cassava, groundnut and maize trials, since it is an established fact that the bulk of food crops is produced by women. In several cases, farmers not participating in the joint researcher/farmer trials were given seeds and cassava planting materials to evaluate their performance under existing practices.

Site selection

Field visits were scheduled with the farmers at the village meeting and then conducted on an individual basis. During the field visits, an attempt was made to characterize the farms into field types based upon the following criteria:

- Length of the fallow, and previous crop(s) before fallow.
- Proximity or distance from the house. This is important since trials have been destroyed by livestock when fields are close to the house, while travelling to distant fields cuts into the team's time.
- Shading (normally avoided).
- Size of field. Fields too small to accommodate a trial were omitted.

In addition to the above, some special factors such as topography, weed population, and species were taken into consideration, depending upon the trial.

Treatment selection

Treatment selection is described for two separate maize fertilizer response trials. One was a maize variety-composite fertilizer (20-10-10) trial. The second was a nitrogen and phosphorus elements response trial.

In the maize variety-composite fertilizer trial, two improved varieties plus a local variety and three fertilizer rates were evaluated in the first and second seasons of 1987 and 1988. The improved maize varieties included CMS 8501 and CMS 8507 in the first season, and CMS 8602 and CMS 8611 in the second season of 1987. In 1988, the same varieties were used as in 1987 first season, but CMS 8704 and CMS 8503 replaced CMS 8602 and CMS 8611 in the second season. CMS 8704 was higher-yielding than CMS 8602, while CMS 8611 had poor plant type. In the second season of each year, medium-maturing varieties were used because the season is normally short. All the improved maize varieties were streak resistant and high-yielding, and were evaluated relative to the local varieties. The improved maize varieties used were all white in the first season of 1987, but farmers requested that yellow maize should be included in subsequent trials, as it has a higher market potential. CMS 8704 is a yellow variety.

The fertilizer rates were 0, 300 and 600 kg/ha in 1987 and 0, 150 and 300 kg/ha of 20-10-10 in 1988. The basis for selecting 600 kg/ha was based on an earlier on-station trial. In 1987, there was no significant difference between 300 and 600 kg/ha, and 300 kg/ha had a higher marginal rate of return. Therefore, 300 kg/ha was used as the top fertilization level in 1988.

In concurrent on-station trials in 1987 to examine maize response to major and minor elements, there was no response to potassium in either forest or derived savanna locations. Therefore, a separate trial was designed in 1988 to determine an appropriate level of nitrogen and phosphorus for maize on farmers' fields. Rates of 0, 60 and 120 kg/ha N, and 0, 30 and 60 kg/ha P were selected, again based on on-station trials. In the variety-composite fertilizer trial, improved maize response was stronger than that of the local varieties. Therefore, a single improved maize variety was used in the N and P trial. CMS 8501 and CMS 8704 were utilized in the first and second seasons, respectively, in 1988.

Experimental design

During 1987, the variety-composite fertilizer trial was designed as a randomized complete block design. Two replications were used per farm in order to assess differences between farms. During 1988, the design was changed to a split plot, with variety as the main plot and fertilizer rates as sub-plots. This was done because significant differences between improved and local varieties had been established during 1987, and the team wanted to increase the precision for analyzing differences in fertilizer response.

In the N and P response trial, the three levels of N and P were factorially arranged in a randomized complete block design.

In 1988, two replications were used for both trials during the first season. During the second season, the team changed to a single replication per farm and attempted to double the number of farms. It was felt that more farms would give a wider range of environments for assessing variety and fertilizer responses. In the end, during the second season, fewer total replications were implemented since several farmers were not ready at the time of trial implementation.

In both trials, plots were laid out by the research team with the help of the farmer. Each plot was 3m x 5m with 0.75m and 1m alley ways between plots and replications respectively.

Trial management and implementation

Joint management and implementation format

In the joint researcher/farmer managed trial format, land preparation was done by the individual farmer. Planting and harvesting decisions were made by the farmers as a group with the researchers. All participating farmers met with the researchers and decided when to plant and harvest. The farmers helped each other in the planting, fertilizer application and harvesting as they moved from farm to farm. This meant that planting, fertilization, and harvesting were done virtually at the same time using the same labor. The farmers, with advice from the research team, took all the decisions about harvesting to enable them to obtain the highest price for their produce on the market.

The team adopted this method of farmer participation and decision-making as a means of minimizing labor costs and interfarm variations, reducing the sample size needed for these kinds of trials. There are problems associated with this technique, however. The major problem was that the farmers' enthusiasm tended to wane towards the end of each operation, especially among those whose fields had already been planted or harvested. It was recommended that in future trials smaller groups of farmers work together, or on an individual basis, depending upon the farmers' choice.

Crop establishment, fertilization and weeding

Maize was planted in collaboration with the farmers in four-row plots. Three treated seeds were sown with 0.75m between rows and 0.5m between hills, and later thinned to two at two weeks after planting to derive a population of 53,333 plants/ha. At the time of thinning gaps were reseeded.

Weeding was done by the individual farmer, normally between three and four weeks after sowing maize. Soon after weeding, nitrogen (urea) and phosphorus (triple superphosphate) were side-dressed to the maize. The timing of fertilization ensured a relatively weed-free environment, so weeds would not compete for the nutrients. Also, at three to four weeks after planting, maize is physiologically ready to make good use of the fertilizer. In the second season, Furadan™ was applied by a trained village-level helper to control stem borers when necessary.

Harvesting

In 1987, the variety-fertilizer composite trial was harvested dry. Farmers reacted negatively to dry harvest, since most maize in the area is consumed as fresh cobs. Hence, subsequent trials were harvested as fresh cobs.

In all trials, two rows of each four-row plot were harvested for each treatment for analysis. The number of plants, total fresh weight and number of ears were recorded for each plot. A sub-sample of ten randomly selected ears was weighed, dehusked and reweighed to determine the husking percentage. This was then multiplied by the total fresh weight per plot to obtain total weight of dehusked ears. During the second season, farmers were asked to separate the harvest sample into marketable and non-marketable ears. In instances where parts of plots had been destroyed by animals such as hedgehogs, total fresh weight was adjusted for plant density. This was done by multiplying prolificacy by average ear weight (plot weight divided by number of ears), and then multiplying by the number of plants per m^2. The entire harvest, including the harvest sample, was given to each farmer for sale and/or consumption.

Trial analysis

Similar agronomic and economic analyses were carried out for both sets of trials. To conserve space, the review of trial analysis will refer to the N and P trial only.

Agronomic analysis

The data were analyzed using analysis of variance (ANOVA). Most of the analysis was done using the MSTAT® computer package. Owing to limitations in MSTAT®, orthogonal polynomials and contrasts were calculated by hand.

For the first season, the analyses of variance were constructed for each location and combined locations. Bartlett's test (Snedecor and Cochran 1968) was applied to evaluate the homogeneity of error variances from the individual location ANOVAs. The X^2 value of 5.16 was not significant, so the six error variances could be considered homogeneous (Table 1). Therefore all six sites were included in the combined analysis, and the F values were computed using the pooled error variance (Table 2). Both nitrogen and phosphorus effects were significant. The interaction between nitrogen and phosphorus was non-significant at all but one site, resulting in non-significant interaction between location, nitrogen and phosphorus.

Table 1. Individual ANOVA of maize yields from N and P trial at six locations; Cameroon, first season, 1988

Source of variation	DF	Sums of Squares[a]					
		L_1	L_2	L_3	L_4	L_5	L_6
Replication	1						
Nitrogen (N)	2	**	**	**	**	**	ns
Phosphorus (P)	2	ns	ns	**	ns	ns	ns
N x P	4	ns	ns	**	ns	ns	ns
Error	8						
CV (%)		18.3	14.5	18.8	12.7	31.8	19.5

Notes: a. **= F test significant at 1 percent level, L = location
ns = F test not significant.

The treatment effects of nitrogen and phosphorus were partitioned into linear and quadratic components to determine the nature of the response by using the method of orthogonal polynomials. The analysis (Table 2) showed that the quadratic function best described the nitrogen response, while only the linear part of the phosphorus response was significant.

Table 2. Combined ANOVA of maize yields from N and P trial at six locations; Cameroon, first season, 1988

Source of variation	DF	Significance[a]
Location	5	
Rep within location	6	
Nitrogen (total)	2	**
Nitrogen (linear)	1	**
Nitrogen (quadratic)	1	**
Location x nitrogen (total)	10	**
Location x nitrogen (linear)	5	**
Location x nitrogen (quadratic)	5	**
Phosphorus (total)	2	**
Phosphorus (linear)	1	**
Phosphorus (quadratic)	1	ns
Location x phosphorus	10	ns
Nitrogen x phosphorus	2	ns
Location x nitrogen x phosphorus	20	ns
Pooled error	48	

Notes: a. ** = F value significant at 0.01 level
ns = F value not significant.

Density turned out to be higher on the plots with 30 and 60 kg/ha P compared with plots with no P (at .94 significance level). Therefore, analysis of covariance was used to determine whether the response to P would be significant after adjusting for population. The analysis using a linear variable for population still indicated a significant response to P, but an analysis including both linear and quadratic population variables showed that the response to P was not significant. Thus, the apparent P response seemingly resulted from a spurious correlation with population.

During the second season, the analysis was for all locations, with each farm being treated as a replication. The ANOVA indicated a significant N response, with no P response and no interaction between N and P. Again, a quadratic function best described the nitrogen response.

Economic analysis

Budgeting was used to confirm the profitability of fertilization. After finding that fertilization would be profitable, stability analysis was then carried out to determine whether particular environments should receive different levels of fertilizer. Regression analysis was used to identify the optimum levels of N and P. Stochastic dominance analysis was used to determine whether risk-averse decision-makers should use N fertilizer.

Budget analysis

Two main issues were addressed using partial budgeting: (a) the net gain from switching from any level and combination of N and P to any other level, and (b) the marginal rate of return to increments in variable costs. Both analyses were carried out using LOTUS 123. The following calculations were made:

1. Cells A1 to A27 = yield. Fresh cob weight was entered sequentially on the basis of increasing treatment variable cost. Three blocks were entered corresponding to first season, second season and combined season results.

2. Cells B1 to B27 = net weight. Yields were reduced to take into account the likelihood that some cobs would not be useable. To estimate a reduction factor, cooperating farmers were asked to separate non-marketable ears from the harvest sample. The ratio of marketable ears to total ears was .7764. This was multiplied times yield (A10-A18). Data on marketable ears were not collected during the first season but, in general, the percentage of marketable ears was substantially higher in the first season (in part because of lower stem borer incidence). Therefore, for the first season, it was assumed that losses were half those in the second season (i.e., 11.18 percent lost instead of 22.36 percent), and yields were reduced using .8832x(A1-A9). Combined yields (A19-A27) were reduced using a weighted average of .7764 and .8832.

3. Cells C1 to C27 = gross benefit = B1x225 (and copied through B27). The price of 225 FCFA/kg was determined on the basis of local market prices. In local markets, maize cobs sell in heaps of four or five cobs for 200 FCFA. To calculate a market price/kg, the following formula was used: (1000/(5x133))x200, where 133 was the average weight/cob in plots with no fertilizer. To determine a farm gate price, the market price was reduced by a 25 percent marketing margin.

4. Cells D1 to D27 = variable cost. Variable cost included the cost of fertilizer and an imputed value for the labor required to apply the fertilizer.
   (a) Labor. Based on the time needed to fertilize the trial plots, it was estimated that ten days or approximately 60 hours would be required to fertilize one hectare, regardless of fertilization rate. 150 FCFA/hr was used

to value labor. The team had paid casual labor 200 FCFA/hr for field work in on-station trials in Ntui during 1987, and felt that a lower rate would be sufficient to attract labor away from alternative farm activities.

(b) Fertilizer. Urea (46 percent N) and triple superphosphate (46 percent P_2O_5) were the sources of N and P. Both fertilizers sold for 6750 FCFA/50kg. The farm price/kg of N and P was calculated as: ((6750+1500)/50)/.46, where 1500 FCFA was estimated to be the cost required to transport a bag of fertilizer from Yaoundé to a farmer's village.

5. Cells E1 to E27 = Partial net benefit = gross benefit - variable cost = C1-D1 (and copied through E27). This figure represents a partial net benefit only since costs which do not change between treatments have not been deducted from the gross benefit.

6. Cells F1 to F27 = marginal rate of return (MRR) = 100x((E2-E1)/(D2-D1)). This formula was duplicated down through F27 and then corrected as needed to eliminate dominated alternatives. Dominated alternatives are those which have a lower partial net benefit for the same or higher variable cost.

With the above spreadsheet, budget analyses of fertilizer profitability were easy to complete. The net gain from shifting from one fertilizer treatment to another was calculated as the difference between the partial net benefit for each treatment. The most interesting comparison was for shifting from no fertilizer to each of the fertilizer treatments. All fertilizer treatments gave a positive net gain relative to no fertilizer. In general, lower increments gave higher net gains relative to the increments in variable cost, but the highest fertilizer levels gave the highest overall net gains.

To present the findings, a table was constructed showing:

1. variable costs,
2. the net gain from each level of fertilization relative to no fertilization, and
3. the MRR from increments in variable costs.

To visually depict a net benefit curve, partial net benefits were plotted against variable costs and a line was drawn between all non-dominated treatments.

Stability analysis

To judge whether the profitability of fertilizer treatments was stable across environments, the average partial net benefit for all treatments was calculated for each farm. This average was used as an index of the environment. Then, for each treatment taken separately, the partial net benefit was regressed against a constant and the farm environmental index. Three indicators of stability were examined:

1. Slope. Divergence from 1 shows that a treatment responded relatively more or less than did the average treatment to improving environments.

2. Dispersion. Treatments with a smaller regression R^2 had more erratic responses to the various environments.

3. Line crossovers. The endpoints for the predicted partial net benefit lines were calculated for the relevant environmental range using the minimum

and maximum observed partial net benefit environments. These lines were plotted to see which treatments had higher expected partial net benefits at various environments. Crossover points were calculated by determining the environment level at which two treatments had the same expected value. The proportion of environments above and below the crossover points were examined in order to judge whether further investigation of environmental targeting would be needed. For the N and P trial, there was a crossover which indicated that one of the lower fertilization levels would be better in poorer environments while one of the higher treatment levels would be better in better environments.

Regression analysis

The budget and stability analyses did not clearly indicate the best level and combination of N and P. Although there were only three levels each of N and P, there were several observations on combinations of N and P levels from two seasons. Therefore, yield regressions were estimated to develop a preliminary profile of an N and P response surface. Population was included as a separate variable, so yield data were not adjusted for population. Fresh cob weight was the measure of yield used as the dependent variable. The analysis entailed the following steps:

1. Bartlett's test (Snedecor and Cochran 1968) was employed to assess homogeneity of yield variance across seasons and treatment levels. Variances were homogeneous, indicating data for the various treatments and seasons could be combined.

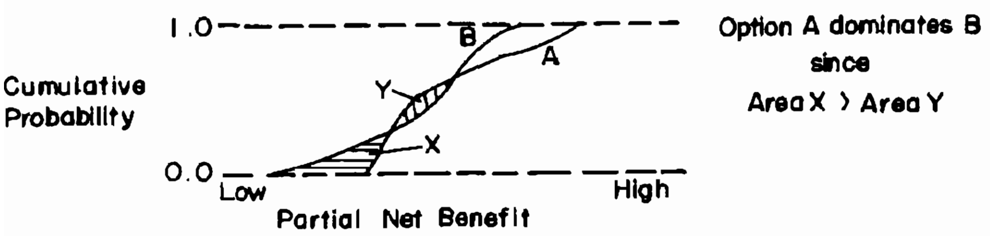
2. Separate regressions were estimated for each season. Generalized linear tests, based on the residual sums of squares, were used to determine the best sub-set of independent variables. In both seasons, there was no significant response to P and no significant interaction between N and P. The final equations included significant linear and quadratic variables for N and population.

3. A combined season regression was estimated. There was no significant difference in the residual variances of the separate season regressions so a generalized linear test was used to determine whether the separate regressions were significantly different. They were not, so the economic analysis was based on the combined season results.

4. To determine the optimum level of N, the marginal physical product (MPP) was calculated for N by taking the first derivative of the yield function. The value of the marginal product (VMP) was calculated as price x MPP. To determine the optimum N rate, the level of N which equated the VMP of N to the price/kg N was calculated. The optimum rate for N, using fresh cob weight, was found to be 102 kg/ha, only slightly lower than the maximum MPP for N.

Stochastic dominance analysis

Second degree stochastic dominance (SSD) analysis was used to examine the desirability of N fertilization. In SSD analysis, it is assumed that utility is a positive function of income, and that farmers are at least slightly averse to taking risks. This has been found to be true of farmers throughout the world. With these assumptions, the areas under the cumulative partial net benefit probability functions can be compared for competing decision options. The distribution for one decision option dominates (is preferred to) that of another option, if the area under the cumulative probability function is always less than that of the competing decision option. This is illustrated below.



While conceptually abstract, implementation of SSD is relatively simple and can be carried out using a spreadsheet such as LOTUS 123. Referring to spreadsheet columns, the following calculations were made:

1. A - the partial net benefit from each plot (all treatments) was entered, ordered from the lowest to the highest.

2. B to D - the probability for observing each plot outcome was entered in a separate column for each treatment (B-0, C-60, D-120 N). When working in the column for treatment A, outcomes corresponding to treatments B and C were assigned a probability of 0. Each outcome corresponding to treatment A was given a probability of one divided by the number of plots with treatment A.

3. E to G - the cumulative probability was computed for each treatment. For example, B1 was copied to E1. Then E2 was entered as E1+B2, and copied down the column.

4. H - the payoff first difference was calculated for all possible outcomes. For H2 this was A2-A1. The formula was copied down the column.

5. I to K - the area under the cumulative probability function was calculated for each increment in payoff by multiplying in turn columns E to G times the payoff first difference (H). For example, I1 was entered as E1*H1, and then copied down the column.

6. L to N - SSD cumulatives (i.e., the cumulative areas under the probability distribution functions) were calculated for each treatment. For L (N=0), I1 was copied to L1. Then L2 was entered as L1+I2, and copied down the column.

For purposes of interpretation, one decision option is preferred to another decision option if the SSD cumulative (the value in column I, J or K) always is less than that for the second option. For the N and P trial, fertilization at either 60kg or 120kg N would be a second degree stochastic efficient decision for risk-averse decision makers (since the SSD cumulatives were always less than for no fertilization). N fertilization at 120 kg/ha did not dominate 60 kg/ha, but there were only 15 individual comparisons out of 315 for which the area under an increment of the N-120 curve was greater than the area of a corresponding increment under the N-60 curve.

With full information, and assuming valuations in the analysis represent subjective perceptions, most decision makers could be expected to choose fertilization at 120 kg/ha rather than 60 kg/ha if forced to choose between levels. However, given risk, limited information, and uncertainty when farmers begin fertilizing using existing management levels, 60 kg/ha would better serve as a recommended rate for verification in farmer-managed trials. As the regression analysis suggests, higher rates could eventually be recommended for certain farmers and certain environments.

Conclusion

Jointly managed fertilizer response trials carried out during 1987 and 1988 showed that both local and improved maize varieties respond significantly to nitrogen. Results to date suggest than neither potassium nor phosphorus gives a significant yield increase. Further investigation of P response perhaps is warranted, taking into account specific locational characteristics.

Building on the trials discussed above, the Nkolbisson TLU has planned two fertilizer response studies for 1989. Since the response to N is highly profitable, more than 200 "test-kits"— of N and an improved maize variety versus a local variety and no N in a four plot factorial combination— will be distributed across the entire Province for farmer-managed on-farm testing. Extension monitors will be recruited to help with trial supervision and harvest measurement.

The second activity will be a jointly managed N and P response trial. During 1989, there will be three key changes in the trial design in order to refine an N recommendation and determine whether additional research on P is needed:

1. The team has selected a new forest-savanna transition zone village, so responses can be compared between the forest and transition zones.

2. There will be five N levels, to better identify the N response surface, but only two P levels. P will still be included in order to determine whether there is a significant response at certain identifiable locations.

3. Trial sites will be blocked according to years out of fallow, since the response to N— if not P— undoubtedly is affected by the cropping-fallow cycle.

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Design and Analysis of On-Farm Trials; An Example of a Trial with Maize and Cassava in Southwest Nigeria

J. B. Oyedokun and S. A. Oyeneye

Farming systems research involves on-farm experimentation with a view to accelerating the transfer and adoption of new technologies relevant to farmers. The conditions on farmers' fields (crop associations, successions, soils) cannot always be reproduced successfully in research stations, and often the only relevant testing grounds for improved technologies (e.g., new varieties, fertilizers, insecticides) are the farmers' fields themselves.

On-farm research (OFR) practitioners agree that in order to make an adequate choice of technologies for testing under real conditions, an exploratory survey to identify these conditions must precede any on-farm trials.

Materials and methods

According to Mutsaers et al. (1986), the word "design" in the context of on-farm trials broadly means:

- the choice of representative villages and farms for the trials;
- the selection of treatments compared in the trials;
- the choice of the number of replicates and of the distribution of these replicates within and between farms;
- the choice of the most appropriate experimental design; and
- the size of trial plots.

Choice of representative trial farms

In Ogun State, following a diagnostic survey, two target areas comprising four representative villages (Akintoye, Otere-Ogunkola, Igbore, and Odebo) were chosen.

The target areas were relatively homogeneous in terms of climate, soil associations, vegetation, population density, ethnic groupings, and farming systems. Monitoring by field assistants was made easy by the relatively short distances between target areas. Target areas were also close to the station of the Institute of Agricultural Research and Training (IAR&T) and were frequently visited by scientists who monitored and evaluated on-farm tests.

Exploratory surveys were used to formulate specific objectives of the on-farm testing program. The first trials involved a mixed crop of cassava and maize using differential seedbed preparation and fertilizer doses. The objective of the trial was to ascertain whether the recommended method of seedbed preparation involving ridges (resulting in a higher plant population) was an acceptable alternative to the local practices of flat and heaps/mounds, with and without fertilizer application. The trial was designed accordingly to enable assessment both by farmers and researchers.

Choice of treatments

Six treatment combinations were compared as follows:

1. Cassava (local) + maize (improved) on flat, without fertilizer =FO
2. Cassava (local) + maize (improved) on heaps without fertilizer = HO
3. Cassava (local) + maize (improved) on ridges without fertilizer = RO
4. Cassava (local) + maize (improved) on flat, with fertilizer = FF
5. Cassava (local) + maize (improved) on heaps with fertilizer = HF
6. Cassava (local) + maize (improved) on ridges with fertilizer = RF

A local maize cultivar (Ilugun Local) which was highly susceptible to maize streak virus was used in 1985.

Management and data collection

Fifteen farmers from four villages participated in the trials conducted in Ilugun Local Government Area (LGA) in 1986.

A simple 3 x 2 factorial arrangement with three seedbed types and two levels of fertilizer (0 and recommended dose) was used. Each farm constituted one replicate of six treatment combinations. TZSR-W, an improved streak-resistant maize variety, was used in a randomized complete block design. Plot size was 8m by 8m. The spacing of maize in the mixture was 90cm by 90cm with two plants per stand on ridges made manually, while spacing was according to farmers' practice on flat and heaps. Maize was sown between cassava stands which were also spaced 90cm by 90cm.

Two doses of fertilizer were applied to maize at the rate of 200 kg/ha NPK 15-15-15 and 100 kg/ha urea at 21 days and 49 days after planting, respectively, giving a total fertilizer application/ha of 75kg N, 30kg P_2O_5 and 30kg K_2O/ha. The plots were hand-weeded twice by the collaborating farmers.

Data were collected on pre-cropping soil conditions, establishment counts, operation and input costs, pest and disease incidence, differences between farms during the season, yields and yield components for maize, and the quantity and quality of the food products *lafun* and *gari* from cassava.

Results

Maize yields and variability among farmers

The on-farm trials had one replicate per farm in randomized complete block designs (RCBD). A high farmer-treatment interaction yielded a very high coefficient of variation (CV = 24 percent) indicating the unreliability of results using conventional statistical analysis. Therefore, the average yield of all treatments on each farm was employed as an environmental index in "stability analysis" (Hildebrand 1984; Nam 1984).

The maize yield for each treatment was related to the environment by simple linear regression. Table 1 gives the maize yields by farmer and by treatment and Table 2 shows the regression of treatments on environment according to the model:

$$Y_{ij} = m_i + b_i I_{ij} + e_{ij}$$

Table 1. Maize yield (t/ha) at 12 percent moisture content from on-farm trials in a maize + cassava intercropping system in Ilugun LGA, Ogun State, 1986

Villages	Farmers	FO	HO	RO	FF	HF	RF	Mean	Index
Igbore	1	2.84	4.10	3.81	4.84	4.43	4.66	4.11	1.29
	2	3.04	3.67	4.03	3.26	4.22	4.74	3.83	1.01
	3**	3.00	3.84	2.01	4.14	5.87	5.17	4.01**	1.19
	4	1.93	1.45	2.14	2.63	1.95	3.05	2.19	-0.63
	5	1.30	1.05	2.41	1.90	3.09	4.04	2.30	-0.52
	6	1.57	1.66	3.43	3.33	1.83	3.27	2.52	-0.30
Odebo	7	2.83	3.98	3.31	3.84	4.48	4.20	3.77	0.95
	8	1.48	1.39	3.05	2.86	2.96	3.68	2.57	-0.25
	9	2.23	2.59	2.56	2.28	3.06	2.07	2.46	-0.36
	10**	2.37	3.03	3.81	3.46	4.12	4.64	3.57**	0.75
Akintoye	11	1.94	0.38	2.02	1.67	0.84	1.60	1.41	-1.41
	12*	0.16	1.36	1.23	1.13	2.55	2.27	1.45	-1.37
	13	1.26	2.21	3.59	2.68	1.61	3.70	2.51	-0.31
Otere-Ogunkola	14	1.41	3.29	3.54	2.52	1.56	2.63	2.49	-0.33
	15	2.23	2.93	2.48	3.60	3.64	4.07	3.16	0.34
	Mean	1.97	2.46	2.89	2.94	3.08	3.59	2.82	

Flat	Heaps	Ridges	Without fertilizer	With fertilizer
2.46b	2.77b	3.24a	2.44b	3.20a

Notes: Any 2 means followed by the same letter are not significantly different.
* Farm tampered with
** Adjacent farms grain yields (t/ha.) - local maize
Igbore 3: 1.70
Odebo 10: 1.09

where Y_{ij} = yield of treatment i on farm j (i = 1, 2 ...t; j = 1, 2 ...n).
The farm index $I_j = Y_L - Y/t_n$

A treatment with a small slope is stable, i.e., it varies little across farms and *vice versa* (Mutsaers et al. 1986). Figure 1 shows that ridges without fertilizer (RO) have the least slope, 0.56, with a mean yield of 2.89 t/ha. Nam (1984), however, following Hildebrand (1984), stated that treatment with a regression slope close to 1.0 implied that the treatment was stable, that is, it had little interaction with farms, and was thus favorable. FF with a mean yield (m_4 = 2.94 t/ha) is the most stable treatment (b_4 = 1.03). However, RF (m_8 = 3.59 t/ha and b_8 = 1.08) is recommended under the condition of the trial. Environmental factors such as rainfall distribution, and management practices, such as timeliness of weeding, plant arrangements, and pest attack influenced the expression of treatments.

Table 2. OFAR maize yields, 1986

Treatment	ΣI_{ij}	$\Sigma I_{ij} Y_{ij}$	ΣY^2_{ij}	Reg. SS_i	Res. SS_i	b_i
	(1)	(2)	(3)	(4)	(5)	(6)
FO	10.7003	8.0410	8.9428	6.0426	2.9002	0.751
HO	10.7003	13.0668	20.0121	15.9561	4.0554	1.221
RO	10.7003	5.9524	9.7553	3.3112	6.4441	0.556
FF	10.7003	11.0439	13.5732	11.3985	2.1747	1.032
HF	10.7003	14.4871	26.8855	19.6140	7.2715	1.354
RF	10.7003	11.6146	16.2200	12.6070	3.6130	1.085
Sum	64.2018	64.2058	-	68.9300	26.4589	-

(4) Reg. SS of treatment$_i$: Reg. $SS_i = (2)^2/(1)$
(5) Res. SS of treatment$_i$: Res. $SS_i = (3) - (4)$
(6) Reg. Coef. estimate of treatment$_i$: $b_i = (2)/(1)$
(7) Reg. SS $(I_1, I_2 \ldots I_t)$ = Reg. $SS_i = 68.9300$
(8) Reg. SS (I) $= (\Sigma\Sigma I_{ij})^2/\Sigma\Sigma I_{ij}^2 = 64.2098$
(9) Res. MS $= \Sigma$ Res. $SS_i/\Sigma(n-2) = 26.4589/78 = 0.3392$
$F = ((7) - (8)/(t-1))/(9) = 2.783^* > 2.33$

Flat with fertilizer $Y_4 = 2.94 + 1.03I$
Heaps with fertilizer $Y_5 = 3.08 + 1.53I$
Ridges with fertilizer $Y_6 = 3.59 + 1.08I$

Table 3 presents the ANOVA and shows that the main effects, seedbed and fertilizer, were highly significant. Ridges produced the highest mean yield (3.24 t/ha), followed by heaps (2.77 t/ha), and flat (2.46 t/ha), but the difference between the means of flat and heaps was not significant (Table 1). The remarkable yield advantage on ridges was due largely to the increased plant population obtained.

Table 3. ANOVA of maize grain yields, 1986

Source	DF	SS	MS	F
Farms	14	64.21	4.59	10.2
Seedbed	2	9.31	4.66	10.4***
Fertilizer	1	13.00	13.00	28.9***
Seedbed x fertilizer	2	0.52	0.26	0.6 ns
Error	70	31.18	0.45	
Total	89	118.22		

Note: CV = 24%

A highly significant yield increase (31.1 percent) was obtained with fertilizer (3.20 t/ha compared with 2.44 t/ha without fertilizer). The response to fertilizer application was largely due to low levels of N (0.15 percent) in all

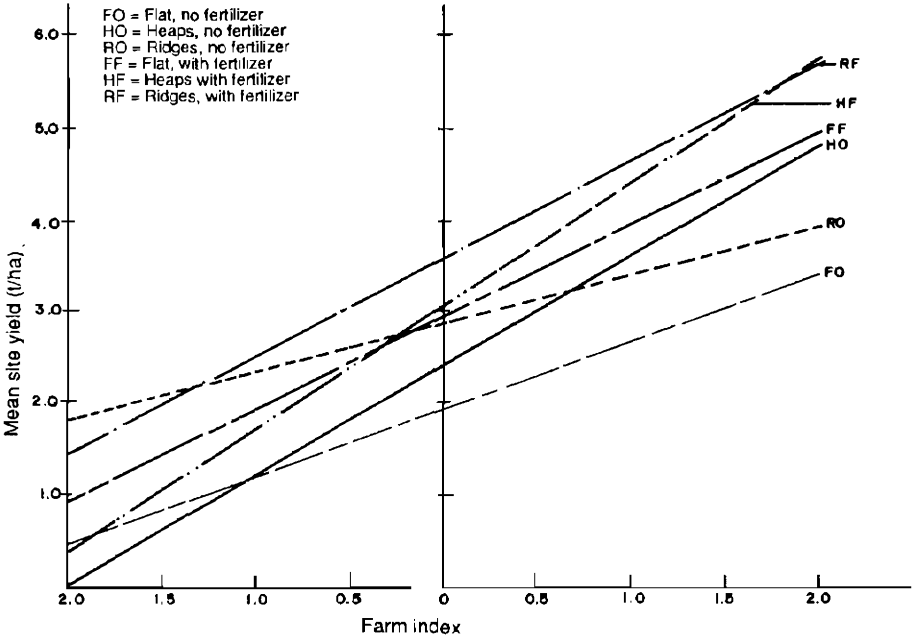

Figure 1. Regression of maize yields of six treatments on farm index, Ilogun LGA, 1986

the soils. The costs of fertilizer and labor for application were ₦ 60.00 and ₦30.00, respectively. With the selling price of dry maize at ₦ 450.00 per ton, the net profit in favor of fertilizer application would be ₦ 252.00/ha in addition to the revenue from cassava. It is noteworthy that yields of 3 - 5 t/ha were obtained with the application of fertilizer on at least 60 percent of the farms and on 33 percent without fertilizer, using improved maize (TZSR-W).

Mean grain yields ranged from 1.41 t/ha to 4.11 t/ha. The high yields obtained were due to timely planting, a high level of streak resistance exhibited by the maize cultivar, and favorable weather. By contrast, 1.70 t/ha and 1.09 t/ha were recorded on adjacent farmers' fields carrying the local maize which was highly susceptible to maize streak virus, in the villages of Igbore and Obebo (Table 1).

Cassava tuber yields

Cassava tuber yield for each treatment was also related to the environment by simple linear regression using the same technique as for maize.

The F test for farm-treatment interaction was not significant, implying that there was no significant difference in the treatments' reaction to the environmental index.

The CV is high, 28 percent, indicating a high variability of plots within farms, mean yields ranging between 3.73 t/ha and 18.88 t/ha (Tables 4, 5).

Table 4. Cassava tuber yield (t/ha) from on-farm trials of a maize+cassava intercrop at Ilugun LGA, Ogun State, 1986/87

Villages	Farmers	FO	HO	RO	FF	HF	RF	Mean
4	15	10.20	10.76	11.62	10.51	13.92	14.08	11.85
	Flat 10.36b		Heaps 12.34a		Ridges 12.85a			
	Without fertilizer 10.86b			With fertilizer 12.84a				

Note: Any two means followed by the same letter are not significantly different

Since the F test for farm x treatment interaction of cassava tuber yields is not significant, it suggests that the conventional analysis in treating each farm as a block in RCBD is appropriate (Nam 1984). Fresh cassava tuber yields are presented in Table 4 and ANOVA in Table 5. The two main effects, seedbed and fertilizer, were significant. Ridges produced a mean yield of 12.85 t/ha which was not different from 12.34 t/ha on heaps, but both yields were significantly higher than 10.36 t/ha on flat (24 percent and 10 percent increases, respectively).

Table 5. ANOVA of cassava yields, 1986

Source	DF	SS	MS	F
Farms	14	1,608.36	114.88	10.4
Seed-bed	2	103.92	51.96	4.7*
Fertilizer	1	87.69	87.69	7.9**
Seedbed x fertilizer	2	33.13	16.56	1.5N.S.
Error	70	773.40	11.05	
Total	89	2,606.50		

Note: CV = 28 %

With the selling price of cassava tubers at₦6-₦7.50/kg,₦120-₦140/ton) additional revenue in favor of ridges and heaps would be ₦324 and ₦258/ha respectively (Table 6 and Annex).

Planting cassava on ridges consistently produced higher yields than on flat. This is due to the improved seedbed, which was more suitable for root and tuber development, and higher plant population. Ridges also minimized erosion after rains since the excess water remained within the furrows. This also ensured a moist seedbed over longer periods and during dry spells, especially before the canopy was fully established. Finally, harvesting tubers was easier on ridges than on flat.

Cassava benefited from the residue of fertilizer applied to early maize. An average yield of 12.84 t/ha was obtained with fertilizer application, significantly higher than 10.86 t/ha without fertilizer (18.2 percent increase). The net profit from cassava from the use of fertilizer would be ₦258/ha which is in addition to the earlier profit of ₦252 from maize.

Table 6. Partial budget analysis of yield from on-farm trials in a maize + cassava intercropping system

Budget element	Trial treatments					
	F0	FF	H0	HF	R0	RF
A. 1. Mean maize yield (t/ha)	1.97	2.94	2.46	3.08	2.89	3.59
2. Gross field benefit (₦ /ha) at ₦450 per ton	886.5	1323	1107	1386	1341	1615.5
3. Mean cassava yield (₦/ha) at ₦200/ha)	10.20	10.51	10.76	13.92	11.62	14.08
4. Gross field benefit (₦/ha) at ₦200/ha)	2040	2102	2152	2784	2324	2816
Total gross benefit ₦ /ha (2 + 4)	2926.5	3425	3359	4170	3665	4431.5
B. Costs						
1. Land preparation:						
Land clearing (₦/ha)	150	150	150	150	150	150
Heap making (₦/ha)	-	-	375	375	-	-
Ridge making	-	-	-	-	375	375
2. Planting maize at (₦ man-days)	60	60	60	60	60	60
3. Planting cassava at (₦ man-days)	60	60	60	60	60	60
4. Planting materials : maize (25 kg/ha) at ₦2/kg + cassava cuttings)	50	50	50	50	50	50
5. Fertilizer application to maize	-	90	-	90	-	90
6. Fertilizer application to cassava (labor + fertilizer)	-	90	-	90	-	90
7. 3 Weedings at 10 mds/ha Each man-day is ₦6.00	180	180	180	180	180	180
8. Harvesting and processing /ha 25 man-days at ₦6.00 each	150	150	150	150	150	150
Total cost	650	830	1025	1205	1025	1205
Net benefit ₦/ha Total A - Total B	2276.5	2595	2334	2965	2640	3226.5

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Annex. Rates of return of on-farm trial treatment in maize+cassava intercrop

Rates of return	On-farm trial treatments					
	FO	FF	HO	HF	RO	RF
1. Net return (₦)	2,276.5	2,595	2,334	2,965	2,640	3,226.5
2. Total cost (₦)	650	830	1025	1205	1025	1205
3. Marginal cost (₦)	0	180	375	555	375	555
A. Average rate	--	$\frac{2505-2276.5}{830} \times 100$	$\frac{2334-2276.5}{1025}$	$\frac{2965-2276.5}{1025}$	$\frac{3226.5-2276.5}{1205}$	$\frac{2640-2276.5}{1025}$
	=	$\frac{318.5 \times 100}{830}$	$= \frac{57.5 \times 100}{1025}$	$= \frac{688.5 \times 100}{1205}$	$= \frac{363.5 \times 100}{1025}$	$\frac{950 \times 100}{1205}$
		= 38.4%	= 5.6%	= 57.1%	= 35.96%	= 78.84%*
B. Marginal rate	--	$\frac{2595-2276.5 \times 100}{180}$	$\frac{2334-2276.5 \times 100}{375}$	$\frac{2965-2276.5 \times 100}{555}$	$\frac{2640-2276.5 \times 100}{375}$	$\frac{3226.5-3276.5 \times 100}{555}$
		$= \frac{318.5 \times 100}{180}$	$= \frac{57.5 \times 100}{375}$	$= \frac{688.5 \times 100}{555}$	$= \frac{353.5 \times 100}{375}$	$= \frac{950 \times 100}{555}$
		= 176.9%	15.3%	= 124.1%	= 96.9%	= 171.2%

A. Target for Average Rate: Any on-farm trial any innovation where average rate of Return exceeds 40% merits further consideration and analysis. This is the situation *HF and *EF (Heal) with Fertilizer and Ridge with Fertilizer.

B. Marginal Rates of Return:

1. For FF (i.e., Flat with Fertilizer) Rate of Return is 176.9% That is on every additional Naira investment on fertilizer, these farms make a return of ₦1.76
2. For RF (i.e., Ridge with Fertilizer) rate of Return is 171.2% That is for every additional Naira investment on fertilizer and ridging, these farms make a return of ₦1.17
3. HF (i.e., Heap with Fertilizer) Rate of Return is 124.1%. that is on every additional Naira investment on heaping and fertilizer, these farms make a return of ₦1.24.

These high rates are significant and further investigations are needed to determine optimal levels of investment on these innovations.

An On-Farm Rice Variety Trial in a Toposequence of Inland Valley Swamps

M.C. Palada, P. Walker, T. M. Masajo and M. Jalloh

Rice yields vary according to the relative position of the paddy or plot along the toposequence of inland valley swamps (Palada et al. 1987). Under natural (farmers') field conditions with minimum or no water control, yields are normally lower in the valley fringe than in the valley bottom. This difference can be attributed to differences in soil fertility and soil moisture or water status (Moormann et al. 1977). Rice yield in the valley bottom is generally favored by better water status and relatively higher soil fertility level than in the valley fringe. Farmers have developed planting strategies to adopt varieties to these conditions (Richards 1985). Some farmers in inland valley swamps (IVS) plant specific varieties for each toposequence. For example, in Makeni, Sierra Leone, farmers plant early-maturing and short-statured varieties in the valley fringe, while tall and medium- to late-maturing varieties are planted in the valley bottom. This strategy used by farmers is based on water availability and duration rather than soil fertility (Palada et al. 1988, Wakatsuki et al. 1988).

Since field size in IVS is generally small and the division of a whole field into various sections along the toposequence would result in still smaller plots, the use of several varieties adapted for each section of the toposequence would be cumbersome to farmers. Using two or more varieties would also impose problems in maintaining a supply of pure seed.

The Rice Research Program at IITA has been developing varieties adapted to hydromorphic soils and shallow swamps. The objective is to identify genotypes that give acceptable yields under unfavorable moisture regimes, but can respond and yield well if conditions become favorable. In addition, these varieties should be appropriate for cultivation based on performance, farmer's need, and agronomic conditions. Some of the varieties developed have performed well in rainfed areas which are typical of IVS (Masajo et al. 1986; Masajo and Aquino 1987).

The objective of this trial is to subject these varieties to on-farm testings and to identify one or two best rice varieties with high and stable average yield. These varieties should be adapted to various sections of the toposequence of IVS and should, therefore, fit into the existing rice-based cropping systems of farmers in IVS.

Methods

This trial was conducted in two inland valleys near Bida, Niger state. Mention will also be made of a related trial at Makeni, Sierra Leone, during the wet season of 1988, which, however, had only two varieties in common with the Bida trial.

Factors

The factors expected to influence yield and which were included in this study are site (village), paddy status, toposequence, and variety. In Bida eight replicates were established in Gadza valley, a relatively favorable (high-moisture) valley, wide (100m) with a gentle slope (<2 percent). Two replicates were established in Gara, a relatively unfavorable (low-moisture) valley, narrow (50m) with a steep slope (2-5 percent). Both valleys have an informal irrigation scheme which is functional only during the rainy season. Farmers in both valleys recognized the importance of water control as shown by small and irregular bunds in their rice fields. In Gadza, the trial was set up both in improved paddy (bunded and leveled) with good water control and farmer's paddy (minimum bunding and leveling) with poor water control. In Gara, the trial was established in farmer's paddy only, as improved paddy was not available. In Gadza, each paddy was divided into valley fringe (upper) and valley bottom (lower). In Gara, the whole field was classified as a valley fringe. In both valleys, the distance of trial plots from the stream was measured to determine the relative location of the plots along the toposequence.

Eight varieties were planted in each section of the toposequence. In Makeni, the trial was conducted in Sawulia valley, a high-moisture IVS. The trial was established in one site using farmer's paddy (no bunding). The field was divided into three blocks representing three sections of toposequence: upper (valley fringe), middle and lower (valley bottom). Ten varieties including a local variety were planted in each toposequence.

Experimental design

Two randomized blocks of the eight varieties were laid out in each of the larger areas (superblocks) defined by combinations of paddy status x toposequence position. At Gadza (eight replicates), all four of these combinations were represented; at Gara (two replicates), only one. At Makeni (six replicates) the toposequence was divided into three groups instead of two, each containing unimproved paddy.

Sampling for yield data

For each plot, two samples, each measuring 1m x 5m ($5m^2$), were taken for grain yield. This consisted of a 5m length of the four middle rows. A total of 80 hills (stands) were harvested per plot. Averages of the two samples were used in the analysis of yield data.

Collection of other data

Data on plant characters such as height, total number of tillers, productive tillers, and number of days to 50 percent flowering were collected. Other data recorded were field water status, depth of ground water, and soil chemical properties.

Statistical analysis of data

No attempt was made to combine results from Sierra Leone and Nigeria since most of the varieties used were different in the two countries. At Bida, a balanced analysis is possible only for the plots at Gadza, and this is given in Table 1. The highly significant variety differences are not affected by the position on the toposequence (topo) where they are grown, or by improvement of the paddy. The increase in yield of 762kg from fringe to bottom is not quite significant because of the low DF at the block stratum.

Inclusion of the plots at Gara is complicated by the fact that the result is an unbalanced set of superblocks with respect to the endogenous factors of topo, paddy status, and site. Analyses of all Bida data including each of these singly in turn, and ignoring the other two, indicated it was likely that the last two were of little importance, together with their interactions with variety. Assuming that these two variety interactions can be ignored, a complete analysis was finally done, using topo and variety as block and plot factors respectively, then introducing successively site and paddy status as covariates, because of the lack of balance. We tried the effect of using the distance from the stream as a covariate in this last analysis, as an alternative to using topo as a factor at the two fairly coarsely grouped levels of fringe and bottom. Another analysis done on a balanced subset of the data, and the effect of omitting one variety which performed inexplicably badly at one site are not reported here. Its omission reduced the error variance and the interaction variety x site, but not so as to affect the conclusions.

The results from Makeni were separately analyzed with a linear regression component taken out for the (block) factor topo.

Results and discussion

Tables 1 and 2 report yield results from the eight blocks at Gadza. Variety differences were significant and topo effects very nearly so, with no interactions. Although all varieties produced (slightly) lower yields on farmers' (unimproved) paddy, the effect of paddy status was not significant. It should be noted that even the farmer's paddies had minimum bunding and water control which, combined with the favorable distribution of rainfall in 1988, meant that the gap would not be too wide from the improved paddy. Also, the improved paddy, in only its second year of operation, may have suffered from uneven distribution of clay and organic matter in the topsoil, particularly in the valley fringe where topsoil clay content is less than in the valley bottom. Once conditions are stabilized we may expect the effect of paddy status to increase.

Table 1. ANOVA of yield for balanced data from Gadza (Site 1), Bida 1988

Source of variation		DF	MS	F	Prob
Blocks:	Topo	1	9309364	7.24	0.10
	Paddy status	1	3611425	2.81	ns
	Topo x paddy	1	741106	0.58	ns
	Remainder	4	1284705	-	
Variety		7	2249619	3.91	<0.01
Variety x topo		7	418167	0.73	ns
Variety x paddy		7	536188	0.93	ns
Residual		35	575615	-	
Total		63	575615		

Note: ns = not significant

Table 2. Effect of toposequence and variety on grain yield (kg/ha) in Gadza (Site 1), Bida 1988

Variety	Toposequence: Fringe	Toposequence: Valley bottom	V mean
ITA 306	.3495	3800	3648
ITA 312	3192	3833	3513
TOX3118-6-E2-3	3313	4710	4012
TOX3118-87-4-2	3589	3891	3740
TOX 3088-3-1-1	1589	3077	2333
TOX3052-46-E2-1	3406	4019	3713
TOX3133-59-1-3	2818	3630	3224
FARO 15	2745	3277	3011
Topo mean	3018	3780	

Notes: SED for variety means ±379.3 CV = 22.3 %
SED for topo means ±536.5 CV = 15.9 %

Of the varieties, both ITA306 and TOX3118-6-E2-3 significantly outyielded FARO 15.

Table 3 reports the result of the analysis of all the blocks at Bida, for the two sites combined. The inclusion of Gara results in the topo difference now achieving significance; furthermore, the effect of paddy, as measured by the covariance, is much more important though not quite significant. There is no evidence of any interactions between variety and the endogenous factors. The table gives variety means adjusted for the covariates, paddy and site, and therefore may be read as giving a ranking of the varieties over the whole range of conditions encountered.

Table 3. Effect of toposequence and variety on grain yield (kg/ha) adjusted for paddy status and site as covariates

Variety	Toposequence: Fringe	Toposequence: Valley bottom	V mean
ITA 306	3705	3747	3722 *
ITA 312	3169	3780	3413
TOX3118–6-E2-3	3305	4657	3846 *
TOX3118-87-4-2	2762	3837	3192
TOX 3088-3-1-1	2152	3037	2506
TOX3052-46-E2-1	3308	3965	3571
TOX3133-59-1-3	2687	3576	3043
FARO 15	2631	3223	2868
Topo mean	2965	3728	

Notes: SED for topo means = ± 231.5 CV = 10.9 %
SED for variety means = ± 372.3 CV = 25.5 %

Farmers' paddy only with variety TOX 3118-87-4-2 omitted

Because we judged that farmer's (unimproved) paddy would continue to be the norm for some time to come, it seemed worthwhile to examine it in isolation. Furthermore, the above variety did very poorly at one site and was masking some important differences. If it is omitted, the analysis of Table 4 results, where the effects of topo (935 kg/ha) and the interaction of this with variety are also now significant. The two-way table of mean yields (Table 6) shows this to be caused by the greater improvement in varieties TOX 3118-6-E2-3 and, to a lesser extent, TOX3052-46-E2-1 as we move from fringe to bottom toposequence.

Table 4. ANOVA of data from farmers' unimproved paddy only, excluding TOX 3118-87-4-2

Source of variation		DF	MS	F	Prob
Blocks:	Toposequence	1	8158810	15.22	<0.05
	Remainder	4	536061	-	
Variety		6	12665219	3.30	<0.05
Variety x topo		6	945820	2.46	~0.05
Residual		24	383806	-	
Total		41			

Table 5. Effect of toposequence and variety on grain yield (kg/ha) in farmers' paddy, excluding one variety

	Toposequence		
Variety	Fringe	Valley bottom	V mean
ITA 306	3177	3301	3218
ITA 312	3196	3253	3215
TOX 3118-6-E2-3	2946	5236	3709
TOX 3088-3-1-1	2255	2681	2397
TOX 3052-46-E2-1	2942	4358	3414
TOX 3133-59-1-15	2358	3941	2886
FARO	2395	3044	2611
	2753	3688	

Notes: SED for variety means = ± 351.7 CV = 20.2 %
SED for topo means = ± 239.7 CV = 9.0 %
SED topo x variety means = ± 551.6 CV = 20.2 %

Analysis of variance using distance from stream as a covariate (not reported here) led, disappointingly, to a greater residual error than that obtained by use of the factor topo, probably because of uneven terrain. We shall in future attempt measurement of water table depth, which should be much more reliable.

The results of the analysis indicate that in Bida the relative position of the paddy in the toposequence is an important physical determinant of rice yield in IVS. Under the natural conditions of the existing farmers' paddies, the use of improved varieties with a high and stable average yield across toposequence would be a feasible short-term solution to low rice yields in IVS. Further investigation is needed to identify and understand what factors are responsible for differences in yields between valley fringe and valley bottom. Research will investigate the role of soil fertility and soil moisture. In addition, studies to characterize outstanding varieties which performed well across toposequence are important in order to understand the mechanism of varietal adaptation.

Table 6. ANOVA for grain yield at Makeni, Sierra Leone, 1988

Source of variation		DF	MS	F	Prob
Blocks:	Topo, linear	1	137540848	118.5	<0.001
	Topo, quadratic	1	9223989	7.9	<0.05
	Remainder	6	1160665	-	
Variety		9	705420	7.17	<0.001
Variety x topo linear		9	1137388	11.57	<0.001
Variety x topo quadratic		9	353021	3.59	<0.01
Residual		54	98345	-	
Total		89			

Effect of toposequence and variety, Makeni, Sierra Leone

Most IVS in Makeni have a natural water flow. Farmers' paddies have no bunds and, therefore, water control is nonexistent. The trial was conducted in farmers' fields where there is a natural flow of water. As shown in Table 6, analysis of variance indicates significant effects of toposequence, variety, and interaction of toposequence and variety. There is a significant linear effect of toposequence on yield. Rice yield increased by an average of 3 t/ha when grown from valley fringe to valley bottom (Table 7). Average yield in valley bottom was significantly higher than middle slope and valley fringe (Table 7).

Using DMRT, yields of varieties within each toposequence were compared. In valley fringe, five improved varieties significantly outyielded the local (farmers') variety. In the middle slope, six varieties had a better yield than the local variety and five in the valley bottom. Overall, four improved varieties performed better than the local check. Two varieties consistently outyielded the local check across toposequence. These varieties were TOX 3142-7-2-3-4 and ITA 230 (Table 7).

These results indicate that there are promising varieties for high rainfall IVS with no water control. These varieties are adapted to varying moisture and water status which occur under natural conditions of IVS. More testing sites should be included to verify the performance of these varieties.

Table 7. Grain yield (kg/ha) from rice variety trial in toposequence of inland valley swamps, Makeni, Sierra Leone, 1988 wet season*

Variety	Toposequence** Fringe	Middle	Bottom	Mean**
TOX3114-10-1-3-2	2020 c	1889 e	3961 e	2624 d
TOX3118-6-E2-3	1627 c	2172 b	5339 b	3226 b
TOX3118-47-4-2-2	1623 c	2970 a	4403 d	2999 bc
TOX3118-56-1-2-1	1152 h	2901 a	4425 d	2826 cd
TOX3133-56-1-3-3	1325 g	2583 bc	4900 a	3269 ab
TOX3142-1-1-1	1436 f	2290 d	5186 bc	2971 bc
TOX3142-2-3-4	2564 a	2902 a	5110 bc	3525 a
ITA 230	1014 d	2689 b	4986 c	3163 b
ITA 312	2180 b	2543 c	3845 e	2856 cd
Local check	1543 c	2154 d	4410 d	2703 cd
Mean	1728	2563	4757	3016
CV (5)	11.1	10.2	9.2	10.4

Notes: * Data from Rice-based Systems Working Group, RCMP.
** For each column any two means with common letter are not significantly different at 5% level by Duncan's Multiple Range Test (DMRT).

Summary

The use of a statistical tool such as the analysis of variance is effective in estimating experimental errors and detecting the importance of factors such as toposequence, paddy status, site and variety as determinants of rice yields in IVS. Based on the analysis, the important factors affecting rice yield in both locations (Bida and Makeni) are toposequence and variety.

In Bida, the effects of site and paddy status were not important. The slight differences in yield due to these factors can be attributed to somewhat improved farmers' paddy with minimum bunding and water control. Using site and paddy status as covariates and excluding one variety which performed poorly in one site, significant effects of toposequence and variety were enhanced.

In Makeni, the linear effect of toposequence on yield was highly significant. The interaction between toposequence and variety was more apparent in Makeni than in Bida. Average yield in the valley bottom was about two to three times higher than in the valley fringe and middle slope.

In Bida three improved varieties consistently and significantly yielded higher than the common variety, FARO 15, across toposequence, whereas in Makeni, two improved varieties consistently outyielded the local check across toposequence.

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An On-Farm Trial to Develop Maize Management Recommendations in Oyo State, Nigeria

L.T. Ogunremi

One of the four major agricultural policy objectives of the Nigerian Fourth National Development Plan (1981-1985) was the evolution of an appropriate institutional and administrative apparatus to facilitate the rapid development of the country's agricultural potential. This has led to government's efforts being geared towards increasing the production of food crops.

In the struggle for self reliance in food crops, peasant farmers continue to take the lead despite years of neglect of their concerns. The farmers of Ifedapo Local Government Area (LGA) of Oyo State are no exception. There is a need, therefore, to interact more closely with farmers through extension services and application of on-farm adaptive research.

The introduction of new varieties without the attendant production technologies may be of little value to farmers. An example is produced by farmers in Ifedapo LGA who adopted TZSR-W (a white, improved open-pollinated maize variety with streak resistance). To date, farmers continue to get yields far below the on-station yields. Based on the 1985 diagnostic survey and trials conducted in this area, low population, inadequate fertilization, and inappropriate weed control were identified as the major constraints on maize production. This study aimed to find solutions to these constraints or to help in further refining the recommendations. The Ifedapo LGA was chosen because of a relative homogeneity in its agroecology, market structures, and farming systems.

Experimental design and management

Nine replicates were used with five treatments. They were:

1. Farmers' production practices of wide and irregular spacing and dependence on hand-weeding. Fertilizer is applied once without micro nutrients and at a low rate (1.5m x 1m; 3 plants/hill (28,000) with 30:30:30 NPK.

2. 90 x 60cm at 2 plants/hill (40,000) with 72:30:30 NPK.

3. 90 x 20cm at 1 plant/hill (55,000) with 72:30:30 NPK

4. 90 x 60cm at 2 plants/hill (40,000) with 72:30:30 NPK and 2.5kg and 10kg of Zn and S, respectively.

5. 90 x 20cm at 1 plant/hill (55,000) with 72:30:30 NPK, 2.5kg and 10kg of Zn and S respectively.

Treatments 2-5 were given preemergence herbicide in addition to supplementary weeding.

Growth differences among treatments were observed on the field and yield data recorded. The participating farmers were interviewed on their assessment of the exercise carried out on their farms, using a structured questionnaire. Non-participating farmers who visited the fields were also interviewed.

The experimental variables were density, method of achieving the desired density, use of macro and micro nutrients, and method of weed control. The plot size was 0.025ha (10m x 25m). Agronomic, statistical, and economic analyses were done.

Results

Agronomic/statistical analyses

Plant population, number of cobs, and ear weight/ha were other factors looked at apart from grain yield. Values for each treatment are the means for nine replicates (Table 1).

Table 1. Effect of management practices on the yield and yield components of maize

Treatment	No. of plants/ha	No. of cobs/ha	Ear wt. (kg/ha)	Grain yield (t/ha)
1.	27876	19187	2258.2	1.51
2.	29813	23067	2777.5	1.88
3.	40187	31640	4000.8	2.78
4.	29604	24889	3021.1	2.06
5.	43373	34711	4438.8	3.02
LSD 5%	4255	3234	506.6	0.39
LSD 1%	5712	4349	681.3	0.52
CV (%)	12.9	12.7	16.0	18.0

The number of plants at harvest was controlled by planting density, even though the observed number in all the treatments was lower than expected. The reduction in the observed number was minimal for the control. Treatments 3 and 5 gave similar yields that were significantly above the yields from other treatments (Table 1). The number of cobs harvested from the control was far below those harvested from the other treatments. This is because farmers plant three to four seeds per hole. Without adequate plant nutrients, many plants were barren. Only about 69 percent of the plants under farmers' practices (treatment 1) had cobs, while in treatments 2, 3, 4 and 5, about 77, 79, 84 and 80 percent of the plants had cobs. Barrenness is thus one of the factors associated with farmer practices. The number of ears harvested in treatments 3 and 5 was still higher than with other treatments.

The weight of ears harvested from one hectare shows the same trend as plant stand and number of cobs which actually contributed and controlled the weight. The observed trend was T5 > T3 > T4 > T2 > T1. Treatments 5 and 3 had the same plant population at planting and the same application of the major elements. The yield difference between them could only come from the application of the minor elements (Zn and S). Plant population again contributed to the type of yields obtained from each of the treatments. The yield from treatment 4 was better than for treatment 2 due to minor elements. Treatment 1 was very inferior to others because of low density, plant number/hill, fertilizer level, and weed problems. This caused barrenness in some plants.

Economic analyses

Total costs that vary. In the compilation of the total costs that vary and the variable inputs, negligible costs are entertained. By way of definition, costs that vary are the costs/ha of purchased inputs, labor, and machinery, that vary between experimental treatments. Two other terms are introduced at this point, viz., field price and field cost. Field price is the value which must be given up to bring an extra unit of input into the field expressed in units of sale, e.g., ₦/kg seed, ₦/L herbicide, and so on, while field cost is the price multiplied by the quantity of the input needed for a given area.

The variable inputs here are planting, herbicide cost and application, fertilizer cost and application, weeding, and harvesting. Table 2 shows the details after employing field price and field cost.

The partial budget. The organization of experimental data and information about the costs and benefits of various alternative treatments is partial budgeting. It deals with (a) average yield, (b) adjusted yield, (c) gross field benefits, (d) total costs that vary, and (e) net benefits.

Table 2. Total costs that vary for density, fertilizer, and weed control experiment

Variable inputs	T1	T2	T3	T4	T5
Labor					
Planting	59.75	104.0	170.25	110.75	194.25
Herbicide application	-	14.75	13.75	13.25	14.25
Fertilizer application	44.25	127.5	183.5	114.75	172.25
Weeding 1st	105.25	79.5	86.0	106.5	101.75
2nd	67.25	-	-	-	-
Harvesting	117.5	259.25	328.0	185.25	320.5
Inputs					
Seed	13.0	18.0	25.0	18.0	25.0
Herbicide	-	140.0	140.0	140.0	140.0
fertilizer	40.0	90.0	90.0	93.0	93.0
Total costs that vary (₦/ha)	447.0	833.0	1036.5	781.5	1061.0

Notes: 1. Assume 8 hours/man-day at ₦5.00/man-day
2. Seeds of TZSR-W to cost ₦1.00/kg in 1986 and 25kg to give 55,000 stands/ha.
3. Elemental S and $ZnSO_4$ to cost ₦7.60 and ₦ 8.50 per 50kg, respectively.
4. A liter of Atrazine™ costs ₦ 35.00: 4 liters required/ha

a. Average yield. The average yields are yields of each treatment after the recommendation domain has been established. The yields are presented in Table 1. Since statistics show yield differences among treatments, a partial budget had to be developed (or the one with lowest total costs that vary should be chosen for further experimentation or recommendation).

b. Adjusted yields. These are average yields adjusted downward by a certain percentage to reflect the differences between the experimental yield and the yields farmers could expect from the same treatment due to differences in management, plot size, harvest date, and form of harvest (for a realistic appreciation of farmers' conditions). In this particular example, the average yields were not adjusted for the trend.

c. Gross benefits. Since the sale price of N650/t was assumed (for 1986), the gross benefits from the treatments were T1 = ₦981.50; T2= ₦1,222.00; T3 = ₦1,807.00; T4 = ₦1,339.00; T5 = ₦1,963.00.

d. Total costs that vary. The total costs that vary for the different treatments are presented in Table 2.

e. Net benefit. The net benefit is the gross benefit minus the total costs that vary. This is presented in the table of the partial budget (Table 3).

Table 3. The partial budget for the density/fertilizer and weeding treatments

	Treatment				
	1	2	3	4	5
Average yield (t/ha)	1.51	1.88	2.78	2.06	3.02
Adjusted yield (t/ha)	1.51	1.88	2.78	2.06	3.02
Gross benefits (₦/ha)	981.50	1,222.00	1,807.00	1,339.00	1,963.00
Total costs that vary (₦/ha)	447.00	833.00	1,036.50	781.50	1,061.00
Net benefits (₦/ha)	534.50	389.00	770.50	557.50	902.00

Marginal analysis. This deals with the method for comparing the costs that vary with the net benefits. Farmers are usually interested in seeing the increase in costs required to obtain a given increase in net benefits. The steps in marginal analysis are dominance analysis, plotting a net benefit curve, and computing a marginal rate of income.

a. Dominance analysis. This is an initial examination of the costs and benefits of each treatment that serves to eliminate some of the treatments from further consideration, thereby simplifying the analysis. A dominance analysis is thus carried out by first listing the treatments in order of increasing costs that vary. Any treatment that has net benefits that are less than or equal to those of a treatment with lower costs that vary is dominated.

The analysis in Table 4 shows that to improve farmers' income it is important to pay attention to net benefits, rather than yields. The yields of treatment 2 are higher than those of treatment 1 (Table 4), but the dominance analysis shows that the value of the increase in yields is not enough to compensate for the increase in costs. Farmers would then be better off using large, irregular spacing dependent on hand weeding, and applying fertilizer once at a lower rate without the micronutrients rather than planting at 90 x 60cm at 2 plants per hill with 72:30:30 with the application of herbicide. The population was too sparse to warrant the use of this fertilizer level and the use of herbicide.

The dominance analysis has then eliminated treatment 2 from further consideration. To compare treatment 1 with treatments 3, 4 and 5, further analyses will be required, for example, by constructing a net benefit curve/ marginal rate of return.

Table 4. Dominance analysis for density, fertilizer, and weeding experiment

Treatment	Average yield (t/ha)	Total costs that vary (₦ /ha)	Net benefit (₦ /ha)
1	1.51	447.00	534.50
4	2.06	781.50	557.50
2	1.88	833.00	389.00
3	2.78	1036.50	770.50
5	3.02	1061.00	902.00

b. Net benefit curve/marginal rate of return. In a net benefit curve, each of the treatments is plotted according to its net benefits and total costs that vary. The alternatives that are not dominated are connected with lines. The slope of the line that connects one treatment to another is the marginal rate of return. This is an indication of what farmers can expect to gain, on the average, in return for their investment when they decide to change from one practice or set of practices to another.

An easier way is by calculating marginal net benefits (i.e., the change in net benefits) divided by the marginal cost (i.e., the change in costs), expressed as a percentage. In this case, the marginal rate of return for a change from treatment 1 to treatment 4 is:

$$\frac{\text{₦}557.50 - \text{₦}534.50}{781.50 - 447.00} = \frac{23.00}{334.50}$$

The marginal rate of return for moving from practice 1 to 4, 4 to 3, and 3 to 5 are 6.87 percent, 83.53 percent, and 536.73 percent respectively. The implications are that in a change from treatment 1 to 4, 4 to 3, and 3 to 5, for any additional ₦1.00 spent in carrying out the change, the farmer recovers his ₦1.00 and gains an additional ₦0.07, ₦0.84 and ₦5.37, respectively.

Summary

The best treatment from the point of the farmer is 5. This is because, for any additional ₦1.00 spent in changing from treatment 1 to 5, the farmers recover their ₦1.00 with an additional ₦5.99. This is attractive enough for the majority of the farmers.

The complete analysis of agronomic, statistical, and economic data enables one to make a better assessment of recommendations to farmers. The agronomic analysis gave a visual analysis of the performance of maize under the five treatments.

Table 5. Marginal analysis for density, fertilizer, and weed control experiment

Treatment	Costs that vary (₦/ha)	Marginal costs (₦/ha)	Net benefit (₦/ha)	Marginal net benefit (₦/ha)	Marginal rate of return (%)
1	447.00	334.50	534.50	23.00	6.87
4	781.50		557.50		
3	1036.50	255.00	770.50	213.00	83.53
5	1061.00	24.50	902.00	131.50	536.73

The statistical analysis gave us information on whether to choose the treatment with the lowest total costs that vary or to proceed to the next step, economic analysis.

Finally the economic analysis presented the most sound base on which to decide either to recommend a given treatment to farmers (or to go for further verification).

Our conclusion was that farmers in Ifedapo LGA of Oyo State should grow TZSR-W (open-pollinated. maize variety) using the following technology:

Spacing; 90 x 20cm at 1 plant/hill.

Fertilizer: 72: 30:30 kg/ha of N, P_2O_5 and K_2O, respectively and 2.5 kg/ha and 10 kg/ha of Zn and S, respectively.

Since treatment 3 is next to treatment 5, plant population is the dominant factor in contributing to increases in yield. However, additional benefits accrue from the application of micronutrients which give even more significant yield increases.

The participating farmers were interviewed using a structured questionnaire. They ranked the component technologies in the following decreasing order: population, fertilization, and the use of herbicide.

The non-participating farmers who visited the OFAR sites were impressed by the results, and it was apparent that the exercise had created an awareness and generated an interest in the use of the improved technologies.

On-Farm Evaluation of Chemical, Manual, and Cultural Practices in Integrated Weed Management in a Yam+Maize Intercrop

Ray P.A. Unamma and F.O. Anuebunwa

A benchmark survey of farming systems in the eastern zone of Nigeria identified weed control in yam+maize intercrop as one of the major agricultural constraints to increased productivity in intercropping. The yam+maize intercrop is one of the commonest cropping systems in the zone (Okigbo 1978; Unamma et al. 1985b). On the basis of this preliminary survey, a series of upstream research projects aimed at developing component technologies for removing the constraints were initiated at the National Root Crops Research Institute, (NRCRI), Umudike. Prototype component technologies were developed including economical ways of controlling weeds by the combined use of herbicides and low-growing crops in yam+maize or cassava+maize intercrop (Unamma et al. 1985b; Unamma et al. 1985c).

Since NRCRI adopted the Farming Systems Research approach (essentially modeled after Shaner et al. 1982), it was appreciated that the development of appropriate technologies requires on-farm testing with the involvement of farmers as a low cost rapid approach to the introduction of research results to the ultimate users (Shaner et al. 1982). In 1983, NRCRI in collaboration with the Federal Agricultural Coordinating Unit (FACU) and the International Institute of Tropical Agriculture (IITA), Ibadan, conducted diagnostic research on the farming systems in the Umuahia area of Imo state for the Imo State Agricultural Development Project (ISADEP). The survey area was selected by a combined team of specialists from the collaborating organizations (Odurukwe et al. 1984).

The sites were chosen to be reasonably representative of the area under ISADEP in the Umuahia zone and of a magnitude that could be effectively monitored by one on-farm research team during the follow-up experimentation stage. The diagnostic survey showed that the major constraints to agricultural productivity in the farms of the Umuahia-ISADEP Extension area included weed infestation. Experimental technologies from upstream research were identified to be used in trials. These were yam intercropped with maize and egusi, relayed with cowpea, and economical ways of controlling weeds by the integrated use of herbicides and low-growing crops in the yam+maize intercrop.

After the exploratory survey and subsequent identification of appropriate technologies for resource-poor farmers, options for trials were considered and selected at a workshop organized by FACU and attended by all OFAR teams in the southern agricultural zone of the country. The trial which is presented here had the following objectives: (a) to use researcher-managed methods of on-farm adaptive research to determine the practicability, economics, and acceptability of specific weed control methods in yam-dominant cropping systems; (b) to evaluate weed control methods in yam+maize intercrop which involved integrated use of egusi and herbicides.

Farm site selection

The research sites were selected during the diagnostic survey. The characteristics of the farm sites chosen for the trial were:

- Areas with a fairly high degree of uniformity.
- Areas where it was possible to group the participating farmers into units who had similar management practices and cultivated the major crops being tested, i.e., yam and maize.
- Areas where a number of small farmers or farmer groups greater than 20 per replicate or block could easily be found.
- Areas where it was possible for each participating farmer to provide at least one 5m x 5m plot or multiples of that.
- Sites where it was relatively easy to form six groups of farmers— each group forming a replication (provided each group allocated sufficient land that was collectively contiguous for the replicate of the trial).
- Sites that were accessible all through the season and located not more than two kilometers from motorable roads.
- Sites that were scheduled for growing the particular crop(s) under test in 1985 and 1986.
- Farmer communities selected were not divided by factions.

Selection of locations

Bende, Ikwuano, Olokoro/Oboro and Uzuakoli ISADEP blocks were selected. Two of the sites at Bende were characterized by loamy sand soils and the other two by gravelly clay. The sites had been in fallow for five years. All the four sites at Ikwuano were characterized by clayey soils and had been in fallow for six years. Olokoro/Oboro had sandy loam soils and had been in fallow for two years. Uzuakoli block sites were characterized by their clayey soil. They had been in fallow for three years.

Selection of farmers

The farmers chosen to participate possessed the following characteristics:

- They were willing to accept innovations.
- They were ready to provide the same labor as under normal non-research situations.
- They were traditional farmers using their normal practices. They were selected over those already enjoying benefits of any special agricultural programs.
- They were ready to be guided by the OFR staff and to carry out operations as prescribed.
- They were younger men/women. They were chosen since there is a common belief that it is more difficult to deal with older male farmers than younger ones or women.
- They would cooperate without financial incentives other than free planting materials.

Experimental treatments

The land was cleared by slashing and burning. In each replication, land preparation consisted of either mounds or ridges. Mounds were tied to form ridges in such a way as to maintain 1m spacing between the rows of connected mounds or ridges, with the ridges running across the slope.

The plots in each replicate were contiguous and each replicate was owned by one or more farmers. The plot size was originally planned to be 10m x 10m but for financial reasons this size was restricted to Olokoro/Oboro. The size at the other locations was 5m x 5m. The 200g yam (Nwopoko) sett sizes were planted 100cm apart along the crests of the ridges or mounds arranged in definite rows (10,000 stands/ha). Maize (FARZ 7) was interplanted at the rate of three seeds thinned to two plants/stand at 14 days after planting (DAP) which worked out to 40,000 stands/ha, 100cm apart on both sides of the ridges and positioned between two yam stands. Egusi (NIHORT improved) was planted at three seeds per hole, thinned to two plants per stand 14 DAP along the crests of the ridges 50 to 100cm apart, which resulted in a range of 20,000-40,000 stands/ha and was planted between the yam and two pairs of opposite maize stands. The planting of each crop in a replicate was completed on the same day. Cowpea (IT82 E-60) was introduced into the relevant plots in the last week of August at populations of 40,000 stands/ha. The seeds were planted at two seeds/hole 50cm apart opposite one another along both sids of the ridges.

The treatments tested were:

1. Yam+maize manually weeded by hoe at 3, 8, and 12 weeks after planting (WAP) (which is the current production recommendation);
2. Yam+maize that received preemergence application of either Alachlor™ (2kg ai/ha)+Fluometuron™ (2.5kg ai/ha) or Chloramben™ (3.4kg ai/ha), plus one hand hoeing at 12 WAP;
3. Yam+maize intercropped with egusi (40,000/ha) and unweeded to maturity;
4. Egusi (20,000/ha) plus one hand-hoeing at 12 WAP;
5. Egusi (20,000/ha) plus preemergence Chloramben™ (3.4kg ai/ha);
6. Egusi 20,000/ha + preemergence Alachlor™ (2kg ai/ha) + Fluomenturon™ (2.5kg ai/ha);

A Cooper Pegler 3 knapsack sprayer fitted with a red polijet nozzle with a 2m swathe was used in applying the chemicals at a rate of 300 - 350 liters/ha.

The treatments were arranged in a randomized complete block design and each was replicated five times at each location. Yield, financial benefit, and farmers' responses were used to evaluate the five treatments. A postharvest survey was conducted to monitor the farmers' responses to the trials.

Results

Weeds

The dominant weeds at each of the locations during the two years were: *Ageratum conyzoides* (goat weed), *Aspilia africana* (African marigold), *Cleome ciliata* (consumption weed), *Chromolaena odorata* (Siam weed), *Commelina* *benghalensis* (day flower), *Tridax procumbens* (tridax), *Digitaria horizontalis* (crabgrass), *Panicum maximum* (guinea grass), *Paspalum orbiculare* (rice grass), *Cyperus rotundus* (purple nut sedge), *Mariscus alternifolius* (umbrella flat sedge) and *Kyllinga nemoralis*.

Table 1 shows the effect of the different weed management techniques on the component yields + maize intercrop under farmers' field conditions. The maize component was least affected by weed management. Generally, all the treatments were as good as or significantly better than the current practice of three timely hand-hoeings carried out at 3, 8, and 12 WAP. The only exceptions were the use of egusi at 40,000 stands/ha without any weed control measures, and egusi at 20,000 stands/ha plus preemergence Chloramben™ (3.4kg ai/ha). Yam yields were affected in these cases.

Economic viability analysis

Economic analysis of the results showed that generally all the weed management practices tested were economically viable (Table 2). In general, the returns on capital investment were higher with treatments involving the use of herbicides than those without. Preemergence application of tank mixtures of Alachlor™ (2kg ai/ha) and Fluometuron™ (2.5kg ai/ha) gave an 83 percent return on capital (₦3497/ha profit) from the yam + maize intercrop.

Table 1. Effect of different weed management techniques on yields of yam/maize/intercrop under farmers' field conditions, Umuahia, 1985 and 1986

	Crop yield (average of 3 locations)*			
	1985		1986	
Weed control measure	Yam	Maize	Yam	Maize
1. Weeded 3+8+12 WAP	10.7 b	5.3 a	6.7 b	5.0 a
2. Egusi 40,000/ha	4.6 d	3.3 b	5.3 b	4.6 a
3. Egusi 20,000/ha+weeding 12 WAP followed by cowpea 40,000/ha	12.1 a	5.2 a	6.6 b	4.3 a
4. Egusi 20,000/ha+preemergence +Chloramben™ (3.4kg ai/ha)	5.9 d	2.8 b	7.3 ab	4.3 a
5 Egusi 20,000/ha+preemergence Alachlor™ (2kg ai/ha)+ Fluometuron™ (2.5kg ai/ha)	10.2 b	4.3 ab	8.3 a	4.0 a
6. Preemergence Chloramben™ (3.4kg ai/ha)+weeding 12 WAP				
7. Preemergence Alachlor™ (2kg ai/ha)+ Fluometuron ™ (2.5kg ai/ha)	9.9 a	3.9 ab	6.7 b	4.3 a

Note: *Figures followed by similar letters are not significantly different at 0.05 level according to Duncan-Newman multiple range test

Acceptability test

Table 3 shows that, generally, the most acceptable weed management measure for resource-poor farmers is intercropping egusi at 20,000 stands/ha followed by one manual weeding carried out at 12 WAP before relay intercropping with cowpea at 40,000 seeds/ha. In the alternative, any of the treatments containing Alachlor™ and Fluometuron™ could be employed.

Discussion

The results of this trial showed that even though all the treatments compared favorably with the current production recommendation, the farmers preferred the technology which gave the least returns (₦1,336.00) compared with all the others (₦ 1,837 - ₦ 3,497). The farmers' choice of the weed management measure was mostly influenced by the time saved for other farm operations, and by the additional crops in the mixtures, particularly cowpea. Most of the farmers said that they were interested in the control measure with egusi at high populations but that the treatment resulted in no yields from the egusi component.

Table 2. Economic evaluation of effects of different weed management techniques on yam+maize intercrop under farmers' field conditions, Umuahia, 1985 and 1986

Weed control measure	Crop yield (average of 2 years and 3 locations): Total returns (₦/ha)	Total cost (₦/ha)	Gross margin (₦/ha)	Return on capital %
1. Weeded 3 + 8 + 12 WAP	7168	4639	2529	55
2. Egusi 40,000/ha	6280	4343	1837	46
3. Egusi 20,000/ha + weeding 12 WAP followed by cowpea 40,000/ha	5929	4593	1336	30
4. Egusi 20,000/ha + Chloramben™ (3.4kg ai/ha) preemergence	6800	4974	1826	37
5. Egusi 20,000/ha + preemergence Alachlor™ (2kg ai/ha) + Fluometuron™ (2.5kg ai/ha)	7709	4263	3446	80
6. Preemergence Chloramben™ (3.4kg ai/ha) + weeding 12 WAP	7008	4500	2508	56
7. Preemergence Alachlor™ (2kg ai/ha) + Fluometuron™ (2.55kg ai/ha)	7700	4203	3497	23

Notes: 1. Based on 1985/86 costs of:
Chloramben™ @ ₦7/Fluometuron™ @ ₦8
Alachlor™ @ ₦ 8/egusi @ ₦2/kg, Cowpea @ ₦1.6/kg, labor @₦8/man-day.

The scientific basis for including the yam+maize+egusi intercrop followed by cowpea after one hand-weeding was to use relay intercropping of relatively high populations of low growing crops, egusi that requires early (March/April) planting, and cowpea requiring late (September) planting to control weeds in yam+maize fields. It was also aimed at introducing improved varieties of cowpea into the farming systems with a view to increasing the protein base of a region that predominantly consumes roots and tubers.

It was observed that the egusi component provided the early soil cover needed for yam, which initially is slow in forming a canopy. Egusi not only suppressed weed growth, but also protected the soil from the destructive impact of the heavy rains associated with the zone. Furthermore, as the maize and egusi were withdrawing from any possible intercrop competition, the cowpea component was introduced to continue with soil protection and weed control. The one hand-weeding, carried out after the maize harvest and before the cowpea was planted, was not considered necessary by scientists since yields showed no significant changes when the weeding was not done in on-station trials. Farmers, however, were known to prefer cleaner plots (Unamma et al. 1985c). Weed management production recommendations for resource-poor farmers, based on the results of this trial, were formulated for multilocational trials in the southeastern states of Nigeria. The recommendation made was a yam+maize+egusi intercrop (20,000 seeds/ha) followed by cowpea (40,000/ha) with hand-hoe weeding at 12 WAP.

Table 3. Weed management measures rated most acceptable by farmers in Umuahia ADP Zone, Imo State, 1985-1986

Weed control measure	Trial site responses		
	Bende	Ikwuano	Olokoro
	% of farmers		
1. Weeding 3 + 8 + 12 WAP	5	10	10
2. Egusi 40,000/ha	0	5	5
3. Egusi 20,000/ha + weeding 12 WAP followed by cowpea 40,000/ha	40	55	56
4. Egusi 20,000/ha + preemergence Chloramben™ (3.4kg ai/ha)	10	15	25
5. Egusi 20,000/ha + preemergence Alachlor™ (2.0kg ai/ha) + Fluometuron™ (2.5kg ai/ha)	15	20	25
6. Preemergence Chloramben™ (3.4kg ai/ha) + weeding 12 WAP	5	10	10
7. Preemergence Alachlor™ (2kg ai/ha) + Fluometuron™ (2.5kg ai/ha)	50	20	25
Total number of farmers responding	20	16	20

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On-Farm Evaluation of Improved Cassava Varieties in the Kasangulu Zone of Bas-Zaïre

O. A. Osiname, L. Simba, C. D. Bartlett, R. Mayala and K. Kasongo

Farming Systems Adaptive Research (FSAR) was introduced into the research activities of the national cassava program, Programme National de Manioc (PRONAM) 12 years after cassava improvement research started in PRONAM. At the time of FSAR introduction, two cassava varieties were already in use, Kinuani in the Bas-Zaïre Region and F100 in Bandundu Region. A third variety, 40230/3, was about to complete its breeding cycle and was later selected as a viable alternative to F100 in light-textured savanna soils. The objectives of this research therefore were:

- to monitor the performance of these varieties under variable farmer conditions;
- to determine farmer assessments of existing PRONAM varieties; and
- to determine feedback to on-station research.

Methodology

From the diagnostic survey of the Kasangulu zone, the low yields and disease susceptibility of local varieties of cassava along with poor soil fertility were identified as major constraints to cassava production. In the first year, Kinuani and F100 were chosen as likely technology (varieties) to address these constraints.

Kinuani is a variety highly resistant to cassava bacterial blight (CBB), low-ramifying, early maturing and high-yielding. F100 has an erect stem and is high-yielding, but is not as tolerant to CBB as Kinuani. In the second trial, a new clone, 40230/3, replaced Kinuani in the trials. Clone 40230/3, like Kinuani, is ramifying, but at a greater height above the ground. It is also late-maturing, high-yielding, and resistant to CBB. The experiment consisted of two improved cassava varieties being evaluated along with the local varieties commonly grown by the farmers. The most frequently encountered local varieties of cassava in the area of test were Kidamu, Sumbakani, and Kidombe.

Site selection

Four villages, Kiboeya, Kinseki, Selo and Kimpika, considered a representative milieu within the area of diagnostic survey, were selected for soliciting participation by farmers. In 1986, the site selection exercise started as early as September after land clearing, but before the heaps were made. An area of 30m x 10m was pegged out within each farm and the farmers were asked to complete the land preparation. In nine out of the ten farms selected for the experiment, the pegged area was ignored until operations were completed in the rest of the field. The result was about two weeks' delay in planting. In 1987, however, only farmers whose farms were ready for planting were selected as participants. All farms selected consisted of land just opened from secondary forest fallows. The length of the fallows, however, varied from six to ten years. The method of land preparation was remarkably similar and consisted of slash and burn, gathering of wood for charcoal production (or direct sale in Kinshasa for fuel), and construction of heaps.

Landforms in the area consist of V-shaped valleys with slope gradients up to 40 percent or higher in some places. Most crop cultivation is on the slopes. The trial sites were, therefore, located on slopes of varying degrees.

Site characterization

The sites were located in the expansive forest Arenoferrals of the Kalahari sand origin. The soils are uniform, deep, and highly-leached medium sands. The color of the top soils ranged from dark brown to brown depending on the age of the forest fallow and organic matter accumulation. The subsoils varied from light brown to near white at depth. All sites were, therefore, susceptible to severe moisture stress during the dry season.

Sites were characterized by topography, number of heaps per plot, and level of soil fertility. Since there was no facility for soil analysis, soil fertility was rated as low, medium, or high, depending on the growth and vigor of the maize intercrop on each farm.

At planting, each farmer was supplied with cuttings of improved cassava varieties F100, Kinuani, or 40230/3. The farmers supplied their own local varieties. All cultural practices were those of the farmers. Intervention by the researchers was limited to observations and data collection on plant population, vigor, disease and pest attacks, and tuber yield at harvest.

Since the farmers do not normally harvest their crops in 12 months as recommended for PRONAM varieties, half of the plot was harvested at 12 months. The remaining half was harvested at intervals ranging from 16 to 18 months, depending on wnen the farmer was ready to harvest his own crop.

Results

The number of heaps per 70m² plot varied from 39 to 70 with an average of 53. At two cuttings per heap plant population/ha at planting should have been between 11,000 and 20,000. At harvest, however, the population ranged from 6857 to 17,400/ha. It appears that even though farmers plant at higher densities than that recommended by researchers, by harvest time the surviving stands come down to near the recommended 10,000/ha. Soil fertility was rated as low in three sites, medium in five sites, and high in three sites.

Poor cultural practices such as poor weed management lead to strong competition from weeds. There is also some destruction by animals. It was observed that the fast-growing and erect variety, F100, was as good as the local varieties in competing with weeds. The slow-growing and ramifying varieties, Kinuani and 40230/3, were more readily submerged under poor weed management practices.

Kinuani was also observed to be more sensitive to drought, a condition that is commonly experienced in these deep sands during the dry season. At the peak of the dry season in August 1987, the stems half way down the plant had dried up . A decision was thus taken to drop Kinuani from further tests.

Observations on the incidence of disease taken three months after planting showed no significant differences among the varieties, even though the degree of attack varied slightly with sites. The severity of mosaic and anthracnose diseases was generally higher than that of cassava bacterial blight in all sites.

The harvest of the 1986 crop, at 12 months after planting, showed that tuber yield from Kinuani was superior to that of F100 or local varieties (Table 1). Delaying harvesting to 18 months after planting raised tuber yields by 58.2 percent, 42.2 percent and 19.2 percent for F100, local, and Kinuani respectively. The early maturity of Kinuani and its high yield in these sandy soils offer two advantages to the farmers: first as an early source of food and cash, and second in the reduction of losses due to damage caused by bush animals. On the other hand, F100, which is a fairly sweet variety, appears to be more prone to damage by animals under poor weed management practices.

Table 1. Tuber yields (t/ha), average of all sites, at 12 and 18 months after planting

	1986-87 season		1987-88 season
Variety	12 months	18 months	12 months
Kinuani	9.4	11.2	-
40230/3	-	-	15.3
F100	7.2	11.4	11.8
Local	6.4	9.1	11.0
SE±	0.85	2.29	0.93
CV (%)	29.0	31.6	10.7

Mean yields for all sites for the three varieties tested in 1987/88 season are presented in Table 1. The mean yield for clone 40230/3 was significantly higher than those of F100 and local varieties. As in the previous year, the difference between F100 and local varieties was not significant.

The soil fertility ratings determined for each site during crop growth were used to calculate average tuber yield for each variety at low, medium, and high soil fertility. The results (Fig.1) show that the yield superiority of PRONAM varieties over local varieties is evident only under conditions of medium and high soil fertility. The data also show that clone 40230/3 was more responsive to high soil fertility than F100 and local varieties.

Stability analysis was performed for each year's data, using the site means of the three varieties tested as an index of environment. The regression lines are shown in Figures 2 and 3.

In the 1986/87 season, although the range of the environmental index was narrow, Kinuani showed the best adaptability in both poor and high-yielding environments. The slope of the regression line was 0.46. With a slope of approximately 1.0 and a reasonable mean yield of 7 t/ha, F100 shows a general adaptability (average stability) at both poor and high-yielding environments. The very low regression coefficient (b = 0.04) associated with the local variety is taken as a measure of greater resistance to environmental change (above average stability), and therefore increasing specificity of adaptability to low-yielding environments.

In the 1987/88 season, the individual yields of all varieties increased as the environmental index improved from poor to high. The high regression coefficient (b = 1.45) for clone 4230/3 shows that it is a variety with increasing sensitivity to environmental change (below average stability), and greater specificity of adaptability to high-yielding environments, a fact that is well illustrated in Figure 1. The variety F100 again emerged as one with general adaptability (b = 0.92) to all environments. In this trial, the local varieties showed a general adaptability to all environments, although not as strongly as F100 (b = 0.79). The inconsistent behavior of the local varieties may be explained by the fact that farmers usually plant 2 to 3 local varieties in unpredictable proportions in their plots.

Farmer assessment

In both cropping seasons, F100 was the unanimous first choice of farmers over Kinuani and 40230/3. The reasons for choosing F100 were:

- Fast-growing and competes well against weeds.
- Erect stem structure makes it easy for intercropping.

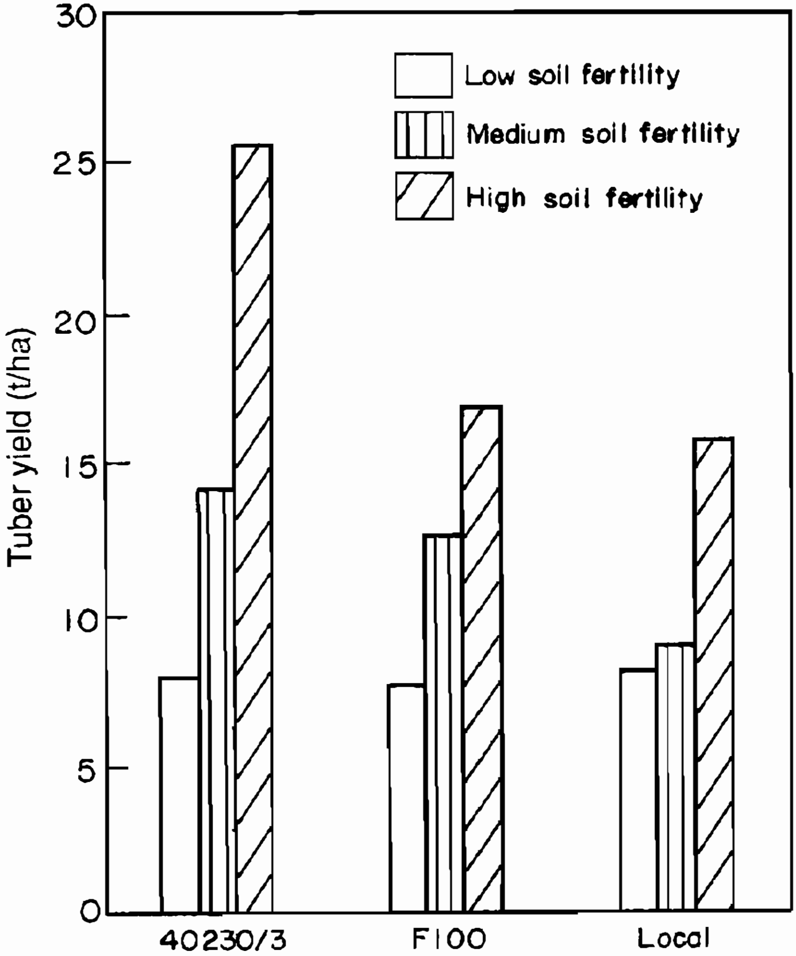

Figure 1. Average tuber yields under different soil fertility ratings

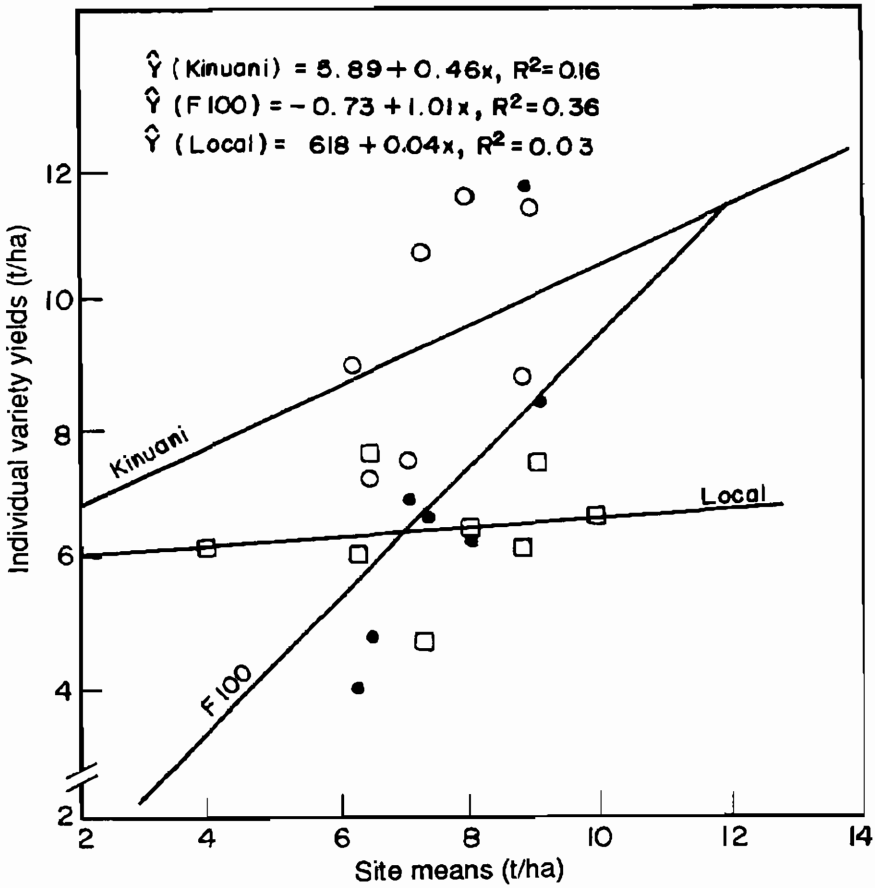

Figure 2. Regression lines showing relationship of individual yields of Kinuani (x), F100 (•) and local (') to mean yields of the three cassava varieties at different sites, 1986/87 season

- Gives more planting materials.
- Leaves are very attractive for *pondu.*
- Satisfactory yields.

Cautious acceptance was given to both Kinuani and 40230/3, mainly because of their higher yield potentials.

Conclusions

Among the cassava varieties available for diffusion from PRONAM, only F100 shows enough general adaptability (average stability) for good performance in a wide range of environments. Kinuani and 40230/3 showed greater specificity of adaptability to high-yielding environments. Breeding programs should give adequate attention to the development of cassava varieties with general adaptability such as F100 for the small-scale farmers. Kinuani and 40230/3 will be more suitable for producers who can afford to create high-yielding environments for improving yield performance.

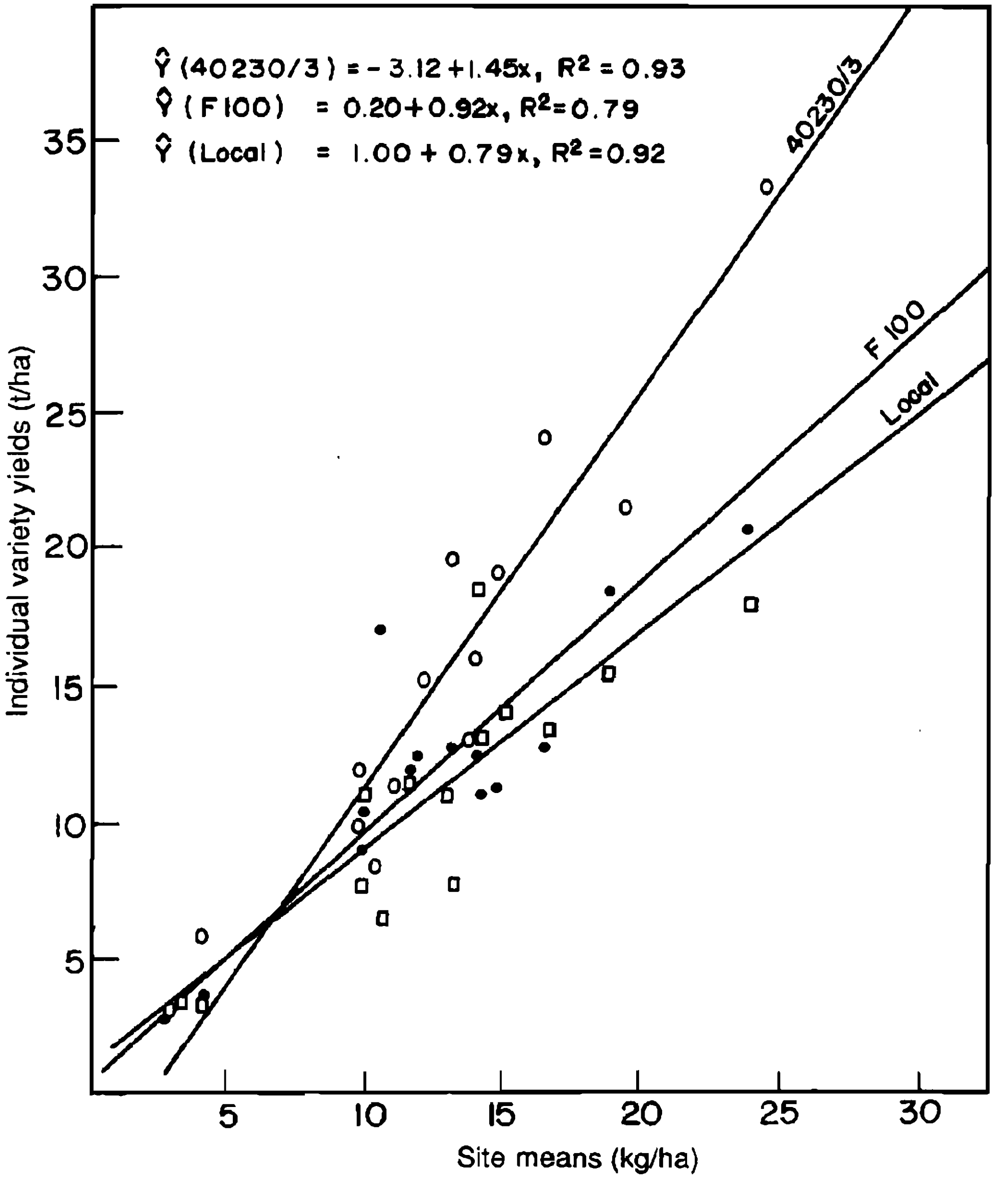

Figure 3. Regression lines showing relationship of individual yields of 40230/3 (x), F100 (•) and local (0) to mean yields of the three cassava varieties at different sites 1987/88 season

Further Analysis of Varietal Yields of Cassava in the Kasangulu Zone of Bas-Zaïre

L. Simba

Following an exploratory survey conducted in the Kasangulu Zone of Bas-Zaïre, a varietal trial was conducted in 1987-88 to test two improved PRONAM varieties against the local variety, Kidamu, in the sandy soils of the same zone.

The selected recommendation domain was the sandy soils of Kasangulu's forest. PRONAM varieties 40230/3 and F100, were recommended for the trial because of their established high yield potential in light sandy soils. (40230/3, the new PRONAM variety recently added to PRONAM's other varieties, Kinuani and F100, has not been released yet and is still being tested in many different on-farm trials.)

Farms and farmers of varied characteristics were chosen for the trials. They included farmers of different clans, civil status, sex, and religion. Trials were conducted on farms in valleys, plateaus, and on hill slopes.

In addition to data on diseases, pests, and yields, other observations were made, such as number of weedings, *pondu* harvestings, and density of plants.

Fourteen farms were harvested for analysis in the 1987-88 planting season. Variety 40230/3 had the highest yield (15.52 t/ha), followed by F100 (13 t/ha), and the local variety (10.76 t/ha).

Modified stability analysis allowed the computation of regression lines for the three varieties across the different farmers' environments.

From the results three environments were characterized. They were poor ($e < 6$), intermediate ($6 < e < 14$) and good ($14 < e < 23$).

Regression analysis and yield data indicate that PRONAM variety 40230/3 could be strongly recommended for the intermediate and good environments, whereas the local variety performed better in the poor environment.

When the results of the intermediate and good environments were combined, the analysis of the distribution of confidence intervals showed that, although the intervals around the mean yields were wide for all three varieties, variety 40230/3 showed less risk (i.e., was less likely to give a very poor yield).

Wide confidence intervals on mean yields indicate low yield stability across environments, which is the case with cassava in general. Even though the confidence intervals of our varieties 40230/3 and F100 are wide, the minimum yield is higher than that of the local variety.

The equations for the regression lines of Figure 1 are:

$$y\,(40230/3) = -2.89 + 40e \quad R^2 = 0.83$$
$$y\,(F100) = 0.38 + 0.97e \quad R^2 = 0.71$$
$$y\,(Local) = 2.55 + 0.63e \quad R^2 = 0.55$$

Good environments were generally valleys, while intermediate environments were generally plateaus and slopes. Poor environments represent farmers and farms with poor management (e.g., only one weeding).

Table 1 represents the range of confidence intervals on yields from different varieties across intermediate and good environments.

Other important criteria to be considered for variety recommendation are the quality of *fufu*, *chickwangue*, and *pondu* as judged by farmers and other consumers.

In the next few years an index of acceptability will be computed, taking into account the number of farmers who participated in the trials, the area occupied by the new varieties in their own cassava fields, and the diffusion of the improved materials among farmers and across neighboring villages.

Table 1. Confidence intervals on yields (t/ha) from different varieties across intermediate and good environments

Range of probabilities	40230/3	F100	Local
0.50	27.85-6.33	25.21-3.69	21.56-0.045
0.40	30.61-3.57	27.97-0.93	24.32-0
0.20	38.13-0	35.49-0	31.48-0
0.10	44.81-0	42.17-0	38.52-0
0.05	51.06-0	48.42-0	44.77-0
0.01	65.03-0	62.39-0	58.74-0

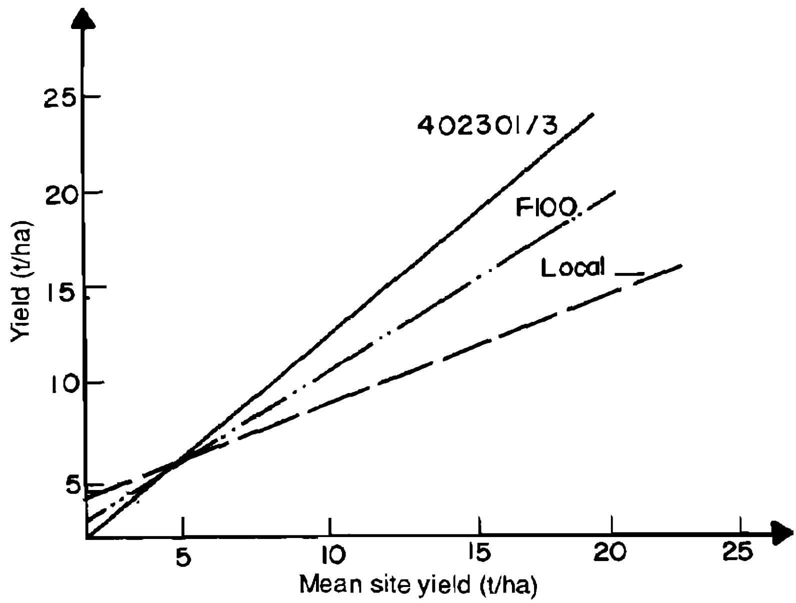

Figure 1. Modified stability analysis of three cassava varieties

On-Farm Trials Comparing the Local Streak-Disease Susceptible Maize with a Streak-Disease Resistant Variety in Southeastern Zaïre

W.O. Vogel, T. Berhe and R.D. Hennessey

Exploratory surveys have identified many constraints to maize production in the South Shaba region of Zaïre. These include maize streak disease, stalk-boring caterpillars, low soil fertility, weed infestations, and irregular end-of-season rainfall. There is also a shortage of labor for land preparation and weeding, and a lack of fertilizer.

Trials were conducted to remedy some of the production constraints. However, because of certain practical problems, more attention was given to the agronomic and short-term entomological and economic factors.

The objectives of the trial were:

1. to compare the yield of the local variety and Babungo-3 under farm conditions,
2. to estimate the economic benefit of growing Babungo-3 to the average farm family,
3. to investigate the varietal traits that are responsible for the difference in economic benefit,
4. to compare the response of the two varieties to fertilizer,
5. to investigate whether the improved variety could extend planting time, and
6. to set the stage for future economic studies.

Materials and methods

Trial design was a 2 x 3 factorial in a randomized complete block design, each farm representing one replication. Plot size was 15m^2 when planting was done on-flat, and 15 to 40m^2 when farmers planted on ridges. NPK levels in kg/ha were 0-0-0, 64-46-0, and 90-46-0. One to four trials were planted at 15 day intervals in each farmer's field. Results from 16 of the initial 19 farmers were suitable for analysis.

Most of the field operations were performed by the farmers. The researchers assisted in planting, fertilizer application, and harvesting. Many farmers now plant in monoculture on flat, especially when they apply fertilizer. Those who wanted to plant on ridges did so, but they were advised to increase the plant populations in the fertilized plots.

Constraints addressed by the trial

Maize streak disease. This constraint was addressed by comparing the local and the improved varieties in the field. Two types of observations were recorded, numbers of streaked and unstreaked plants, and severity of streak symptoms (0 to 5 scale).

During the 1986-1987 season, both streak incidence and mean severity increased parabolically with delays in planting (first day of planting = 0) and with plant age. Differences between farms were significant in incidence and severity. The R^2 for the regression of yield on a set of variables was unaffected by the choice of plant age (whether 8 weeks or 11 weeks). Also, incidence alone gave almost the same fit as incidence and severity together.

In 1987-1988, the entomology team collected data on streak disease severity to detect differences between the local and the improved varieties.

Maize stalk borer. At present little information exists on losses due to stalk borers over large areas of South Shaba. In 1986-1987, damage by *Busseola fusca* had been significant. It varied with planting date and differed among farms. It is known to vary from year to year. A single percentage count of attacked plants was taken later in the 1987-1988 season to see whether borers were a problem. The data on borers and streak were collected on the same day.

Low soil fertility. Research on soil fertility at the National Program for Maize (PNM), Lubumbashi, Zaïre, has just begun. Soil fertility varies greatly within the region. Although small farmers have access to fertilizer, there is a great demand for fertilizer by the large farmers of the region. They use modern inputs and import hybrid seed from Zimbabwe at great cost.

In their effort to find out whether the improved variety responds well to fertilizer, and if so, whether or not it performs better than the local variety under various environmental conditions, the team included fertilizer treatments in their trials.

Since the benefits from fertilizer and seed were the only reward that farmers received for their participation, they wanted the fertilized trials to be as large as possible.

Weeds. Farmers address this constraint by weeding, but their performance is very uneven, and labor is a constraint. PNM lacks the capacity to launch its own weed research program, but it employs a technician who has some training in weed science. Data were collected on weed infestations to document the influence of weeds on yields in present farming practices. The severity of weed infestation (0 to 5 scale) was evaluated in each plot twice per season before farmers weeded the plots.

Increasing disease pressure. Beyond the increasing pressure of maize streak disease and stalk borers, other maize pests, notably *Helminthosporium turcicum*, occur later in the season. Farmers tend to stop planting maize when yields become uneconomical. To see whether the economic planting period could be extended by planting the improved variety, farmers were asked to establish a trial very late in the season. They were offered compensation in cash in case those trials failed.

Insufficient labor supply for land clearing and weeding. This constraint cannot at present be addressed by the team. Farmers may incur considerable costs by staggering their planting, depending on how fast yields decline with planting date, and on how much land they plant during a particular period. The research team tried to approximate farmers' conditions by planting up to four trials in each farmer's fields at 15-day intervals, (i.e., a period of about six weeks). The increase in field size from the first to the last planting date was measured.

Data collected

Observations were made on the following variables: yield/ha, plant population density at harvest time, delay in planting (first planting date = day 0); planting method, on ridges or on-flat; fertilizer level, weed score; percentage of streak-infested plants (11 weeks after planting); streak severity (11 weeks after planting); percentage of plants attacked by borers; total rainfall occurring after planting of the trial; and area planted by planting date.

Rainfall was recorded for each village. Area planted by planting date was measured for each farmer. All other variables were measured for each subplot. Observations from 222 subplots were analyzed (111 subplots for each variety, 37 subplots for each fertilizer level).

Data analysis

The multiple regression package of the MSTAT™ statistical computer package was used to analyze the data. In the first step of the analysis, a regression procedure for a two-factor ANOVA model was employed. In the second step a multiple regression model with continuous and indicator variables was used. Since regression models encompass both ANOVA and regression analysis, only one data file was required.

Regression Model for a Two-factor Analysis of Variance. There were four sources of variation: fertilizer treatment, maize variety, between-farm differences, and within-farm differences. (Note that the term fertilizer is used, since the effects of phosphorus and nitrogen cannot be separated). When subscripts are suppressed for simplicity, the basic ANOVA model takes this form:

$$Y=b+F+V+V^*F+BF+WF+e \qquad (1)$$

Where:
Y=yield
b=the overall mean yield
F=fertilizer at three levels
V=maize variety, at two levels
F*V=interaction between fertilizer and variety
BF=between-farm differences
WF=within-farm differences
e=error term

The complete regression model for the two-factor ANOVA with indicator variables for fertilizer, maize variety, variety x fertilizer interaction, and between farm differences then is:

$$Y=b_0 + b_1F_1 + b_2F_2 + b_3V_1 + b_4F_1V_1 + b_5F_2V_1 + b_6BF_1 + b_21\,BF_{16} + b_{22}WF_{1.1} + \ldots + b_{42}WF_{16.3} + e. \qquad (2)$$

The ANOVA model was analyzed in three steps. First, each of the two varieties was analyzed separately. The ANOVA was then intended to be run for both varieties simultaneously with indicator variables for variety and the interaction terms being included.

Results

ANOVA for local and improved variety

The full model for the local variety is

$$Y=b_0 + b_1N_1 + b_2N_2 + b_3BF_1 + \ldots + b_{18}BF_{15} + b_{19}WF_{1,1} + \ldots + b_{40}WF_{16,3} + e \quad (3)$$

For simplicity, no subscript was introduced to denote the local variety. Tests of significance for the second fertilizer level and between-and within-farm variability were performed by running reduced forms of the model and then comparing the differences in error terms (SEE) between the full (F) and the reduced (R) model.

The results showed that variability was both between and within farms was highly significant. The first dose of fertilizer increased yield by about 640 kg/ha (from 860 kg/ha to 1500 kg/ha), $P<.01$. The increase in yield from the first to the second dose was not significant. For the final ANOVA, only one indicator variable for fertilizer was used.

The summary results of the final ANOVA are: $R^2 = .87$ adjusted $R^2 = .81$; SEE = 505, and F= 13.27. The F-value is significant at the 0.01 level.

The same model was employed for the ANOVA of the improved variety, Babungo-3. Again, variability between and within farms was highly significant. Babungo-3 responds better to fertilizer than the local variety. The first dose increased yield by about 880 kg/ha [from 1200 kg/ha to 2000 kg/ha). The relatively large difference in the intercept terms for the local variety and Babungo-3 indicated a probable varietal effect. Again the increase from the first dose to the second dose of fertilizer was not significant. The results of the final ANOVA are $R^2 = .90$, adjusted $R^2= .85$; SEE = 542 and F = 17.87. The F-value is significant at the 0.01 level.

ANOVA of the whole model

The whole ANOVA model as specified in equation (2) could not be run because it exceeded the memory capacity of the available micro-computer. However, a test of significance for varietal effect and fertilizer x variety interaction was performed. When both terms were included in the analysis, neither was significant. When the interaction term was dropped, the varietal effect was highly significant. Babungo-3 gave 570 kg/ha higher yields than the local variety.

Comments on ANOVA. The ANOVA showed very useful preliminary results. Since the treatments are independent of each other, the results are clear-cut and easy to interpret. The model shows that fertilizer was a significant factor in determining yield, that the two varieties were different, and that between- and within-farm variability was significant. The model also shows how much each of the factors contributed to variability of yields. However, it does not identify the factors that caused the differences between the varieties and the variability within and between farms, such as the shape of the curve that describes the varietal response to fertilizer, the differences between the varieties or the reasons for the large variability between and within farms. Answers to some of these questions can be provided by regression analysis.

Regression analysis

Two sets of regression analyses were run. The first set attempted to explain differences in yield. The second set attempted to explain what the differences are between the varieties.

Regression of yield on observed variables. As the ANOVA, the regression was done in steps. First, the regression model was run on each variety separately. If the same variables were found to influence yields of the two varieties, the variables accounting for varietal difference and the interaction terms were included and all observations used in the analysis.

The major objective of the regression analysis was to explain within-farm variability. To achieve this objective, the block of indicator variables for within-farm variability was replaced by a set of observed variables. The set of between-farm indicator variables was retained. Unfortunately, the computer memory was too small to retain the set of within-farm indicator variables. They could have picked up remaining variation not explained by the newly-introduced observed variables. Some variables were squared to test for curvature.

The original model had the form:

$$Y=b_0 + b_1PP + b_2DD + b_3PMETH + b_4W + b_5STR + b_6B + b_7R + b_8F_1 + b_9F_2 + b_{10}BF_1 + \dots + b_{24}BF_{15} + e \quad (4)$$

Where: PP = plant population density at harvest.
DD = delay in planting (in days)
PMETH = planting method; 0 = on ridges, 1 = on flat
W = Weed score.
STR = Percentage of plants attacked by maize streak virus 11 weeks after planting
B = Percentage of plants attacked by stalk borers 11 weeks after planting
R = total accumulated rainfall (planting day to end of season).
F = level of fertilizer
BF as defined before

Insignificant variables were omitted from the regression. Plant population density and planting method are highly correlated because plant populations on flat-planted plots were always much higher than those on ridge-planted plots. As such, planting method was omitted since it explained less variation than plant population density. Prior field studies had suggested that differing levels of weed infestation would explain some of the observed differences in yield. However, weed score was not a significant variable in the present study. It is likely that the scoring method was insufficient. For unknown reasons, borer incidence was so low in the 1987/88 season that yields were not reduced.

The total amount of rainfall from planting to end of season is only a rough approximation for available moisture. In principle, some measure of available moisture is a more desirable variable than delay in planting because it is related to yield. However, methods to measure this variable need to be discussed with an agro-climatologist first. Total rainfall showed a lower correlation with yield than did delay in planting. The latter was used in the regression.

The quadratic term for fertilizer was left in the regression although it was not significant at the 5 percent level. The result is, however, useful for economic interpretation.

Comment on regression analysis. When regression analysis is used instead of ANOVA, the results are as clear-cut as those of ANOVA. When regression analysis goes beyond ANOVA to include variables observed in the field other than the treatments planned by the researcher, the results are more complex and more difficult to interpret.

Difficulties in interpretation stem from linear relationships among several explanatory variables (multicollinearity). An important effect of multicollinearity is that the t-value of a coefficient decreases when a correlated variable is included in the regression. In extreme cases, two correlated variables may be statistically insignificant when they are both included in the regression, yet when either is omitted from the regression, the t-value of the remaining one increases to a significant level (see Koutsoyiannis 1977; Neter and Wasserman 1974).

In most analyses, explanatory variables are correlated with each other. In the present example, plant population, percentage of streak-attacked plants, percentage of borer-attacked plants, and accumulated rainfall after trial establishment are all correlated with days of delayed planting.

There is no perfect solution to the problem of multicollinearity. The choice of which variables to include in the regression will always be somewhat arbitrary. All that the analyst can do is to ask an expert whether his choice of variables and his estimated coefficients are plausible, and to adjust his choice accordingly.

Regression of the local variety. The results of two regression analyses are reported here. For the sake of simplicity the average of the between-farm indicator variables has been incorporated in the intercept term.

$$Y = 1594 + 0.019PP^{**} - 18.497DD^{**} + 16.90F^{**} - .105F^2 - 15.33STR^{**}$$
$$R^2 = .79;\ \text{adjusted } R^2 = .74;\ SEE = 584;\ F^{**} = 16.57 \qquad (5)$$
(* = significant at 0.05 level, ** = significant at 0.01 level).

The equation states that each additional plant increases total yield by .019 kg/ha, each day of delayed planting reduces total yield by 18.5 kg/ha, and each 1 percent increase in streak-infected plants causes a loss of 15.3 kg/ha.

The ANOVA showed that a 64-46kg dose of fertilizer increases yield by 640 kg/ha, i.e., 10kg grain/kg fertilizer. The result from the regression analysis, 650kg grain/ha, is almost identical. Note, however, that the first kg of fertilizer increases yield by 16.8 kg/ha, while the 64th kg of fertilizer increases yield by only 3.6 kg/ha. Suppose that fertilizer costs five times as much as grain maize on a weight basis, the ANOVA results indicate that applying 64kg of fertilizer would be highly profitable. The regression results show that at 57kg of fertilizer, the increase in grain yield is 5kg. Applying more than 57kg of fertilizer/ha is unprofitable, and to be on the safe side, 50kg of fertilizer is recommended.

Note that the ANOVA gives an R^2 of .87 while the regression model has an R^2 of .79. If the ANOVA is considered the full model and the regression the reduced model, the F-test indicates significance between the two models at the

1 percent level, $F_{17,73} = 2.79$. Within-farm variability is likely to be still significant and including the within-farm indicator variables should reflect this.

An attempt was made to determine the upper bound on the losses due to streak. When differences in planting days (DD) is dropped from the regression, a part of its influence is absorbed by the streak variable, and the estimate of streak-induced losses consequently increases from a 15.3 kg/1 percent streak incidence to 26.3kg/1 percent. The true value lies between 15.3 and 26.3 kg/ha.

$$Y = 1975 + .017PP^{**} + 16.18F^{**} - .098F^2 - 26.3STR^{**}$$
$$R^2 = .77;\ \text{adjusted } R^2 = .72;\ SEE = 607; F^{**} = 15.75 \qquad (6)$$

Regression for Babungo-3

$$Y = 1244 + .020PP^{**} - 53.5DD^{**} + 19.5F^{**} - .081F^2 + 5.4STR \qquad (7)$$
$$R^2 = .81;\ \text{adjusted } R^2 = .77;\ SEE = 672;\ F^{**} = 19.39.$$

Focusing on the differences between the coefficients obtained for the local variety and Babungo-3, the result of this regression indicates that the yield of Babungo-3 declines more steeply with delays in planting than does the yield of the local variety. Babungo-3 responds slightly better to fertilizer. The streak variable has the wrong sign, but the coefficient is not significant.

When the DD variable was dropped from the regression, the streak variable was highly significant.

$$Y = 1762 + .014PP^{**} + 19.2F^{**} - .068F^2 - 28.2STR^{**} \qquad (8)$$

The true coefficient for the streak variable lies between 0 and 28.2 kg/1 percent increase of streak-infected plants.

A comparison of the regression equations for the local variety and Babungo-3 reveals an intervarietal difference in susceptibility to streak disease. Also, in all trials the mean plant population was about 6,000 plants/ha higher for Babungo-3 than for the local variety, (41,000 vs. 34,800).

Since the varieties behave differently, the data were analyzed separately for each variety. The only test performed with the whole data set was for the significance of various interaction terms. No interactions were significant at the 5 percent level.

Differences between the local variety and Babungo-3. Yield losses to streak disease are greatest when the plants are infected while they are still young. Yield losses may occur in two ways. An infected plant may survive in stunted form and either produce no ear or a smaller-than-normal ear, or the infected plant may die and diminish the plant population beyond the point where the remaining plants can compensate for the loss.

The incidence of streak-infected plants is expected to vary in two ways: (1) among different fields having different planting delays (DD), and (2) within the same field depending upon the day of observation. Also, incidence varies among farms. All of these differences depend upon the population densities of the disease vectors (*cicadulina* spp.), and upon the rate at which the vectors acquire the virus. The rate of virus acquisition depends largely upon the incidence of streak in the field.

Regressions for the two varieties included delay in planting (in days), the day of observation (DO), and the set of between-farm indicator variables. The average value of the indicator variables was incorporated into the intercept term.

The results for the local variety were:

$$STR=-146 + 2.1DD^{**} - .01DD^{2**} + 4.2DO^{**} - .02DO^{2**} \quad (9)$$
$R^2 = .74$; adjusted $R^2=.70$; SEE=15.1; $F^{**} = 18.2$

The results for Babungo-3 were:

$$STR=-156 + 1.3DD^{**} + 4.4DO^{**} - .03DO^{2**} \quad (10)$$
$R^2 = .73$; adjusted $R^2 = .69$; SEE = 13.5; $F^{**} = 17.85$

The overall mean of streak infected plants for the local variety was 52 percent; for Babungo-3 it was 32 percent. The range of the dependent variable, (percent of streak-infected plants), is restricted to values between 0 and 100 percent.

Useful observations on streak can be made about two weeks after planting. The two-week delay explains the negative intercept term. Most observations were taken after the sixth week.

The development of streak over time within the same plot is the same for both varieties. However, in the local variety, streak incidence rises faster with delays in planting. Thus, it appears that Babungo-3 is more resistant.

Babungo-3 and the local variety differ also with respect to attrition rates of the plant populations. Two regressions were run for both varieties. In the first regression, plant population was regressed on DD, planting method, and the between-farm indicator variables. In the second regression, the DD variable was replaced by the streak incidence variable. The second regression leads to an overestimate of the contribution of streak disease to plant losses over the season, since the effect of DD will be absorbed partly by the streak variable.

Differences in plant population among farms were highly significant. The average value of the indicator variables was included in the intercept term. The results of the second set of regressions were:

$$\text{Local variety: } PP = 29{,}766 + 24{,}499\ PMETH^{**} - 186STR^{**} \quad (11)$$
$R^2 = .51$; adjusted $R^2 = .42$; SEE = 13,548; $F^{**} = 5.70$

$$\text{Babungo-3: } PP = 23{,}000 + 32{,}849PMETH^{**} - 107STR \quad (12)$$
$R^2 = .60$; adjusted $R^2 = .52$; SEE = 14,108; $F^{**} = 8.06$

Plant populations of the local variety were about 7,000 plants/ha higher on ridges compared with Babungo-3. This difference is unexplained.

Plant population densities were estimated at harvest time in the first planted trials (day 0) and in the last planted trials (day 60). Streak disease plays a significant role in the decline of plant population densities for the local variety ($p < .01$) but not for Babungo-3 ($p < .10$). The mean population decreases over the 60 day period were 11,200 plants/ha for the local variety and 4,700 plants/ha for Babungo-3. The influence of streak may be overestimated since no observations were taken on other mortality factors.

The contribution of Babungo-3 to home consumption. To estimate the contribution of each of the two varieties to home consumption, it is not necessary to include all explanatory variables in the regression. A variable which captures most of the differences between the varieties is sufficient. Yields were regressed on planting date and on the between-farm indicator variables for the two varieties for the first two fertilizer levels. The best fit was provided by four straight lines (see also Fig. 1).

N-P level: 0-0

local: $Y = 1345 - 26.5DD^{**}$; $R^2 = .80$; SEE = 505 (13)

Babungo-3: $Y = 1747 - 31.6DD^{**}$; $R^2 = .82$; SEE = 582 (14)

N-P level: 64-46

local: $Y = 3129 - 55.8DD^{**}$; $R^2 = .78$; SEE - 816 (15)

Babungo-3: $Y = 3839 - 56.5DD^{**}$; $R^2 = .83$; SEE = 811 (16)

To calculate the quantity of grain-maize available for home consumption, the following assumptions were made:

1. The average field size of maize for grain is 0.7ha.
2. Land preparation begins in early October.
3. About $90m^2$ are prepared per day.

Without fertilizer use, the average family production is about 800 kg/ha for the local variety, and about 1050kg/ha for Babungo-3 (Table 1). A family of two adults and four children requires 125kg of maize flour/month, i.e., 1500kg/year. Even if the family could plant all 0.7ha on the optimal planting date, the annual production would be only 950kg for the local variety and 1200kg for Babungo-3. Both quantities would fall short of family requirements.

Table 1. Family production of maize for grain with the local variety and Babungo-3 at 0-0-0, NPK. Area in ha, yields in kg/ha, production (area yield) in kg

		Local variety		Babungo-3	
Date of planting	Planted area	Yield	Production	Yield	Production
30 Nov	.4700	1360	640	1710	800
10 Dec	.0900	1100	100	1390	130
20 Dec	.0525	830	40	1080	60
31 Dec	.0525	540	30	730	40
10 Jan	.0350	270	10	420	20
Total	.7000		820		1050

By using fertilizer (64-46-0, NPK) on the local variety, the average family could produce enough maize for its own consumption. By using the same amount of fertilizer on Babungo-3, the family could produce a surplus of 900 kg (Table 2).

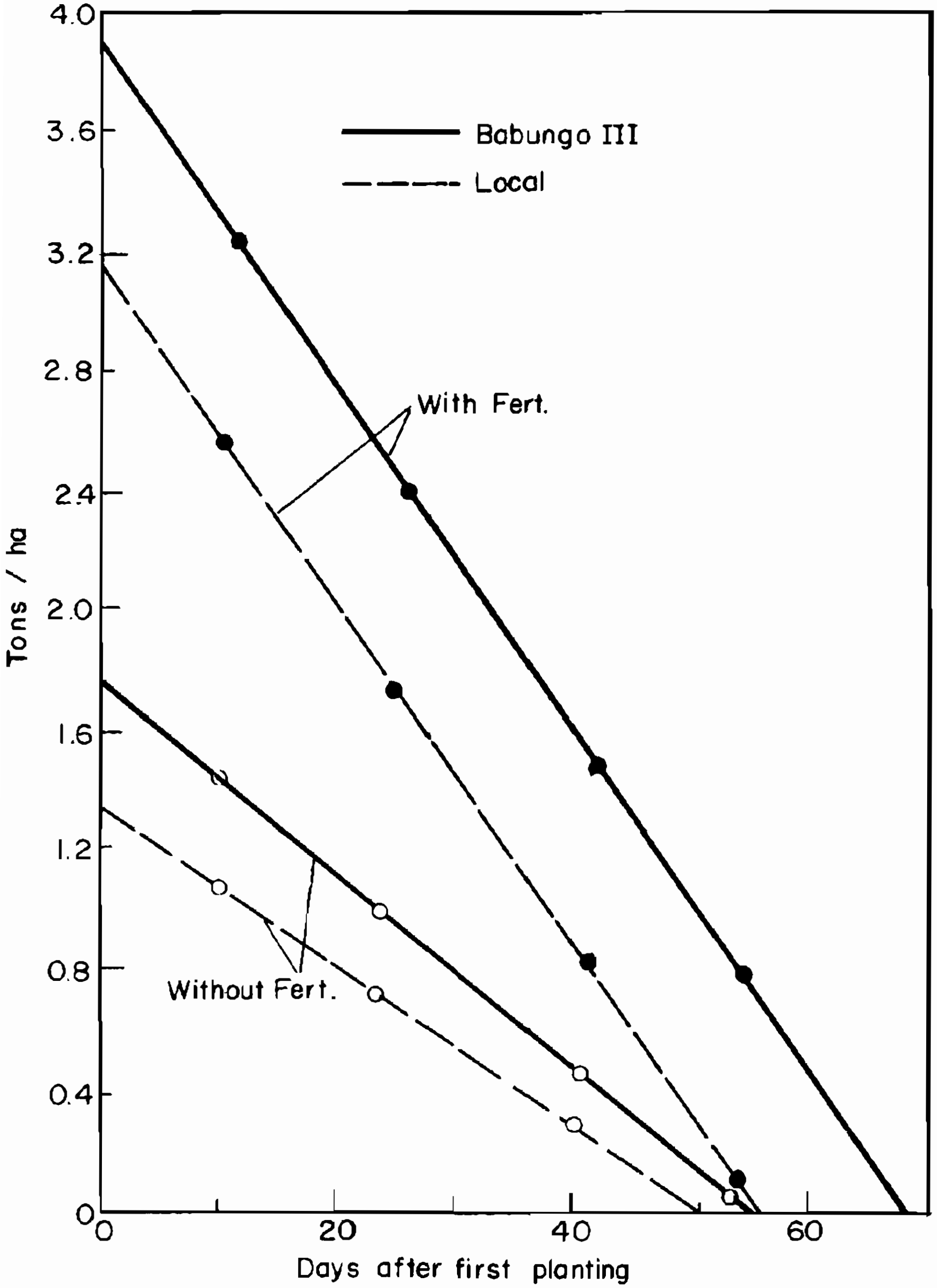

Figure 1. Yield responses as functions of delaying planting for two maize varieties, local and Babungo-3, each subject to two levels of N-P fertilizer (0-0 and 64-46 kg/ha)

Policy implications and further research

The introduction of Babungo-3 into the present farming system would increase maize production. However, the surplus necessary to feed urban populations in the regional mining centers of Lubumbashi, Kipushi, Likasi, and Kolwezi would be forthcoming only if both fertilizer and an improved varieties were made available simultaneously.

Table 2. Family production of maize for grain with the local variety and Babungo-3 at 64-46-0, NPK. Area in ha, yield in kg/ha, production (area x yield) in kg

		Local variety		Babungo-3	
Date of planting	Planted area	Yield	Production	Yield	Production
30 Nov	.4700	3080	1450	3840	1800
10 Dec	.0900	2520	230	3270	290
20 Dec	.0525	1960	110	2710	140
31 Dec	.0525	1350	70	2140	110
10 Jan	.0350	800	30	1580	60
Total	.7000		1880		2400

PNM is presently in the process of multiplying Babungo-3, and the variety may be available to farmers as early as the 1989-1990 season. If PNM can monitor the diffusion of this variety, the present estimates of the benefits of Babungo-3 could be used to calculate the impact of the variety on regional production.

Summary and conclusions

Maize streak disease is a major constraint to maize production in southeastern Zaïre. The local maize variety, which is susceptible to streak, and the improved variety, Babungo-3, were compared in farmers' fields in three villages.

The data were first analyzed by ANOVA. The results showed that between-farm and within-farm variability was highly significant and that only the first fertilizer dose increased yields significantly. The difference in yields between the local variety and Babungo-3 was significant.

In the second step, regression analysis was used to explain the causes of within-farm variability. The results showed that yields increase with fertilizer and higher plant population density, and decline with delay in planting and higher incidence of streak disease.

In the third step, an attempt was made to discover what caused the differences in yields of the two varieties. It was found that the increase in the percentage of streak-infected plants with respect to delay in planting was lower for Babungo-3. Also, plant population density declined more rapidly with delay in planting for the local variety than for Babungo-3. Streak disease was a major cause of plant losses.

The contribution of Babungo-3 to home consumption was estimated from the regression results. Babungo-3 increases total production of an average farmer substantially, but the increase from fertilizer application would even be higher. If the small farmer had both fertilizer and the improved variety, he could produce a maize surplus for the open market.

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Issues in On-farm Experimentation at Gandajika, Zaire

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Farming Systems Research (FSR) at Gandajika, Zaïre, is conducted by the National Legume Program (Programme National Légumineuses— PNL), which is part of the Applied Research and Extension Project (Projet de Recherche Agronomique Appliquee et Vulgarisation— RAV) of the Department of Agriculture of Zaïre. RAV has a mandate for crop improvement, FSR and extension in cassava, maize and four grain legume crops.

Gandajika is located in a grassland savanna which traverses the eastern and western Kasai regions. Rainfall averages about 1500mm distributed roughly biomodally between late August and mid-May.

On-farm trials are conducted in three villages surrounding the experiment station at Gandajika. These villages were chosen both for their accessability and for the range in soil texture, characteristic of the ecological zone. In each village is placed a technician, equipped with a bicycle, whose responsibility it is to assist the farmers in planting and harvesting of trials and to make weekly observational visits to each field. The three field technicians are assisted and supervised by a research assistant equipped with a motorcycle. A research assistant trained in sociology visits each farmer to obtain the farmer's assessment of the technology being tested.

This approach allows us to assess very quickly the suitability of station-generated technology for farmers' conditions within the ecological zone, but brings with it some management and technical problems which will be addressed with reference to trials conducted in the 1987/88 growing season.

On-farm maize variety trial

The farming system practiced in the grassland savanna of the Kasai regions centers on a rotation/relay of the two staple crops, maize and cassava. Two major diseases, maize streak virus and downy mildew, reduce maize yields in the region and their effect is intensified by the practice of staggering maize planting over three months in the first season and two months during the second season.

The trial was designed to test a maize population, DMR-ESR(W), resistant to maize streak virus and downy mildew. As controls, we included the currently recommended variety, Salongo II, and the farmers contributed their own variety. Plot dimensions were large enough to enable farmers to properly assess the varieties and small enough to allow a sufficient number of farmers to participate, given a limited seed supply.

The question arose as to which planting pattern was to be adopted. Some maize is planted with the fertilizer and spacing recommended by the extension service while the majority is planted at much wider spacings, without fertilizer and often intercropped with cowpeas, squash, etc., and/or relay-cropped with cassava. Because we wanted farmers to have a good opportunity in the first instance to assess the disease resistance of DMR-ESR(W), we opted to compare varieties under the more uniform and favorable growth conditions of the recommended practices of spacing and fertilizer use. If results were promising, we would compare the varieties under farmers' own practices in the following year.

Because the comparative advantage of a disease-resistant variety should be greater when planted late in the season than when planted early, it was necessary to follow local farmers' practices and plant over an extended period in both seasons.

Materials and methods

Maize varieties DMR-ESR(W) and Salongo II and the farmers' own variety were planted in 43 farmers' fields from 18 September to 31 October 1987 (season A), and in 28 farmers' fields between 29 January and 29 February 1988 (season B). A randomized complete block design was used with each farmer constituting one block. Plots measured 6m x 8m. Spacing was fixed at 75cm x 50cm with two plants per hill. A fertilizer rate of 64kg P_2O_5/ha was applied in split application with diammonium phosphate applied at 15 days after planting (DAP) and urea at 45 DAP. All other management aspects were determined by the farmer.

Observations were made with respect to the dominant vegetation of the site, crop history, type and method of land preparation, seeding method and depth, surface soil texture and moisture conditions at planting. During weekly visits, observations were made on emergence, dates of weeding, flowering dates, and on any problems encountered. Streak virus was scored on a 1-5 scale at silking, while downy mildew-infected plants were counted from 20 DAP onward and the incidence was calculated. Yield, ear height, days to harvest, and percent sterility were recorded. Shelling percentage and weight of a market measure *(mudu)* of maize was determined on a limited sample in season B.

Farmers were interviewed in the field before harvest and again in their homes following harvest, and asked to evaluate each variety on a series of criteria relating to crop performance and quality, and to indicate their preference.

Results

The trials were installed on predominantly sandy soils (characteristic of this ecological zone), most often following maize or cassava in the rotation and mostly on a flat seedbed. In most cases, the land was prepared by hand and seeding was done with a hoe, cutlass, or heel of the foot. Seeding depth varied from 2 to 8cm and one or two weedings were carried out. The maize population DMR-ESR(W) outperformed the local and recommended varieties in terms of yield (Table 1) and disease resistance (Table 2), had a lower percent sterility, a lower ear height, averaged 25 days earlier than the local variety, and lodged less than the local variety in season A.

Farmers recognized the superior disease resistance of DMR-ESR(W) (Table 2) and overwhelmingly preferred DMR-ESR(W) for its short growing-cycle (Table 3). However, they generally liked the larger ears of Salongo II. In contrast to our own calculations, a majority of farmers thought that Salongo II yielded highest in season A, and they ranked the local variety higher than the other two for yield by volume.

Table 1. Yields of maize varieties (kg/ha) in on-farm trials at Gandajika, Zaïre, in 1987/88 growing season

Variety	Mean yields: Season A	Season B	Mean	Range: Season A Min	Season A Max	Season B Min	Season B Max
DMR-ESR(W)	2500	2510	2500	700	4600	570	4380
Salongo II	1940	2000	1970	100	4600	10	4380
Local	1840	2120	1980	300	3800	160	3810
SE ±	100	110	±				
LSD.05	290	300					
CV %	32	28					
No. of farmers	41	28					

Table 2. Farmer assessment of maize streak virus and downy mildew diseases compared with researcher assessment in maize varieties tested in on-farm trials at Gankajika, Zaire, in the 1987/88 growing season

Variety	Season A: -	x	xx	xxx		Season B: -	x	xx	xxx	
A. Streak	% of 42 farmers				Researcher score	% of 27 farmers				Researcher score
DMR-ESR(W)	84	14	0	0	1.1	89	11	0	0	1.1
Salongo II	48	36	14	2	2.1	48	37	15	0	2.9
Local	48	40	12	0	1.7	67	33	0	0	2.8
LSD	.05				0.3					0.2
B. Downy mildew										
DMR-ESR(W)	83	14	2	0	0.2	85	14	0	0	1.3
Salongo II	62	23	12	0	2.7	44	44	11	0	8.7
Local	64	23	11	0	3.9	55	44	0	0	6.1
LSD .05						2.2				5.7

Notes: - = no disease symptoms
x = little importance
xx = important
xxx = very important

Streak score (researcher)
1 = less than 10% infection
5 = 76-100% of foliar surface covered

In terms of quality, the local variety was preferred for ease of shelling and small cob diameter (believed to be inversely related to grain yield), while Salongo II was ranked highest for seed size and shape (Table 4). Color preferences and overall seed preferences were inconsistent. Salongo II was judged best and the local variety worst for commerce, while the dense seed of Salongo II and DMR-ESR(W) were overwhelmingly ranked superior to the floury seed of the local variety for home consumption in the local staple.

nshima (Table 5). DMR-ESR(W) received the highest ranking for preference overall. The main reasons given were its early maturity, disease resistance, flour consistency, and yield. Difficulty in shelling and pounding and the large cob diameter were considered liabilities by these farmers.

Table 3. Farmer preference of agronomic characteristics of maize varieties tested in on-farm trials at Gandajika, in the 1987/88 growing season

Character / variety		Season A					Season B				
		1	2	3	4	5	1	2	3	4	5
		% of 42 farmers					% of 27 farmers				
Days to harvest	DMR-ESR(W)	100	0	0	0	0	70	26	4	0	0
	Salongo II	0	77	23	0	0	11	74	15	0	0
	Local	8	15	77	0	0	0	15	85	0	0
Ear size	DMR-ESR(W)	16	35	48	0	0	26	39	30	4	0
	Salongo II	65	19	13	0	0	57	26	13	4	0
	Local	16	45	39	0	0	17	30	52	0	0
Grain yield by weight	DMR-ESR(W)	35	48	16	0	0	52	26	22	0	0
	Salongo II	61	25	13	0	0	30	57	13	0	0
	Local	6	29	65	0	0	26	13	61	0	0
Grain yield by volume	DMR-ESR(W)	28	26	45	0	0	30	30	35	4	0
	Salongo II	32	48	19	0	0	13	48	35	4	0
	Local	48	25	26	0	0	48	35	17	0	0

Notes: 1 = very good 2 = good 3 = fairly good
4 = poor 5 = bad

Discussion

By use of a very simple experiment, it was possible to obtain information demonstrating the superiority of DMR-ESR(W) to the local and recommended varieties over a wide range of soil and environmental conditions and to obtain information on farmer acceptance of the variety. In addition, we have obtained information useful to maize breeders in determining selection criteria.

The adoption of on-farm research methodology gives rise to a number of technical and management issues. Most of these revolve around the related problems of data analysis, sample size, number and type of observations, and number of trials an individual can handle. In the following discussion, we will show some of the approaches we have taken to interpret the trial results, some of the limitations we face in analyzing these results, and the issues that are raised with respect to research management. It must be stressed that a number of the problems with data analysis discussed here could be solved if computer facilities were available.

Data collection

Choice of data to be collected depends upon the research objectives and capabilities of the researcher. Non-experimental factors most likely to affect crop productivity are rainfall, soil fertility, the state of weed control, and pests and diseases.

Table 4. Farmers' preference of quality characteristics on maize varieties in on-farm trials at Gandajika, Zaire, in the 1987/88 growing season

Character	Variety	Season A 1	2	3	4	5	Season B 1	2	3	4	5
		% of 31 farmers					% of 23 farmers				
Ease of shelling	DMR-ESR(W)	0	32	65	0	0	4	13	70	13	0
	Salongo II	16	58	25	0	0	0	65	30	4	0
	Local	84	6	10	3	0	96	0	4	0	0
Cob size											
	DMR-ESR(W)	6	55	35	3	0	4	13	70	13	0
	Salongo II	19	32	48	0	0	17	39	39	4	0
	Local	77	13	10	0	0	87	13	0	0	0
Seed size											
	DMR-ESR(W)	19	48	32	0	0	35	35	30	0	0
	Salongo II	68	23	10	0	0	48	48	4	0	0
	Local	13	29	58	0	0	13	26	61	0	0
Seed shape											
	DMR-ESR(W)	29	42	29	0	0	39	26	35	0	0
	Salongo II	71	19	10	0	0	48	43	9	0	0
	Local	32	29	41	0	0	9	26	65	0	0

Notes: 1 = very good 2 = good 3 = fairly good 4 = poor
5 = bad

In the present trial, rainfall data was obtained from the Gandajika weather station, which is centrally located in relation to the three villages. Most fields were located within 2-10km of the station, and it was hoped that these data would be adequate for interpretation of trial results. However, experience has shown that significant rainfall may occur in one village and not at the weather station, and vice versa. In the 1988/89 growing season, we installed a rain gauge in each of the three villages. Each rain gauge is intended to represent rainfall in fields within a radius of less than 2 km.

The use of three series of rainfall data further complicates the association of trial results with rainfall events, but more truly represents the rainfall conditions in each of the trial fields.

Variations in crop growth due to soil factors are very evident in the savanna. Gandajika has no soil analysis laboratory, and it is not possible to send soil samples from each farmers' field for analysis by an outside laboratory, so one is limited to what can be practically done on site.

The most obvious way to distinguish soils is on the basis of texture. Research technicians are asked to classify each soil by field observation into one of four classes usually used locally. Initially, this was done only for surface soils, but examining the texture at two depths, 0-20cm and 20-50cm, may become a more useful tool for evaluating crop growth. It is hoped that in combination with information on cropping history, these data will provide at least a crude indication of potential soil productivity in each field.

Table 5. Farmer preferences for maize varieties tested in on-farm trials at Gandajika, Zaire, in the 1987/88 growing season

Condition of preference	Variety	Season A 1	2	3	4	5	Season B 1	2	3	4	5
For commerce		*% of 30 farmers*					*% of 8 farmers*				
	DMR-ESR(W)	30	30	40	0	0	0	50	37	0	0
	Salongo II	57	37	30	0	0	0	62	37	0	0
	Local	27	30	43	0	0	0	12	87	0	0
Flour for *nshima*		*% of 24 farmers*					*% of 23 farmers*				
	DMR-ESR(W)	42	37	21	0	0	50	50	0	0	0
	Salongo II	54	38	37	0	0	33	67	0	0	0
	Local	8	13	79	0	0	0	0	100	0	0
For next season		*% of 31 farmers*					*% of 23 farmers*				
	DMR-ESR(W)	42	39	19	0	0	61	17	22	0	0
	Salongo II	39	45	16	0	0	22	65	17	0	0
	Local	23	19	58	0	0	13	22	65	0	0
Overall		*% of 31 farmers*					*% of 8 farmers*				
	DMR-ESR(W)	42	35	23			64	17	18		
	Salongo II	39	45	16			23	59	18		
	Local	26	23	52			18	23	59		

Notes: Except for overall preference
1 = very good 2 = good 3 = fairly good 4 = poor 5 = bad

Competition from weeds is a factor that changes throughout the season. Field technicians observed the presence of weeds at the time of planting. During their weekly visits, they noted the general condition of the fields and weeding dates. It is difficult to handle such information in a simple but quantitative manner. One can consider the number of weedings done throughout the season, but the importance of such weedings is very much related to timing and the original state of weediness. In 1989, the technician is being asked to give a simple score for weediness over the entire season. This requires the technician to integrate in his mind the relative importance of periods when a given plot was weed-free and periods when the plot was very weedy. This would appear to be not a very easy task to do objectively and as the number of plots per technician increases, it may become difficult to remember the condition of each plot over the entire season. It will, however, enable us to clearly distinguish the extremes from the bulk of moderately well or moderately poorly weeded plots.

An alternative might be to score each plot for weediness at fixed periods, e.g., 2, 4, and 8 weeks after planting. The importance of weed infestation at each period could be tested by multiple regression.

Field technicians are expected during their field visits to note the activities of the farmer since the last visit, the general condition of the field, and any problems such as pests and diseases. These observations are intended to permit a better understanding of the final results of the trial. If done meticulously, the amount of information obtained from weekly visits could easily become unmanageable. In practice, few unplanned observations are made by our technicians. We are obliged to anticipate in advance what observations might be necessary and what the technician should do in case a given problem is encountered. For example, if several plants are destroyed by rats, attacked by the *nshimbu* mealy bug, *Vrydagha lepesmei*, or parasitized by *Striga asiatica*, the technician is to count the number of hills affected in each plot.

This brings up the question of harvestable area in the case of partially damaged plots, such as may occur with the problems mentioned above. It is a common practice in such cases to restrict the harvest area to unaffected parts of the plot, so as to maintain uniformity under test conditions. If the prime objective is to test between treatment effects, and the number of replicates is low, this is the best course to follow. However, if one wishes to evaluate the effect of the pest or parasite on plot yield, then the harvest area must be unaltered and even parasitized plants harvested. Since both objectives are useful, it may be necessary to harvest affected plots in two steps, especially if the number of farmers is small. This would mean having two series of yield results for the same trials.

In collections of data on farmer evaluation of maize varieties, we have learned three things. (1) Farmers seemed to have difficulty discussing any given trait in isolation from others. For example, the choice of variety for seed type might also be influenced by their conception of the yield potential of the various varieties. (2) In some cases, asking a farmer to justify his ranking of varieties caused him to alter the ranking. (3) While we were able to obtain clear opinions on certain characteristics, such as earliness, ease of shelling, or flour quality, we were unable to find the relative importance of the various criteria. We have since attempted to obtain a ranking of criteria.

Data analysis and reporting

In on-farm trials, a large sample size is desirable in order to be representative of the large variations present under farmers' conditions of soil, climate, and management and to have sufficient replication in order to reach a conclusion, given that variability. This latter point can be illustrated by the breakdown of the yield data from season A according to the three villages represented (Table 6). In this case, 12 and 14 farmers were not adequate for differences of 28 percent and 44 percent to be significant at the 0.05 level.

Once one begins to divide the data into subsets according to various factors encountered in the trial, the requisite number of farmers increases. The larger the data set, the greater the chance of computational errors.

Table 7 shows the data subdivided according to soil texture classes. This type of data manipulation is very time-consuming when it requires manually reorganizing the data into new data sets and repeating the analysis for each class seperately. A more thorough analysis would have consisted of combined analyses to test the significance of soil texture on yield and the interaction of variety with soil texture on yield.

Such calculations would be relatively simple with the use of a computer and regression analysis. In this case, we have contented ourselves with an examination of trends, which show little evidence of a variety x texture interaction but show that yields tend to be higher on fine than on coarse-textured soils.

Table 6. Maize yields (kg/ha) analyzed by village

	Village			
Variety	Mbemba-Nzeo	Mpasu	Kaniaka	Whole experiment
DMR-ESR(W)	2400	2550	2600	2500
Salongo II	1700	2210	2000	1940
Local	1700	1980	1800	1840
SE±		110		158
251		104		
LSD.05	300	ns	ns	290
CV %	21.7	24.4	42.6	31.7
No. farmers	15	12	14	41

Table 7. Maize yields (kg/ha) analyzed by surface soil texture

Variety	Clayey	Sandy Clay	Sandy	Whole Experiment
DMR-ESR (W)	3300	2400	2400	2500
Salongo II	2600	2100	1800	1990
Local	2500	1800	1700	1840
Mean	2800	2100	1900	2090
SE±	280	220	130	104
LSD.05	ns	700	360	290
CV %	22.9	26.0	36.8	31.7
No. farmers	5	6	30	41

A data set involving 43 farmers offers many opportunities such as the one described above, for identifying trends resulting from differences in environmental conditions or in management practices, e.g., the effect of depth of seeding on percent emergence, of the number of weedings on yields, and of the previous crop on yields.

A researcher must weigh the likelihood of any possible relationship and its potential usefulness against the time spent calculating such relationships.

One problem associated with the reporting of results, analyzed by standard analysis of variance techniques, is the loss of information. This can be illustrated with an on-farm trial of early-maturity soybean varieties. The local and improved varieties were scored on a 1-5 scale for nodulation at > 75 DAP (days after planting).

Normally one reports treatment means, together with standard error or an LSD (least significant difference), provided the data test significant using the appropriate F test. Treatments means were 2.0 and 2.2, respectively, with a variety mean square of 0.28. These data suggest no real differences between the varieties for nodulating ability. However, examination of the full data set revealed that in two fields out of 20, the local variety contained no nodules, while the improved variety nodulated in all fields. One would obviously prefer a variety that nodulated in all fields rather than one that nodulated in only 90 percent of fields.

In order to compensate for this loss of information in a large data set, we look at minimum and maximum values together with treatment means for the more important data (e.g., Table 2). However, this may place too much importance on outliers which may in fact be errors. With a computer, this problem of lost information could be solved by superimposing a scatter diagram of real observations on a regression curve of yield on nodulation score.

Data may be analyzed with respect to time. Figure 1 presents season A variety yields plotted according to week of planting. This plot indicates that DMR-ESR(W) yielded better than or equal to the other two varieties at all planting dates except for the week of 18-22 October. This simple plotting technique does not prove confidence limits on individual variety curves, which could be obtained by regression analysis. Regression curves would also eliminate some of the "noise" or random error from the plots of actual means. Such an analysis of on-farm trials eliminates the need for classic date-of-planting trials. Similar analyses could determine the effect of planting date on disease scores, or the stage of first appearance of disease symptoms on yield.

Research management issues

It should be evident from the foregoing discussion that the lack of computing facilities is the major limitation to adequately exploiting the data generated by on-farm trials. As is typical of probably most isolated agricultural experiment stations in Africa, our most sophisticated equipment for data processing and analysis is the pocket-sized scientific calculator. While it is possible to do all the analyses described above on a pocket calculator, it is not in most cases practical for the researcher to do so. The trial described above was only one of several research activities for the assistant, and one of about 20 research activities for his supervisor. It is thus necessary to plan observations and the type and number of analyses on the basis of this limited computing capacity. In most cases, analyses must be restricted to the primary treatment effects and those factors most likely to interact significantly with the primary treatments. Given the availability on the market of battery-operated portable computers, Farming Systems Research (FSR) teams should be provided with the means to exploit the data they are now collecting more efficiently and more fully.

Another issue is the number of on-farm trials to be handled by a researcher. Generally speaking, administrators tend to measure productivity by the number of trials a researcher conducts, not by the number of observations made, or the number of repetitions in a given trial. If FSR is associated with crop improvement programs, there will be pressure on the team to test varieties of each crop in each year. The temptation will be to conduct many trials with relatively few replications, with the probable result that many trials will be inconclusive and sufficient data will be lacking to study interactions with environmental and management factors.

In our experience, three to four trials per season are a maximum that can reasonably be handled by one research assistant. This, of course, will vary, depending on the variability in farmer practices, and the number of associated crops on which observations are to be made. It is suggested that rather than trying to do too many trials at one time, testing of varieties of different crops be programmed over time, so that over a limited period of years, all crops can be tested. This will enable the researcher to also program trials testing management practices in addition to crop varieties.

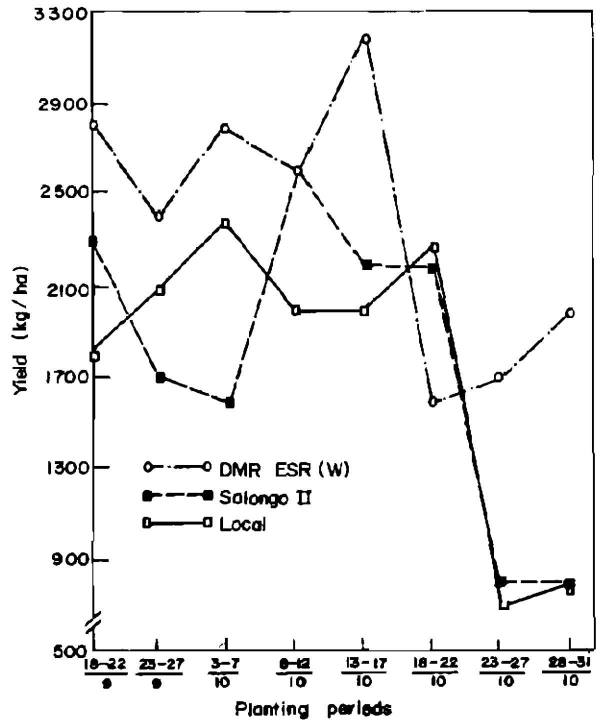

Figure 1. The effect of planting period on maize yields at Gandajika, Zaire, in season A, 1987/88

On-farm trials, for management reasons, must be limited to restricted geographical areas. On-farm testing should be coordinated with either multi-locational testing or on-farm trials by people at other sites within the ecological zone to confirm the universality of results of the on-farm trials.

Conclusions

On-farm experimentation with a large sample of farmers provides a wealth of useful information, far beyond the limited objectives included in the treatment design. A simple trial such as that presented above may provide not only the intended evaluation of genetic materials, but may also supply breeders with information concerning selection criteria, pathologists and entomologists with useful data on the importance of significant diseases and pests at various times of the year, and may provide agronomists with information on a number of cultural practice issues as well as the effects of various environmental factors on yield. In so doing, simple on-farm trials may eliminate the need for certain types of trials conventionally conducted by agronomists and other specialists, thus freeing resources for other tasks.

There is a need to rethink staff and financial resource allocation within research programs so that the potential benefits from on-farm experimentation may be realized. This will imply planning for a sufficient number of farmers per trial, and an adequate quantity and quality of observations, and also providing computing facilities and time to allow researchers to adequately exploit the data they collect.

The Design of an On-Farm Trial to Stabilize an Upland Rice-Based Cropping System, Côte d'Ivoire

Mamadou Diomandé and Kouadio Tano

Bush fires, shifting cultivation and other forest-related human activities have decreased the forest reserves of Côte d'Ivoire from 15.6 million ha in 1900 to around 3 million ha in 1984. By 2000, there will be no more forest land. Small-scale coffee and cocoa production has fallen as soil fertility declines. The more fertile forest is cleared for crop production and the area of fallow land expands.

The On-Farm Research in Ivory Coast (OFRIC) project is examining sustainable ways to stabilize cropping systems on fallow land through a research program entitled "Fallow Management in the Improvement of Ivorian Agriculture". Three main cropping systems have been identified in the first phase, 1983-1984, based on yam (central and eastern regions), upland rice (western region), and cotton, more recently introduced, (northern region). Various minor crops are grown in association with yam and rice but not with cotton. All three systems traditionally rely on shifting cultivation and annual bush-burning. Three reasons for such practices are the decline in soil fertility, the increase in weeds and pests, and a lack of resources for the purchase of modern inputs.

In this presentation, planned experimental steps are described for only the upland rice-based system.

Materials and methods

First the cropping system was characterized as to

- cropping patterns and farming practices;
- soils, vegetation and topography;
- biological and climatic constraints to rice production; and
- socioeconomic characteristics.

After a survey of 12 villages in the Gagnoa region, Tchedjelet wàs selected. A 6ha plot of 3 year old fallow land was offered by the community for the project and fenced with barbed wire.

A team of four young men with some secondary education were selected from the village to help run the experiment. An experienced farmer from the village was in overall charge. The team of scientists working on the experiment was made up of a soil scientist, a plant pathologist, an agronomist and an agricultural economist.

Trial preparation

An inventory was taken of fauna and flora. The soil was characterized by texture, structure, prevalent minerals, and pH. Land clearing was done with hand tools, and land preparation involved as little use of machinery as possible.

Trial layout for the first year

The first year should allow the identification of the main constraints to be addressed in future. The 6ha block was divided into 5 blocks: natural fallow (2ha); improved fallow (1ha); annual crops (1ha, where 1 variety of soybean, 3 varieties of groundnuts, 2 varieties of maize are grown using recommended practices); upland rice (1ha farmer-managed growing 2 cultivars, Azico and Koleche, and 1ha experimental, .5ha research-managed, .5ha farmer-managed, applying some of the researchers' techniques).

The researcher-managed experimental block will consist of a 2^3 factorial experiment with 4 replicates (factors: rice variety, fertilizer and herbicides.)

Data to be collected

Agronomic data required include plant characteristics over time and treatment (stand count, plant height, tuber numbers, panicle characteristics and yield); the evaluation of soil fertility parameters; and the identification and prevalence of weeds and pests (insects, nematodes and fungal diseases).

The socioeconomic data include labor source, type and cost (for land clearing and preparation, sowing, weeding, input application and harvesting); input costs (seeds, fertilizer, herbicides, tools and equipment); and benefit/cost ratio and other relevant economic analyses for all crops.

Conclusion

This approach to on-farm experimentation to stabilize traditional farming systems is a challenging undertaking in the area of sustainable agriculture. The follow-up study depends largely on the results of the first year. The village experimental plot approach to on-farm research has obvious advantages and shortcomings.

The conduct of farmer-managed and researcher-managed trials on the same land saves time, since long-term on-station testing is unnecessary. Team and interdisciplinary work is improved when actual constraints are faced with the farmers. The results are easily transferred in case of success.

However, high costs limit the number of sites and $300m^2$ plots may be too small. Farmers may be unwilling to wait 6-8 years for significant results and may lose confidence in innovation if a project fails.

A Wheat Variety Trial in Southern Borno State, Nigeria

M.C. Ikwelle

Wheat *(Triticum aestivum)* can be grown in Nigeria between the latitudes 10° and 14°N with irrigation during the dry, cool, harmattan season, November to March. With the ban on wheat importation by the Federal Government and the campaign to grow wheat locally, the crop has in recent times assumed great importance in the cropping calendar of Nigeria.

On-station trials

The Lake Chad Research Institute has the national mandate for genetic improvement of wheat, barley, and millet, as well as the total farming system covering Borno and Gongola states of Nigeria. Over the years, the Institute has screened and tested many lines/cultivars of wheat from CIMMYT, Mexico, and other internal and external sources for desirable agronomic characteristics. From these testings, five promising lines/varieties of wheat have been selected for further testing and evaluation on the farmers' fields.

On-farm trials

Five promising lines of wheat and a recommended variety were tested under farmer-managed conditions during the 1987/88 dry season. Eight sites were selected in southern Borno (latitude 13°N). Each site was regarded as a replicate.

The crop was sown in 10m x 10m plots in the middle of November at the rate of 100kg seed/ha. Fertilizer was applied at the rate of 100kg N/ha and 40kg P_2O_5/ha. Half the dose of nitrogen and the entire dose of phosphorus fertilizer were applied at planting, while the remaining half of nitrogen was topdressed six weeks after planting. The crop was irrigated after planting and at weekly intervals, until the crop reached the hard dough stage of maturity. There was no weed infestation during the growing season, and no weeding was carried out.

Results

The mean grain yield of the entries from five sites is presented in Table 1.

The highest grain yield (2.24 t/ha) was obtained from T1-37608, followed by Veery "S" 601 with 2.19 t/ha, but yield differences were not significant. The relatively low yields recorded resulted from moisture stress experienced during the flowering and grain-filling stages, as the water level from the source of irrigation became low. Nevertheless, farmers in the area showed great interest in the crop and were eager to grow it during the following season.

Table 1. Mean grain yield (t/ha) of six wheat lines/varieties at five sites in South Borno state, Nigeria during 1987/88 dry season

Line/variety	Grain yield
T1-37608	2.24
Veery "S" 601	2.19
R37-88-78	1.96
CM3-1729	1.79
AL-BB-284	1.81
Siete Ceros (check)	1.80

A great potential for wheat production exists in Nigeria. There is an urgent need to identify improved high-yielding varieties to boost farmers' production.

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