Conduct and Management of Maize Field Trials

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Acronyms and abbreviations

AMS	African Maize Stress
ARC	*ad hoc* Research Committee
CID	Crop Improvement Division
CIDT	*Compagnie Ivoirienne de Développement des Textiles;* Ivorian Company for Textile Development
CIMMYT	*Centro International de Mejoramiento de Maíz y Trigo*, International Centre for the Improvement of Maize and Wheat
CNRA	*Centre National de Recherche Agronomique*
CORAF/WECARD	*Conseil Ouest et Centre Africain pour la Recherche et le Développement Agricoles* / West and Central African Council for Agricultural Research and Development
CRI	Crops Research Institute
DTMA	Drought Tolerant Maize for Africa
DS	derived savanna
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO Statistical Data Base
GDP	gross domestic product
HS	Humid savanna
IAR	Institute of Agricultural Research
IARC	International Agricultural Research Center
IER	*Institut d'Economie Rurale* / Rural Economy Institute
IFAD	International Fund for Agricultural Development
IITA	International Institute of Tropical Agriculture, Nigeria
INERA	*Institut d'Etudes et de Recherche Agricoles /* Agricultural Research Institute
INRAB	*Institut National de Recherches Agricoles du Bénin* / Béninois National Institute of Agricultural Research
INSAH	*Institut du Sahel*
IRAD	*Institut de Recherche Agricole pour le Développement /* Institute of Agricultural Research and Development
ITRA	*Institut Togolais de Recherches Agricoles* / Togolese Institute of Agricultural Research
ITRAD	*Institut Tchadien de Recherche Agronomique pour le Développement* / Chadian Institute of Agronomy Research for Development
MBT	Mother-baby trial
MSV	Maize Streak Virus
NAERLS	National Agricultural Extension Research and Liaison Services
NARS	National Agricultural Research Systems
NGS	northern Guinea savanna
OPV(s)	Open-pollinated variety/varieties
PPB	Participatory plant breeding
QPM	Quality Protein Maize
RE	Reference entry
RUVT	Regional Uniform Variety Trials
SAFGRAD	Semi-Arid Food Grains Research and Development
SARI	Savanna Agricultural Research Institute
SG 2000	Sasakawa Global 2000
SGS	Southern Guinea savanna
SS	Sudan savanna
SSA	sub-Saharan Africa
STRC	Scientific, Technical and Research Commission
UN	United Nations
UNDP	United Nations Development Program
UNIMAID	University of Maiduguri
USAID	United States Agency for International Development
WARDA	West Africa Rice Development Association
WCA	West and Central Africa
WECAMAN	West and Central Africa Maize Collaborative Research Network

Foreword

Technicians and technologists are indispensable research support personnel. In the agronomic sciences, technicians handle all aspects of research execution from seed preparation for planting through management of field trials, data collection, harvesting, postharvest operations, and data analysis. One of the major constraints to maize research and development in west and central Africa (WCA) is the inadequate number of well-trained and skilled research support staff. This situation often leads to erroneous field designs and data collection, spurious results, and the wasteful spending of research funds.

Over the years, the International Institute of Tropical Agriculture (IITA) has conducted training courses and workshops for maize researchers in WCA. The training courses and workshops have been of immense benefit to the participants, as reflected in the research output of both the technicians and the scientists in the subregion. Unfortunately, the number of participants in each training course or workshop and the total number trained over the years are still a far cry from the number needed to make a comfortable impact on maize research in all countries of the subregion. In response to this perceived need, IITA has embarked on the publication of a series of books documenting the materials covered in the many years of experience in the execution of training courses and workshops. *Conduct and Management of Maize Field Trials* is one in the series. The objective is to provide resource material for the training courses organized by IITA under the sponsorship of the Drought Tolerant Maize for Africa (DTMA) Project. Training courses were designed to upgrade the technical capabilities and skills of maize research technicians and scientists involved in the laying out, planting, and management of field trials, accurate data recording, as well as the production and maintenance of open-pollinated varieties, inbred lines, and hybrids. Each section was handled by expert maize researchers drawn from international and national organizations and universities. The book brings together the experience of maize scientists in a form that can be used by budding researchers, teachers, and students specializing in maize research and development.

IITA is pleased to publish this book on a very important topic in maize research, which has been grossly neglected in the literature.

Nteranya Sanginga
Director General, IITA

Preface

Field trials are very important in maize research. In particular, breeders conduct different types of field trials in the process of developing new varieties. Each type of trial has its peculiarities. Apart from those conducted by the individual breeders in their research programs, there are collaborative trials conducted nationally or internationally. Annually, national collaborative trials are constituted from candidate varieties submitted by participating researchers in a country. Similarly, IITA coordinates international trials from candidate varieties developed by IITA's scientists and their national counterparts in the countries of WCA. Data obtained from field trials are intended for use in arriving at decisions on the varieties to release, the agronomic practices to recommend, and the disease, insect, or weed control measures to adopt. Therefore, a certain measure of uniformity of execution that would minimize spurious results is expected in national and regional collaborative trials.

The experience of maize researchers accumulated over several decades in the subregion has clearly indicated the need for training researchers and technicians in the conduct and management of maize field trials. The data recovery rate from national and particularly from international (regional) trials has never been 100% in WCA. Very often, data returned to trial coordinators are not analyzable and are, therefore, not usable. Sometimes, the coefficients of variation (CV) associated with measured traits are too large, thus rendering such data unusable. Researchers define certain traits differently. An example is plant height. Some researchers define it as the distance from the soil surface to the node bearing the flag leaf (topmost leaf); some others define it as the distance from the soil surface to the height of the central tassel branch.

The purpose of this book is to correct these anomalies as far as possible. The materials were carefully thought out and are presented in a logical sequence by the authors. The contents have been used in several training courses and refined over time. Starting with the purpose and types of maize variety trials, the authors follow with an exhaustive description of designing, laying out, and conducting maize variety trials. Sources of spurious data in maize research include the timing and rate of application of agronomic practices, data collection, harvesting, and preparation of data for analysis. The authors focus attention on these areas in four different sections. Examples, illustrations, practice problems, materials needed for field work, and revision questions are given in the annexes. Students, technicians, as well as research scientists will find this book an invaluable companion in the execution of their research work.

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1 Purpose of maize variety trials

Maize (*Zea mays* L) is a cereal crop adapted to a wide range of environmental conditions and is cultivated in all agro-ecologies of West and Central Africa (WCA). It is used for many different purposes including food for humans, feed for livestock, and raw material for agro-allied industries. For this reason, there are different types or varieties bred specifically for each end-use. The term “variety” refers to a subdivision of a species that is morphologically or physiologically distinct. It is used in a general way to refer to open-pollinated populations (landraces and improved varieties), inbred lines, and hybrids. “Cultivar” is another term used by plant breeders and agronomists. It refers to a variety which is widely cultivated and generally implies that the variety has been improved by selection. Although the two terms are often used interchangeably, variety seems to be more commonly used in maize research and production.

A variety or cultivar is different from others in at least one characteristic or trait. Varieties can be distinguished by a number of features, including the following:

- Ecological adaptation – temperate vs. tropical adaptation, lowland vs. mid-altitude, mid- vs high altitude.
- Maturity – time required to reach physiological or harvest maturity (< 90 days = extra-early; 90–95 days = early; 105–110 days = intermediate; 115–120 days = late; > 120 days = extra-late).
- Grain texture – flint, semi-flint, semi-dent, dent, floury.
- Grain color – white, yellow.
- Protein quality – normal vs. quality protein maize (QPM).
- Endosperm content – field maize, popcorn, or sweet corn.
- Resistance to biotic factors including diseases, insects, and parasitic weeds.
- Resistance to abiotic factors, such as drought, adverse fertility conditions, acid soils, and temperature extremes.
- Yield of grain or fodder.

Some morphological features are used as descriptors to identify maize varieties in the field, including grain color and texture, plant architecture, leaf angle or orientation, plant and ear height, tassel size, shape, and color, silk color, and stem pigmentation. The genetic diversity among maize varieties provides a high degree of versatility for the crop. However, it is not always easy to identify specific open-pollinated varieties (OPVs) of maize in the field, due to the out-crossing nature of the crop and the variation that exists within varieties. Inbred lines and hybrids are more readily distinguished because they are more uniform.

One requirement of the varietal release mechanism in WCA countries is that maize varieties should be described for specific and stable morphological features before they are released. Another requirement is a description of the extent or range of variation expected for the specific features as well as for some other traits, including the ecological adaptation of the variety. The variation may be expressed as the standard deviation from the mean for quantitative traits, and as percentages for qualitative traits. This information is obtained from field trials.

The success of any seed production agency or seed company depends on the quality of the products it offers. The marketed varieties must be highly productive and well-suited to the needs and preferences of maize farmers and consumers in the region. Some commercial companies establish and maintain their own breeding programs and produce their own proprietary hybrids. Others produce and market seeds of varieties that are in the public domain. Public varieties may originate from international agricultural research centers involved in maize improvement (IITA and CIMMYT) or from the breeding programs of national research programs.

In WCA, each year IITA prepares and distributes international trials. These trials contain the most promising varieties currently available from the international centers and regional programs. National programs and seed companies in the region also submit their own varieties for inclusion in international trials. Special purpose trials are also available including germplasm with resistance to *Striga hermonthica* and maize streak virus (MSV), and with drought tolerance. These trials afford national research programs and private seed companies the opportunity to identify and select materials which may be useful as new varieties or source germplasm for their breeding programs.

Field trials involving large numbers of progenies are conducted for the purpose of selecting the top-performing lines to be used in developing improved varieties, such as experimental varieties (EVs) or, in recurrent selection, to be recombined to form a new population for further improvement. Progeny trials are a regular component of maize breeding programs.

2 Types of maize variety trials

In Section 1, we showed that maize variety trials are conducted to achieve different purposes. There are several types of variety trials, depending on the purpose of the trial. The different types and the information that may be obtained from them are presented here.

There are five types of maize variety trials:

- Progeny trials
- Observation/preliminary trials
- National, Regional, and International Variety Trials
- On-farm trials
- Demonstrations

Progeny trials

Progeny trials involve large numbers of progenies of a family type, such as full-sib, half-sib, or S_1 lines. The progenies are evaluated to identify those that may be used to generate synthetic or experimental varieties, or recombined to form an improved population in a recurrent selection program. Progenies in the trials are normally a random sample from the particular population under study. Therefore, data obtained from progeny trials may be used to estimate genetic variances and covariances from which heritability estimates, predicted responses to selection, genetic correlation coefficients, and correlated responses to selection may be obtained. Progeny trials are normally researcher-managed.

Progeny trials involve complex field designs, such as balanced incomplete block, lattice, and alpha-lattice. Some examples of lattice are 11 × 11 for 121 progenies, 14 ×14, 16 × 16, etc. Randomization and replication arrangements are available in textbooks, such as Cochran and Cox (1957), or in some computer packages. Because of the large number of entries, single-row plots with only 2–3 replications in a few environments are used in progeny trials. Also, the progenies may be divided into smaller groups called sets and evaluated in blocks to minimize the confounding effects of soil variability. For example, 16 families (four sets of four families) may be assigned to a block. In the analysis of variance, each set is treated as a separate experiment; the sum of squares and degrees of freedom are pooled over sets for a combined analysis.

Observation/Preliminary trials

Knowledge of the performance capability of new introductions is a prerequisite for the judicious choice of populations for improvement in a breeding program. Such knowledge is accumulated by the breeder through observation or preliminary trials. The number of entries in such trials may be small or large, but the trials are usually conducted on-station and closely monitored by the researchers and experienced technicians. It is important to evaluate the agronomic, disease and pest responses of potential parental or source populations under the soil and climatic conditions of the geographical region in which the germplasm will be used. If the number of entries is large, the new introductions may be classified for specific traits before they can be used wisely as parental breeding stocks. Similarly, the data may be used to determine trait associations under different environmental conditions, such as different agro-ecologies.

Observation or preliminary trials are also used to evaluate previously untested technologies in a simple comparative manner with existing technologies, usually on experimental stations under close supervision to determine whether they have any merit. A newly developed variety may be tested in an observation or preliminary trial to compare it with existing varieties in a limited number of locations to see if it is promising before more extensive testing is carried out.

Observation or preliminary trials are usually planted into single-row plots in a few locations or years with 2–3 replications/site. Data are recorded on as many traits as possible; the larger the number of traits assayed the better.

National, Regional, and International Variety trials

Years before international centers with mandate for maize research were established in West Africa, national programs conducted research and had national variety trials. The establishment of IITA in Nigeria in 1967 not only strengthened the national maize trials but also extended the trials to several other countries in WCA. With time, CIMMYT also collaborated with IITA and the national maize programs to conduct variety trials in the subregion. In addition, special projects with funding support from sources other than IITA and CIMMYT facilitated uniform variety trials across the countries of the subregion. This led to the formation of the regional maize networks under the auspices of Semi-arid Food Grain Research and Development (SAFGRAD) Project. Eventually, the West and Central Africa Collaborative Maize Research Network (WECAMAN) was established and the conduct of regional uniform variety trials (RUVTs) and collaborative research activities were put on sound footing in WCA.

Apart from national and regional variety trials, IITA and CIMMYT send special trials to countries within and beyond WCA. Such trials have been tagged international trials. On a few occasions, national programs have also conducted international trials. For example, in 1995 and 1996, the Maize Research Program of the Crops Research Institute of Ghana conducted Quality Protein Maize (QPM) variety trials in 20 countries of Africa, Central America, South America, and Asia (Twumasi-Afriye et al. 1999).

National, regional, and international trials are traditionally conducted on research stations but in recent decades more and more of these trials are conducted in farmers' fields. Usually the trials are multi-location experiments involving one or two check varieties, which are the commonly grown and well known as the best varieties in the locations where the trials are planted. The check varieties form the standard against which the test varieties may be compared. Check varieties are normally similar in type, maturity, and vigor to the experimental varieties. In some cases, however, and depending on the objective of the trial, check varieties may not be similar to the test varieties in some specific characteristics. For example, the best available OPVs may be used as check varieties in a situation where hybrid varieties are being evaluated for the first time. However, such checks must be similar to the test varieties in most other characteristics. Although each collaborator provides the check variety for his location, the institution coordinating the trials may also add a common check, usually called a reference entry (RE). Reference entries are common in trials evaluating maize varieties for biotic or abiotic stresses. Apart from local checks, all entries in national, regional, or international trials are the same for all the locations in the trials. Randomization and replication are done by the coordinating institution, but agronomic practices are carried out as recommended for the ecology of each collaborator. The coordinating institution normally sends field books with seeds of each trial to the collaborators.

Collaborators are required for national, regional, and international trials. Such collaborators normally volunteer as individuals. Although the institution originating the trials may provide some form of assistance, in most cases the collaborators use part of the available resources in their institutions to execute the trials. Therefore, the institutions of the volunteer collaborators should have a formal notification of the collaboration. Also, some form of incentive should be provided for the collaborators, including acknowledging them or listing them as co-authors of any publication emanating from the collaborative project.

National, regional, and international trials are a fast, effective, and inexpensive way of introducing improved varieties to areas where they were not developed. An example is the WECAMAN approach to developing improved maize varieties for WCA. Countries that had strong national programs in specific subject-matter areas were selected as lead centers and funded through competitive grants to conduct research in such areas. Technologies emanating from the centers were composed into regional trials and sent to all member countries of the Network. In this way, the duplication of effort was minimized and the limited funds for the Network were spent more judiciously.

National, regional, and international trials have several challenges, especially in WCA. These include the following:

1. Low data recovery rate
2. Delays caused by the bureaucracy of quarantine services of the different countries
3. Loss of seeds in transit
4. Loss of seed viability from delayed delivery
5. Seed delivery expenses
6. Incomplete or non-analyzable data

The low rate of data recovery and submission of incomplete or non-analyzable data seem to have been the two prevalent challenges in WCA. In 2002, the 195 international trials coordinated by IITA had a data recovery rate of only 48%. In the RUVTs conducted in WCA in the early 1990s, recovery rates were only 27–50% in several countries (Fakorede 1996). The situation seems to be improving in WCA, probably because WECAMAN conducted several skill acquisition training courses for technicians and scientists in the region (Badu-Apraku et al. 2004). In the 2007 DTMA regional trials coordinated by IITA, usable data were received from 80% of the 64 sets sent to collaborators; in 2008, 76% of the 143 sets returned usable data to the coordinators (IITA, 2009; 2010).

On-farm trials

Maize varietal development is normally done through on-station research and is researcher-managed, with the goal of increasing maize production at the farm level. The researcher evaluates potential new varieties in small plots (e.g., four 0.75 m rows, 5 m long = 15 m^2) with optimum levels of production inputs, such as fertilizer and herbicide application for effective weed control. The production environment in farmers' fields may be very different from the near-ideal situation in on-station research fields. Varieties that perform well on-station may not carry through in the farmers' fields. Farmers adopt new varieties that are economically superior to the existing one(s). They are interested in net benefits and in protecting themselves against risk. Before changing from one variety to another, the farmers consider many factors such as agro-ecological requirements, the availability of additional production resources (farmland, credit, labor, skill, equipment, etc.), and the potential additional income resulting from the change. They also consider the compatibility of the new variety with their farming system. To make good recommendations, researchers must keep in mind the farmers' goals and evaluate new varieties under their production conditions and practices. Varietal evaluations carried out in the farmers' fields are referred to as on-farm trials.

On-farm trials may be researcher-managed, farmer-managed, or jointly managed. The varieties are evaluated under real farmers' conditions and the trials create opportunities for communication and interaction among all stakeholders (farmers, breeders, extension staff, and seed companies) as well as enable farmers to participate in the evaluation of varieties under situations very similar to their production environments and practices.

There are several variants of maize on-farm trials. The oldest, more conventional, and most commonly used involves two or three test varieties and the farmer's variety, planted in replicated plots of relatively large size if researcher-managed or without replication if farmer-managed. Apart from the seeds of test varieties which are supplied by the researcher, the volunteer farmer provides all the inputs and manages the trial from land preparation to harvest as he normally does in his farm. The researcher visits the trial often to take data, if necessary, as well as interact and exchange views with the farmer. The farmer has the benefit of keeping the harvest at the end of the season.

Another type of on-farm trial is called the Mother-Baby Trial (MBT). Although relatively new, it has gained popularity as an effective method of evaluating maize varieties under the farmers' conditions. An MBT involves evaluating a relatively large number of potential new varieties in a trial (mother trial) and subsets of the varieties (baby trials) in several satellite farmers' fields. Mother trials are researcher-managed; baby trials are farmer-managed. Mother trials may be conducted by the researcher under the farmer's typical management practices or with researcher-specified inputs.

Participatory Research, such as Participatory Plant Breeding (PPB) is another form of on-farm trial. This method involves farmers working with breeders early in the process of varietal development. Progeny trials, selection, and recombination to form new varieties are not only carried out in the farmers' fields but also involve both farmers and researchers working together. This method has not gained much popularity in maize research in WCA because it is more appropriate for the self-pollinated crops, such as rice and the legumes.

Advantages of on-farm evaluation trials include the following.

- Testing the acceptability and profitability of the newly developed varieties before they are promoted on a larger scale;
- Obtaining realistic input–output data for cost–benefit analysis;
- Providing important diagnostic information about farmers' problems;
- Enabling researchers to identify the impediments to a rapid and higher adoption of improved technologies;
- Providing an avenue for a better understanding of the processes involving the integration of farmers' indigenous knowledge into the scientific knowledge of researchers.

Demonstrations

- Demonstrations are used to illustrate previously tested and approved technologies to farmers.
- Only a few technologies are demonstrated in comparison with known and commonly used technologies on relatively large, unreplicated plots in farmers' fields.
- Demonstrations of the same set of technologies may be conducted at many locations.
- Farmers are invited to visit and evaluate the technologies so that they may become familiar with them and be encouraged to adopt appropriate options into their own farming practices.

3 Experimental designs in maize variety trials

Research is a planned investigation into a subject to discover new facts, or establish, confirm, or revise existing information or theories. As presently done in sub-Saharan Africa in general and WCA in particular, the results of maize research are used to develop a plan of action based on the facts discovered in the research. For example, research is the basis for recommending new technologies to farmers. In government, it is useful in policy formulation, and national development depends a whole lot on research findings.

As clearly spelt out in Section 2, there are different types of variety trials in maize improvement research, each serving a different purpose. Necessarily, each trial must be subjected to statistical analysis to obtain the desired information. ***Statistics*** is a branch of Mathematics that deals with data collection, summarization, analysis, presentation, and interpretation. It has its own assumptions, theorems, rules, notations, and terminology. Statistics is a tool, a means to an end, and NOT an end in itself. The use of appropriate statistical concepts or tools (methods) is important for the correct interpretation of data. Abuse of statistics could lead to the erroneous and misleading interpretation of research results and inappropriate conclusions, which may have grave consequences.

In this section, we present the experimental designs frequently used in maize research. To enhance the proper understanding of the materials presented here, basic definitions, concepts, and steps in field experimentation are first discussed briefly.

Some basic definitions and concepts

Experimental unit–the lowest level or smallest subdivision of the experiment to which independent application of the treatment is made. Examples in maize research are plot, pot, and soil samples.

Experimental design–the plan for grouping experimental units and assigning them to treatments.

Experimental factor–an external item or variable under investigation. A factor of an experiment is a controlled independent variable, a variable whose levels are set by the experimenter. Examples are variety, fertilizer, and planting density.

Experimental treatment–magnitude of external factors imposed by the researcher; usually with two or more levels or rates. In research, a treatment is something that researchers administer to experimental units. For example, a corn field is divided into four and a different type of fertilizer is applied to each part to see which produces the highest yield. Treatments are administered to experimental units by "level", where level implies amount or magnitude. For example, if the experimental units were given 5 mg, 10 mg, and 15 mg of a micronutrient, those amounts would be three levels of the treatment. Level is also used for categorical variables, such as drugs A, B, and C, where the three are different kinds of drug, not different amounts of the same thing.

Factor and treatment are words often but erroneously used interchangeably in research. A factor is a general type or category of treatments. Different treatments constitute different levels or rates of a factor. For example, in a study evaluating the response of five maize varieties to four levels of N fertilizer, variety and fertilizer are factors while the different varieties and fertilizer rates are treatments. Experimental units contain the treatments.

Randomization is the process by which experimental units (the basic objects upon which the study or experiment is carried out) are allocated to treatments; that is, by the process of chance or probability and not by any subjective and hence possibly biased approach. The treatments are allocated to units in such a way that each treatment is equally likely to be applied to each unit. Randomization is preferred to any other possible way of allocating treatments to experimental units, since the alternatives may lead to biased results. The main advantage of randomization lies in the fact that it tends to distribute evenly on the experimental treatments any uncontrollable external effects likely to influence the outcome of the research. Most statistical methods, but in particular the analysis of variance, assume that treatments have been applied randomly.

Replication means repetition, another copy, to look (exactly) alike. It is the number of times a treatment appears in an experiment.

Population A population may be defined as all possible individuals in a specified situation. The individuals have one or more characteristics in common. A population could be finite or infinite, homogeneous or heterogeneous. Thus, we could have a population of maize clearly distinct from other maize populations.

Sample–part of a population drawn to represent the whole population**.** In most cases, treatments in maize variety trials are samples. In practice, a sample could be obtained at random by a process referred to as probability sampling. Samples could also be non-random or fixed. The analysis and interpretation of data collected from maize variety trials are affected by the type of sampling used to obtain the treatments and the sample size of the trials. For the purposes of statistical analysis, individuals in a sample are represented as x_1, x_2,……,x_n

Statistic–a quantity computed from a sample. Note here that this is singular and the plural is statistics. Distinguish this from Statistics as a subject, which is a singular noun.

Parameter–a quantity computed from a population. Because parameters are rarely computed, statistics are used as estimates of the corresponding parameters. Therefore, statistics are computed with a measure of uncertainty of their *accuracy*. In this context, accuracy is defined as lack of bias in an estimate such that, if a large enough number of measurements were to be taken, the estimate would equal the true parameter of interest. The unknown and inadvertent bias in an estimate is referred to as *experimental error variance*. It is the quantified differences for a particular characteristic among experimental units subjected to the same treatments.

Notation for parameters and statistics– Greek letters are used to designate parameters while the English alphabet is used to represent statistics. Following are some examples.

Quantity	Population	Sample
Mean	μ	$\bar{x}$
Variance	σ^2	s^2
Standard deviation	σ	s
Correlation coefficient	ρ	r
Regression coefficient	β	b
Chi-square, t-stat, F-stat, *etc*	Same symbols	

Variable–a characteristic of a sample or population whose value is not the same from one individual to another in the population or sample. A variable is *qualitative* or *discrete* when the individuals can be grouped into distinct classes without ambiguity. Examples are sex, color, taste, rank, nationality. Qualitative variables are not subject to mathematical operations, such as addition, subtraction, multiplication, and division. On the other hand, *quantitative* or *continuous* variables are not easily grouped into distinct classes without ambiguity. They take values ranging from zero to infinity, including both integers and non-integers. Quantitative traits are subject to the rules of mathematical operations. The statistical method to use for data analysis is determined by the type of variable on which the data have been collected.

Frequency distribution

Data obtained on a number of individuals may be cast into groups known as frequency counts or frequency distribution. Depending on the sample size and the variation among the individuals from which the data are obtained, plots of the distribution will result in different shapes. For a large sample size, the frequency counts will result in a **normal distribution**, a bell-shaped curve which is also called **continuous probability distribution** or the **Gaussian distribution** in honor of Carl Friedrich Gauss, a famous mathematician. Figure 1 is an example of normal distribution.

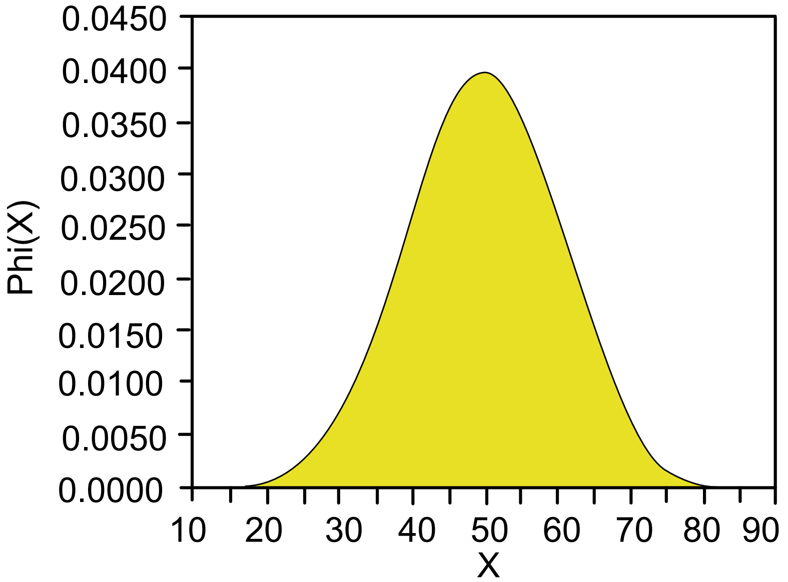


Figure 1. A normal distribution with μ = 50 and σ = 10.

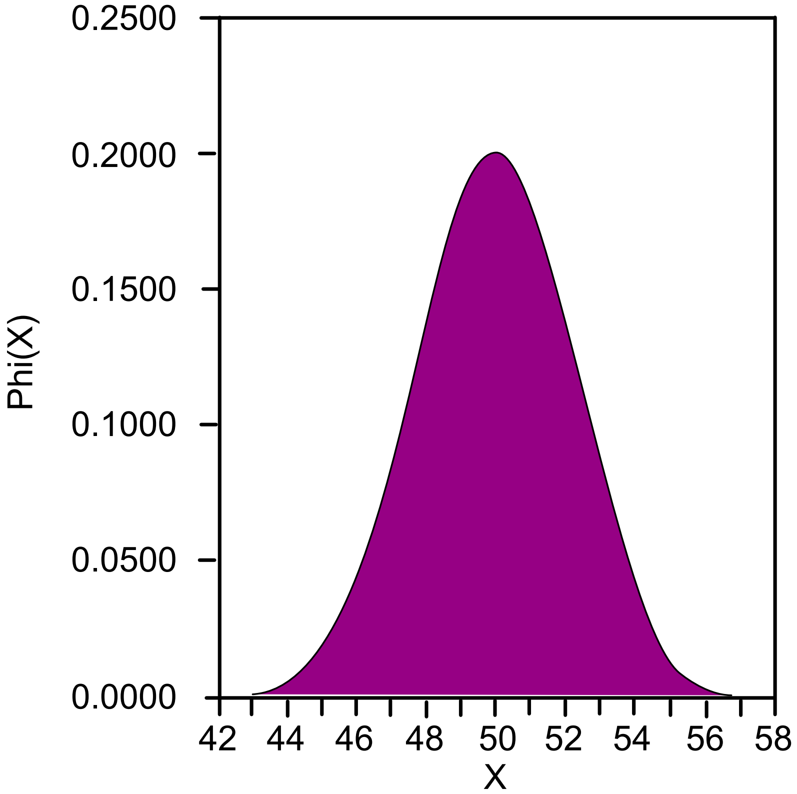


Figure 2. A normal distribution with μ = 50 and σ = 2.

Although there are several types of distribution, the assumption of normality underlies most analysis pertinent to the agricultural sciences. Normal distributions have two quantities, the mean, μ, where the peak of the density occurs, and the standard deviation, σ, which indicates the spread or girth of the bell curve. $N(\mu,\sigma^2)$ refers to a normal distribution with mean μ, and variance σ^2. Note the italicized *N* to distinguish it from N (Nitrogen). The bell-shaped curve has several properties as typified by the example illustrated in Figure 1.

- The curve concentrates in the center and decreases on either side; that is, the set of data has less of a tendency to produce unusually extreme values, unlike some other distributions.
- It is symmetric; that is, the probability values of deviations from the mean are comparable in either direction.
- Most of the area in this case falls between 20 and 80.
- This means that values smaller than 20 or larger than 80 are extremely rare for this variable. Compared to a normal distribution with μ = 50 and σ = 2 (Fig. 2), the picture looks similar but the scale has changed. Almost all of the area is between 44 and 56. *Therefore, with a smaller standard deviation, the probability is much more concentrated.*

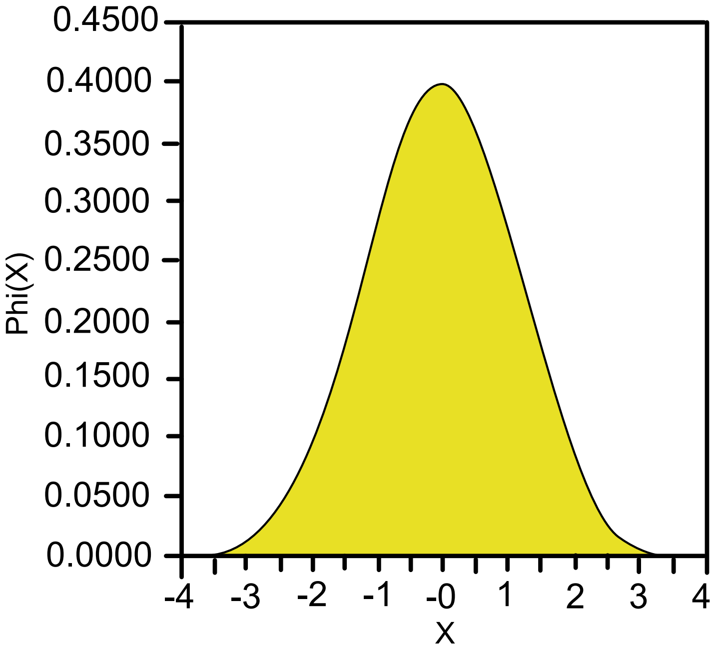


Figure 3. The Standard Normal Distribution; μ = 0, σ = 1.

Statistical distributions and hypothesis testing

Normal distributions can be transformed to *standard normal distributions*. The standard normal distribution is a normal distribution with $\mu = 0$ and $\sigma = 1$ (Fig. 3). Most of the area of the standard normal distribution lies between –3 and +3 standard deviations (s.d). Many statistical tables will show areas (or equivalently, probabilities) for the standard normal distribution. In a standard normal distribution, approximately 95% of the area is covered by 2 s.d and 99% by 3 s.d. These are the basis for using $\alpha = 0.05$ or 0.01 as the acceptable significant levels in the statistical test of hypothesis.

Statistics used to measure the spread or dispersion of data include variance (σ^2 or s^2), standard deviation (*s.d.*), standard error of the mean (*s.e.*), standard error of a difference (*s.e.d.*) and coefficient of variation (CV). These statistics are computed as follows:

$$\sigma^2 = \frac{\Sigma(x-\mu)^2}{N}$$

$$s.d. = \sqrt{s^2}$$

$$s.e. = (\sqrt{s^2})/n$$

$$s.e.d. = \sqrt{[(s_1^2 + s_2^2)/n]}$$

$$CV = (s/mean)100$$

The mean represents a lot of values, depending on sample size, but it does not indicate the variability in the data. Generally, Analysis of Variance (ANOVA) followed by separation of means is commonly done for maize variety trials. Means should be presented with an indication of the dispersion of the data. The three statistics, *s.d.*, *s.e.*, and *s.e.d*. are often used as indicators of dispersion. Practical application of this process is given in Section 9. Other estimates of error are the least significant difference (LSD) and the Duncan new multiple range test (DNMRT). These can be misleading and should be used with caution.

Steps in experimentation

Research requires planning to be effective. The steps involved in field experimentation are as follows:

- Define the problem.
- State your objectives and hypotheses.
- Select the treatments and experimental material.
- Select the appropriate experimental design.
- Determine the experimental unit (the unit for observation) and number of replications.

- Consider the traits to assay and the minimum amount of data to be collected.
- Outline the statistical analysis and summarization of the data.
- Conduct the experiment.
- Analyze the data and interpret the results.
- Prepare a complete, readable, and correct report.

These steps are discussed more extensively from a practical viewpoint in subsequent sections of this book. Our emphasis in this section is on experimental designs. The researcher's goal is to obtain usable information from the analysis of data generated from an experiment. It is wise to take time and effort to organize the experiment properly to ensure that the right type and amount of data are available to answer the questions of interest as clearly and efficiently as possible. This may be effectively done by proper experimental design.

The specific questions that the experiment is expected to answer must be clearly identified before carrying out the experiment. The researcher should also attempt to identify known or expected sources of variability in the experimental units since one of the main aims of a designed experiment is to reduce the effect of these sources of variability on the answers to questions of interest. In other words, experiments are designed to improve the precision of answers to research questions.

The commonly used designs in maize research are as follows.
1. Completely Randomized Design (CRD)
2. Randomized Complete Block Design (RCBD)
3. RCBD with factorial arrangement (also known as Factorial Design)
4. Split-plot and Split Split-plot Designs
5. Balanced Incomplete Block Designs
6. Lattice Designs

Completely Randomized Design (CRD)

The structure of the experiment in a completely randomized design is assumed to be such that the treatments are allocated to the experimental units completely at random but not haphazardly. In other words, the treatments are assigned to experimental units without restriction on randomization. Following is the CRD layout of an experiment with four treatments a, b, c, d replicated three times each. The numbers refer to plots or experimental units. Note that the treatments are not in any particular order or grouping.

1 a	2 d	3 b	4 c
5 b	6 a	7 c	8 d
9 d	10 b	11 a	12 c

The advantages of CRD include the following:
1. Flexibility.
2. Number of replications need not be equal for all treatments.
3. A missing plot may be disregarded without any adverse effect on the analysis and results.
4. Statistical analysis is simple.

A major disadvantage of CRD is that it is very inefficient if plots are not homogeneous.

Randomized Complete Block Design (RCBD)

The randomized complete block design involves matching the subjects according to a factor which the experimenter wishes to investigate. The subjects are put into groups (or blocks) of the same size as the number of treatments making up the factor. In other words, a block contains as many experimental units or plots as the number of treatments. The treatments are then randomly assigned to the different experimental units within the block. Blocking may then be defined as the procedure by which experimental units are grouped into homogeneous clusters in an attempt to improve the comparison of treatments by randomly allocating the treatments within each cluster or ‘block’.

The example given under CRD may be laid out as RCBD as follows:

	Plot 1	Plot 2	Plot 3	Plot 4
Block 1	a	b	c	d
Block 2	c	b	d	a
Block 3	a	d	b	c

In RCBD,

1. Each block contains all the treatments and is, therefore, the same size as all other blocks in the experiment (hence the name “complete block”).
2. The number of blocks is the same as the number of replications;
3. Treatments are randomized within each block independently of other blocks.
4. All units (plots) within the same block are handled in the same manner except for the treatments applied.
5. In the analysis, treatment effects are assumed to be independent of block effects; therefore, the two can be cleanly isolated in the analysis.
6. Variability within each block is minimized while that among blocks is maximized.

The real advantage of RCBD is evident in situations where the field for the trial is heterogeneous for factors such as soil fertility and slope. Where the soil is homogeneous and relatively uniform in flatness, RCBD may have little or no advantage over CRD.

Randomized Complete Block Design with Factorial Arrangement (or Factorial Design)

This design is used to evaluate two or more factors simultaneously. The treatments are combinations of levels of the factors. The advantages of factorial designs over experiments containing one factor at a time are that they are more efficient and they allow interactions to be detected. In the analysis of data from this design, three sources of variation may be obtained in addition to block and residual (error) effects. These are variations due to factor A, to factor B (both of which are referred to as main effects) and the interactions of factor A with factor B, which are referred to as interaction effects.

Main effect–This is the simple effect of a factor on a dependent or response variable. It is the effect of the factor alone, averaged across the levels of other factors.

Interaction effect–An interaction is the variation among the levels of a factor as influenced by the levels of another factor.

Example–In a study designed to determine the response of four varieties (V1, V2, V3, V4,) to four levels of N fertilizer (N1, N2, N3, N4) the total treatment combination is 4 × 4 = 16. This is referred to as a 4 × 4 factorial; each replication contains 16 experimental units (plots). The 16 treatment combinations are randomized in each replication and each treatment combination occupies a plot as shown in the following diagram for one replication of the experiment.

One replication of a 4 × 4 factorial experiment

V1N1	V2N1	V4N2	V3N1
V3N3	V2N2	V4N1	V1N2
V1N3	V4N4	V2N3	V3N4
V2N4	V1N4	V3N2	V4N3

In this design, equal precision is expected on the determination of the main effects on the variable (trait) of interest such as grain yield. Of equal or greater interest is the interaction effect.

Split-plot and Split-split plot designs

Split-plot design involves introducing a second factor into an experiment by dividing the large experimental units (whole unit or whole plot) for the first factor into smaller experimental units (sub-units or sub-plots) on which the different levels of the second factor will be applied. Each whole unit is a complete replicate of all the levels of the second factor (RCBD). The whole unit design may be CRD or RCBD.

Randomization–The first factor levels are randomly assigned to the whole plots according to the rules for the whole plot design (i.e., CRD or RCBD). Similarly, the second factor levels are randomly assigned to sub-plots within each whole plot according to the rules of an RCBD. The name of the split-plot design is prefixed with the design name associated with the whole plot design; for example, Randomized Complete Block Split-Plot Design. The design for the sub-plot is, by definition, always RCBD.

Advantages

1. Since sub-plot variance is generally less than whole plot variance, the sub-plot treatment factor and the interaction are generally tested with greater sensitivity.
2. It allows for experiments with a factor requiring relatively large amounts of experimental material (whole units) along with a factor requiring relatively little experimental material (sub-unit) in the same experiment.
3. If an experiment is designed to study one factor, a second factor may be included at very little cost.
4. It is an effective design for experiments involving repeated measures on the same experimental unit (whole unit), while the repeated measures in time are the sub-units.

Disadvantages

1. Analysis is complicated by the presence of two experimental error variances, which leads to several different standard errors for purposes of comparisons.
2. High variance and few replications of whole plot units frequently lead to poor sensitivity on the whole unit factor.

Split-plot designs are particularly useful in experiments where (1) one factor requires larger experimental units than the other factor, and (2) greater sensitivity (precision) may be desired for one factor than the other. In this latter case, the factor on which the greater precision is required is allocated to the sub-plots. The example given for the factorial design may be designed as a RCB split-plot, with a 4 × 4 factorial arrangement of treatments as contained in the following diagram.

One replication of a Split-plot design

N1	V1	V2	V4	V3
N3	V3	V2	V4	V1
N4	V1	V4	V2	V3
N2	V2	V1	V3	V4

Other replications are the same except that a new randomization is done for each replication.

The Split-split plot design is an extension of the Split-plot design to accommodate a third factor. Levels of the third factor are randomized and assigned to sub-divisions of the sub-plot, which are referred to as sub-sub plots. Our example with a third factor, micronutrient fertilizer at two levels, M1 and M2, may now be laid out in a Split-split plot design as shown in the following diagram for one replication:

One replication of a Split split-plot design

N1	V1M1	V2M2	V4M2	V3M1
	V1M2	V2M1	V4M1	V3M2
N3	V3M2	V2M2	V4M1	V1M1
	V3M1	V2M1	V4M2	V1M2
N4	V1M2	V4M1	V2M2	V3M1
	V1M1	V4M2	V2M1	V3M2
N2	V2M2	V1M1	V3M2	V4M1
	V2M1	V1M2	V3M1	V4M2

Here also, the greatest precision is on the sub-sub plot main effect and the associated interaction terms. Obviously, the analysis is much more complicated than that of Split-plot design.

Balanced Incomplete Block Design

In the designs discussed thus far, each block contains all treatments. In some situations, it may not be possible to have a sufficient homogeneous space of land that would contain all treatments in one block. In such cases, the treatments may be grouped into subsets that are assigned into different blocks. Treatments in each block form an incomplete block. Block designs which have blocks of sizes less than the total number of treatments in a study are called Incomplete Block Designs.

One of the most commonly used incomplete block designs is called Balanced Incomplete Block Design (BIBD). This design allows all comparisons among pairs of treatments to be done with equal precision. Each pair of treatments occurs in an equal number of times; that is, they occur together in the same number of times.

Construction of incomplete block designs is not as easy as that of complete block designs. To effectively construct the design, some relationships must be established as illustrated in the following equations:

$b = t!/[k!(t-k)!]$ …………………………... [1]
$\lambda = (t-2)!/[(k-2)!(t-k)!]$ ……………………[2]
$r = (t-1)!/[(k-1)!(t-k)!]$ ………..……………[3]

In these equations, t = number of treatments, b = number of blocks, k = number of plots per block, λ = number of times each pair of treatments occurs together, and r = number of blocks in which each treatment appears.

An example: Construct a BIBD for an experiment containing 5 treatments in blocks of size 4.

Here, $t = 5$, $k = 4$, $b = 5!/4!1! = 5$ blocks, $r = 4!/3!1! = 4$ and $\lambda = 3!/2!1! = 3$.

The design is therefore ABCD ABCE ABDE BCDE

Analysis of data from BIBD is more complicated than data from other designs; however, the availability of user-friendly statistical packages on the computer has greatly reduced the drudgery.

Lattice Designs

The Lattice design is a special case of the incomplete block design used when the number of treatments is large, such as in progeny trials or preliminary trials. Lattice designs involve grouping the blocks containing the treatments in such a way that each treatment appears only once in each group.

The block size of lattice designs must be the square root of the number of treatments; that is, $t = k^2$. Each pair of treatments occurs together in a block only once; that is, $\lambda = 1$.

Example: Consider a case of $t = 9$ and $k = 3$. The parameters are obtained as follows:

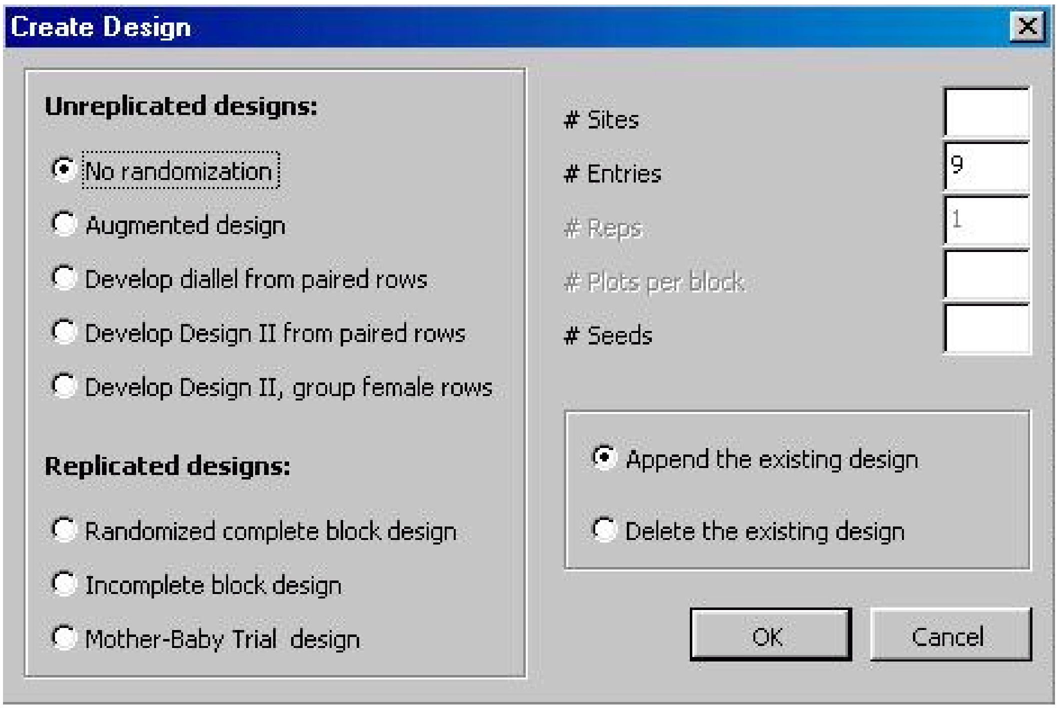
From Equation [1], $b = 9!/3!6! = 84$; from Equation [2], $\lambda = 7!/1!6! = 7$; and from Equation [3], $r = 8!/2!6! = 28$. Since 7 is a common factor to the three parameters, we can reduce the design by dividing each parameter by 7 to obtain $b = 12$, $r = 4$ and $\lambda = 1$. The design is therefore as follows:

ABC	DEF	GHI
ADG	BEH	CFI
AFH	BDI	CEG
AEI	BFG	CDH

Lattice designs may be used also when the number of treatments is not a perfect square. Such cases are referred to as rectangular lattice designs. Details of the randomization plans of lattice designs may be found in textbooks on experimental designs and statistics, such as Cochran and Cox (1957). Also, computer packages with suites for experimental designs are available in the market. One such package is *Fieldbook*, a user-friendly software developed by CIMMYT to assist researchers in creating improved designs and analyzing data obtained from the designs (Fig. 4). The software handles different types of experimental designs, including those less frequently used, such as Augmented and Incomplete Lattice Designs. The menu for analysis and output options are shown in Figure 5.

Distribution and orientation of blocks and plots, along with plot size (number of rows, row length, and width) are very important in minimizing experimental errors. When comparing a large number of varieties, use lattice designs because they correct heterogeneity. Place entire experiments, replicates, or incomplete blocks within areas of uniform stress. Select the best layout and the correct number of replications to minimize experimental error. In an experiment to evaluate 100 varieties, possible ways of laying out the trial are shown in Figure 6 It is advisable to opt for the most compact layout, as shown in Figure 6C for the 10 × 10 layout.

Improved statistical designs increase the precision with which parameters are estimated from field experiments. For example, the heritability of grain yield of maize under low-N improved from 30% in an RCBD to 41% under a lattice design. Similarly under high-N, the values were 55% for the RCBD and 63% for the lattice design.



Unreplicated designs:

● No randomization
○ Augmented design
○ Develop diallel from paired rows
○ Develop Design II from paired rows
○ Develop Design II, group female rows

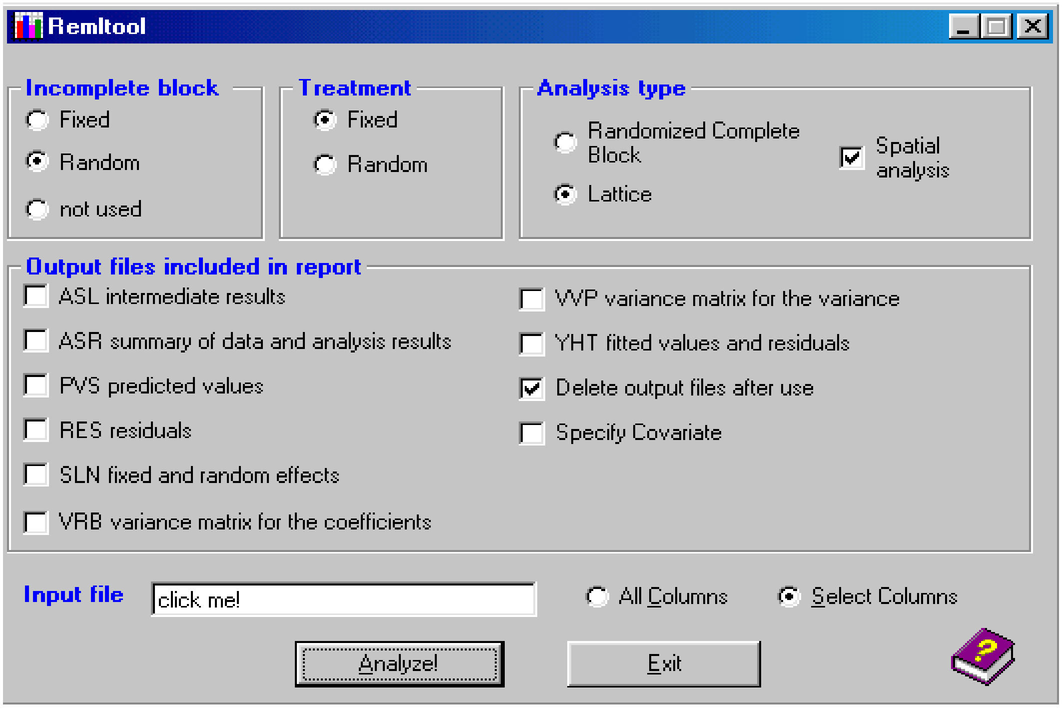
Replicated designs:

○ Randomized complete block design
○ Incomplete block design
○ Mother-Baby Trial design

Sites:
Entries: 9
Reps: 1
Plots per block:
Seeds:

● Append the existing design
○ Delete the existing design

Figure 4. EXCEL Fieldbook software from CIMMYT for creating improved designs.



Incomplete block
○ Fixed
● Random
○ not used

Treatment
● Fixed
○ Random

Analysis type
○ Randomized Complete Block
● Lattice
☑ Spatial analysis

Output files included in report
☐ ASL intermediate results
☐ ASR summary of data and analysis results
☐ PVS predicted values
☐ RES residuals
☐ SLN fixed and random effects
☐ VRB variance matrix for the coefficients
☐ VVP variance matrix for the variance
☐ YHT fitted values and residuals
☑ Delete output files after use
☐ Specify Covariate

Input file click me!
○ All Columns
● Select Columns

Figure 5. RemlTool for spatial analysis of field trials.

A (5 × 20)

1	6	11	16	21	26	31	36	41	46	51	56	61	66	71	76	81	86	91	96
2	7	12	17	22	27	32	37	42	47	52	57	62	67	72	77	82	87	92	97
3	8	13	18	23	28	33	38	43	48	53	58	63	68	73	78	83	88	93	98
4	9	14	19	24	29	34	39	44	49	54	59	64	69	74	79	84	89	94	99
5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100

B (25 × 4)

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24
25	26	27	28
29	30	31	32
33	34	35	36
37	38	39	40
41	42	43	44
45	46	47	48
49	50	51	52
53	54	55	56
57	58	59	60
61	62	63	64
65	66	67	68
69	70	71	72
73	74	75	76
77	78	79	80
81	82	83	84
85	86	87	88
89	90	91	92
93	94	95	96
97	98	99	100

C (10 ×10)

1	11	21	31	41	51	61	71	81	91
2	12	22	32	42	52	62	72	82	92
3	13	23	33	43	53	63	73	83	93
4	14	24	34	44	54	64	74	84	94
5	15	25	35	45	55	65	75	85	95
6	16	26	36	46	56	66	76	86	96
7	17	27	37	47	57	67	77	87	97
8	18	28	38	48	58	68	78	88	98
9	19	29	39	49	59	69	79	89	99
10	20	30	40	50	60	70	80	90	100

Figure 6. Possible ways of laying out a lattice design containing 100 varieties.

4 Laying out and conducting maize variety trials

The goal of maize variety trials is to discriminate effectively among the test varieties so that the varieties selected are truly the best. To achieve this goal, the experimenter must minimize experimental error and maximize information on the experimental material. The term “error” as used in data analysis is not synonymous with mistake. It refers to variations in the data that cannot be attributed to any of the factors of the experiment. It is sometimes referred to as “residual”. The larger the error or residual, the greater the difficulty in detecting real differences between or among treatments.

An effective indicator of experimental error relative to the mean performance of the varieties or treatments in maize field trials is the coefficient of variation or coefficient of variability (CV). This statistic is computed as (standard deviation ÷ mean) and multiplied by 100 to be expressed as a percentage. The experience of scientists, accumulated over many years of research, indicate that maize yield trials in WCA are characterized by large CVs and that the CV has a negative relationship with grain yield, as shown in Figure 7 and 8. The standard error should be made as small as possible so that the CV may be minimized. Optimum CV for maximum yield in RUVTs was 10–16% (Fakorede 1996).

To minimize experimental error, the researcher must take precautions right from the planning stage of the experiment.

a. Package the seeds very carefully. Careful packaging of seeds for planting starts from harvesting, processing, and storage. Avoid mix-ups at this stage. When preparing seeds for planting, handle one variety at a time; that is, label and count the seeds into all the seed envelopes for one variety before proceeding to another. Pay particular attention to trials involving different numbers of seeds/plot, such as plant density experiments.
b. Randomize to ensure the uniform distribution of neighbor effects and the absence of systematic error. Randomization is the assignment of treatments to experimental units (field plots in maize variety trials) so that all units considered have an equal chance of receiving a treatment. Randomization assures the unbiased estimates of treatment means and experimental error. It also ensures that experimental units receiving one treatment differ in no systematic way from those receiving another treatment, thereby making it possible to obtain an unbiased estimate of each treatment effect.
c. Replicate the experiment. Replication means repeating each treatment twice or more times. Replication makes it possible to estimate experimental error and obtain a more precise measure of treatment effect. The number of replications to use in a particular experiment depends on several factors, including the size and type of experiment, the availability of resources (land, labor, etc.,) and the magnitude of differences to be detected among treatments, the inherent variability in the field environment and treatments, and the objectives of the experiment. Statistical methods are available for determining the optimum number of replications (and environments) to obtain minimum standard errors.

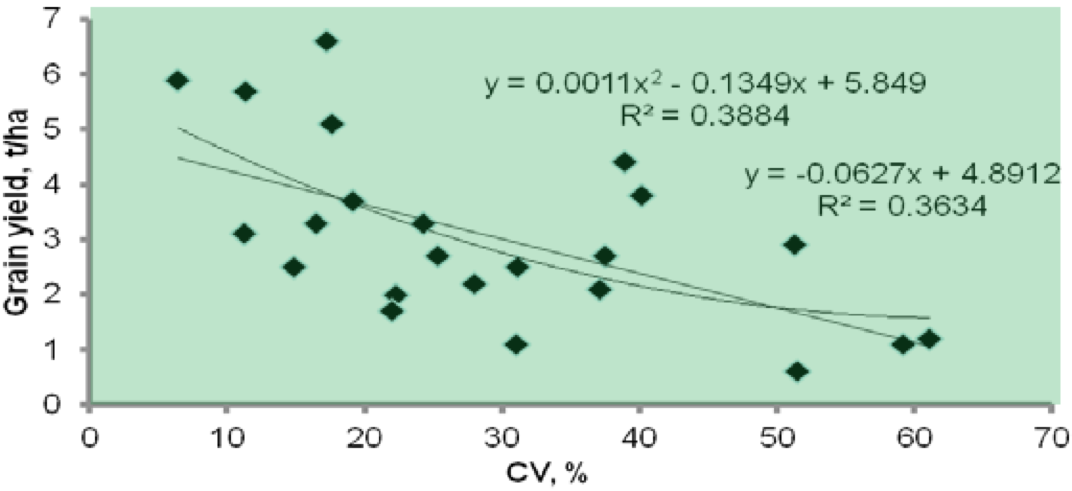


Figure 7. Relationship between CV and grain yield of intermediate and late maturing DT OPVs evaluated in Benin and Nigeria, 2007

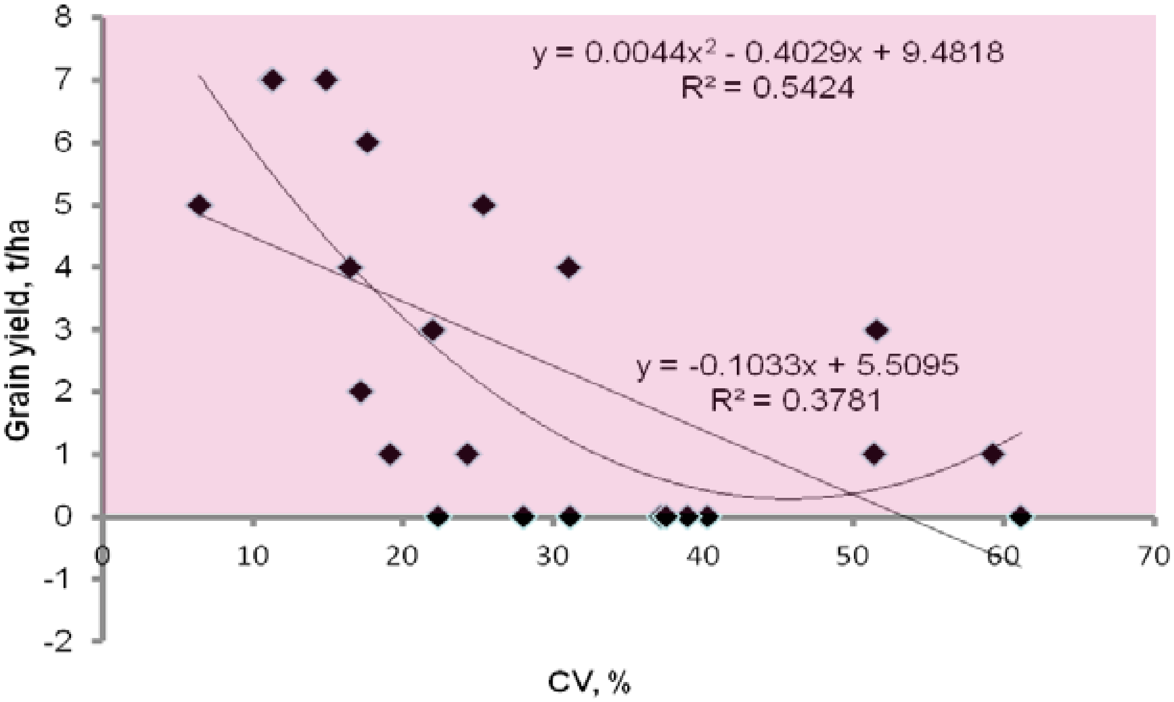


Figure 8. Relationship between CV and grain yield of DT three-way and topcross hybrids evaluated in Benin and Nigeria, 2007.

Box 1 – Class exercise on randomization

To randomize a trial having nine varieties numbered 1,2,3,...., 9, pick a point on the table in Annex 1 and record the figure. Thereafter, proceed in any direction on the table until you have completed the number of varieties. If you come across a number already picked earlier, disregard it and continue to the next. If you reach the end of the direction before completing the randomization, you may repeat the process, starting again from another point on the table. Alternatively, you may turn to another direction on the table and continue. When all the varieties have been fixed, you have completed one replication. Repeat the process for each additional replication, starting each time at a randomly picked point on the table.

Use pairs of columns or rows for experiments having 1 to 99 treatments or varieties. Now randomize a field trial of 15 varieties replicated four times.

The combination of replication and randomization produces a principle of experimental design called *local control*. This principle allows special restrictions on randomization to reduce experimental error in certain types of experimental designs, such as randomized complete block, incomplete block, split block and lattice designs. In all of these designs, treatments are grouped into blocks that are expected to perform differently, thereby allowing a *block effect* as a distinct source of variation that could be removed from the total variation in the analysis of the trial data. For example, the randomized complete block design is expected to be more efficient than the completely randomized design for the same set of treatments, although both of them are randomized and replicated.

Characteristics of a well-planned experiment

- The treatments, design, management, and data collected should be consistent with the objectives.
- The experiment should be planned and conducted so that there will be a high probability of measuring differences between treatments with an acceptable degree of precision.
- The experiment must be planned and executed to ensure that treatment effects are estimated in an unbiased way.

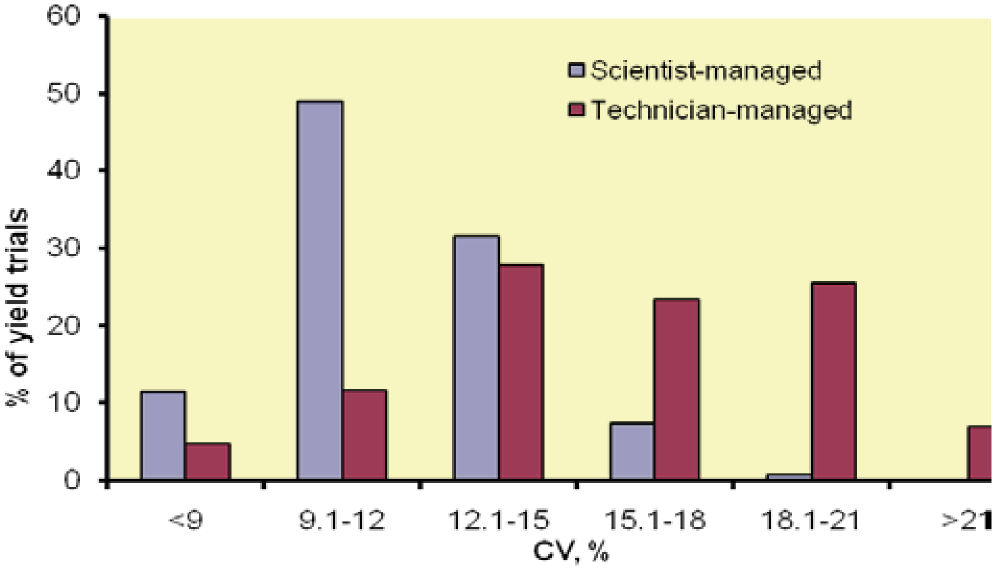


Figure 9. Distribution of CV in scientist-managed and technician-managed yield trials of maize.

- If an experiment is replicated in time and space, and if it is conducted in environments similar to those where the results will be applicable, then the conclusions have greater validity.
- There is always a degree of uncertainty about the validity of the conclusions. The experiment should give an estimate of the probability that the observed results were obtained by chance alone.

Field operations – While in the field, pay attention to the following:

1. Consider the gradient of the land (slope), stress factor, fertility, etc., and arrange blocks accordingly.
2. The scientist or an experienced technician should supervise the field layout and application of agronomic practices–fertilizer application, weeding, etc. Efron et al. (1993) found that CVs were lower for experiments planted under the direct supervision of the scientist than those supervised by technicians (Fig. 9).
3. Plant full reps or blocks if you cannot complete the planting of the whole experiment in one day. This is particularly applicable to experiments with a large number of entries, such as progeny trials.
4. In most WCA locations, soil variability is a major obstacle to obtaining accurate research results. Erosion, water-logging, low spots, and the remains of termite and ant hills cause soil variability. Ensure that the land is well prepared. Minor levelling may need to be done routinely before planting.
5. Proper field management – the timely execution of agronomic practices – is very important in maintaining uniformity.
6. Pay attention to minute details that technicians and field assistants would easily gloss over, such as avoiding or soil-filling low spots in the field after land preparation before planting, ensuring that all plots are handled in similar manner, harvesting and picking all ears from the plot.
7. Errors in weighing and recording are very common and researchers need to supervise all of these rather than always leaving them to technical assistants alone.
8. The scientist also should be very familiar with his experiments and, from experience, should be able to identify outliers and spurious values in his data. Outliers and spurious values are the major causes of extraordinarily large CVs.
9. When in doubt, be cautious about analyzing and interpreting the set of data.

Field layout. To decide which varieties to release for production, trials are conducted in the target ecologies. It is advisable to have at least one testing site in each of the major ecologies in your region or country. Varieties which perform well in the northern Guinea savanna of West Africa do not necessarily possess the required disease resistance for adaptation in the forest and forest/savanna transition zones.

For standard OPV trials, we recommend that varieties are planted in 2- or 4-row plots of 5 m length, with a final plant density of 53,333 plants ha^{-1}. However, the current trend is to use 2-row plots, each 4 m long because of resource constraints. It is a good idea to overplant and thin back to one plant/hill for a within-row spacing of 25 cm, or to 2 plants/hill for a 50 cm spacing. Depending on the material and objectives of the trial, the number of rows/plot may vary from two to four. Progeny trials may be conducted in single row plots; on-farm trials may contain more than 20 rows/plot. Similarly, row length and within-row spacing may vary. Early and extra-early varieties may be spaced within-row 20 cm apart for one plant/hill or 40 cm apart for 2 plants/hill, resulting in about 66,667 plants ha^{-1} in each case.

Criteria for selecting an experimental field

Conduct trials on good, uniform land well-suited for maize production. In selecting an experimental field it is important to consider the following: the nature of the crop, the nature of the soil, cultural practices, the accessibility of the site and cropping history, the slope and previous management of the land. The land should be well prepared to be of good tilth; that is, by land clearing, plowing and harrowing or ridging. Plowing should be done early enough to allow the stubble to decay sufficiently before harrowing is done. If necessary, remove stubble and root stumps, especially roots of grasses that do not decay quickly. Apart from facilitating vigorous root development, good land preparation delays and reduces weed infestation, thereby giving the crop a good start.

Demarcation and layout of the field

For proper demarcation and layout, the following operations should be done.

- Assemble all the necessary demarcation materials, such as rope, tape, ranging pole, and pegs before the demarcation day.
- Establish a base-line using the Pythagoras theorem, as shown in Figure 10.
- Make sure that the four corners of the trial have right angles.
- Ensure that ridges are uniformly spaced at the right distance apart, e.g., 75 cm apart, i.e., from the middle top of one ridge to the middle top of the next ridge should be 75 cm and so on.
- Label all plots in the serpentine fashion and distribute planting materials accordingly.
- Provide at least two guard/border rows for the trial.

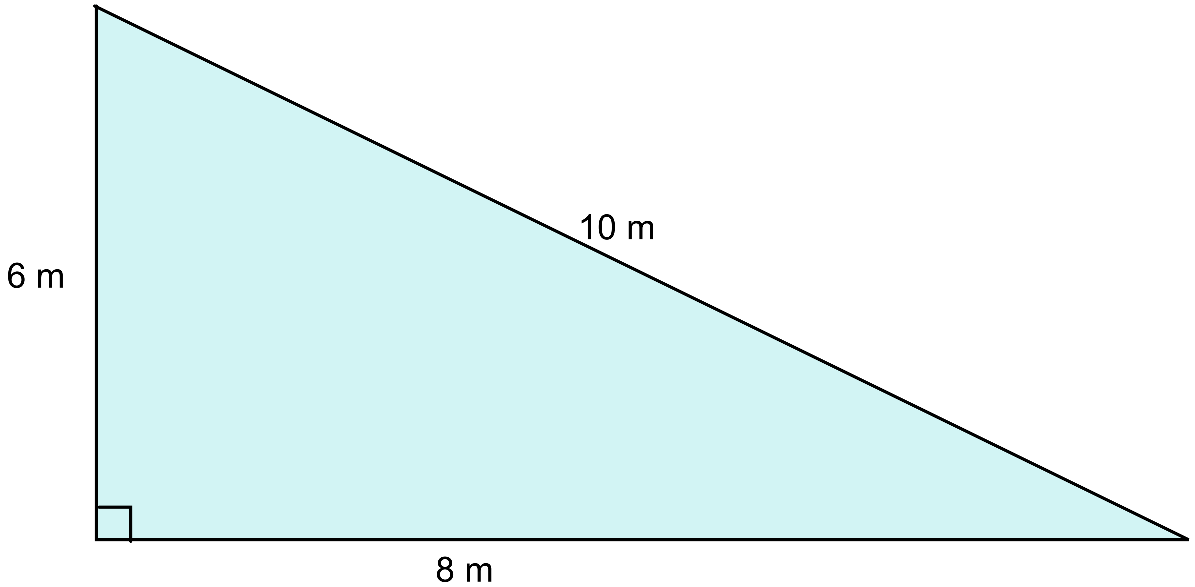


Figure 10. Method of establishing a right angle in the field by measuring three sides of a triangle with the dimensions indicated.

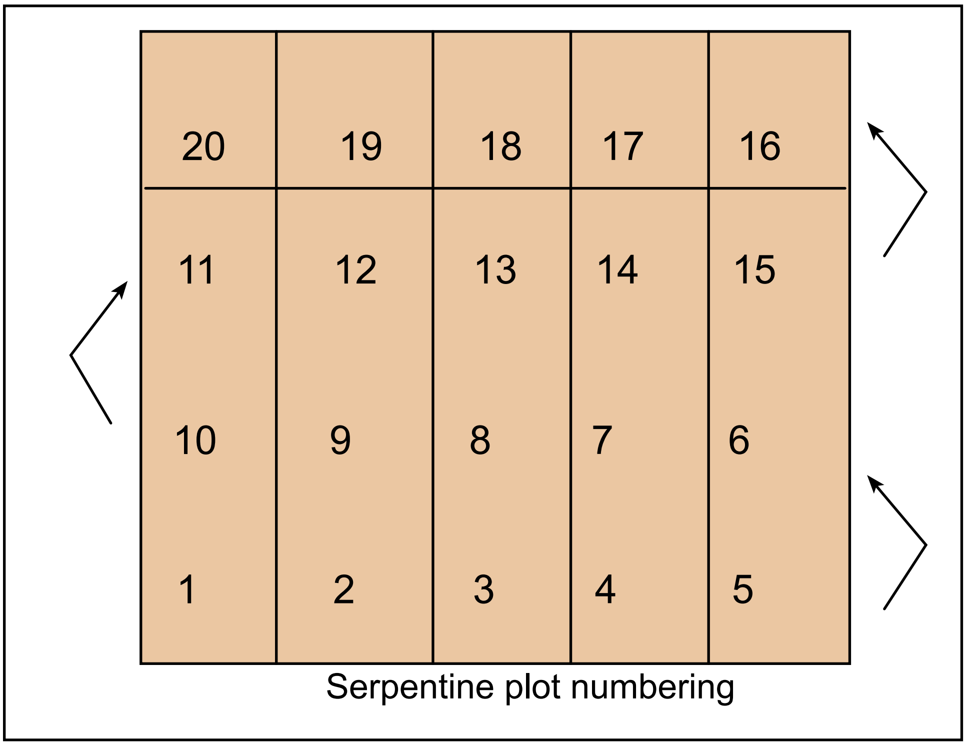


Figure 11. Serpentine plot numbering.

Scheduling of the trial

Trials are designed and conducted in a particular way to meet specific research objectives. Ensure that all materials needed for the trial package have been provided and orderly arranged. All operations should be planned and carried out at the scheduled time to meet the objectives of the trial. Laying out maize variety trials in the field will depend on the plans made for the trial. For example, the person laying out the trial must know the following:

- Trial design and plot sequence (Serpentine or Cartesian) –see Figures 11 and 12
- Plot size (number of rows, number of planting holes/row, spacings)
- Fertilizer application required

Furthermore, the person laying out the trial must be prepared with the following: (1) field map, (2) tape measure, (3) pegs, sisal twine, and labels, (4) sufficient labor to carry out the work, (5) seeds, fertilizer, hoes, planting sticks, etc.

The normal step-by-step procedure for laying out and planting a variety trial is as follows, (assuming the trial has been designed and the seeds packed into packets for each plot):

- Choose the most uniform area in the field.
- Establish a base-line (using the Pythagoras theorem) and from this mark the corner points of the trial in a square of rectangle fashion, taking into account the need for border rows and the optimum layout of plots and blocks.
- Make the planting holes at the optimum plant population using twine marked at the required spacing.
- The number of rows, plot length, alley ways, and borders should be established according to the design.
- Apply the basal fertilizer in the planting holes on one side of each hole using an appropriate fertilizer cup to give the required amount/hole.
- Label the plots with plot markers, if necessary. At least, mark the first plot.
- Lay out the seed packets according to the design and field map. Note whether this is in a Serpentine (Fig. 11) or Cartesian (Fig. 12) arrangement.

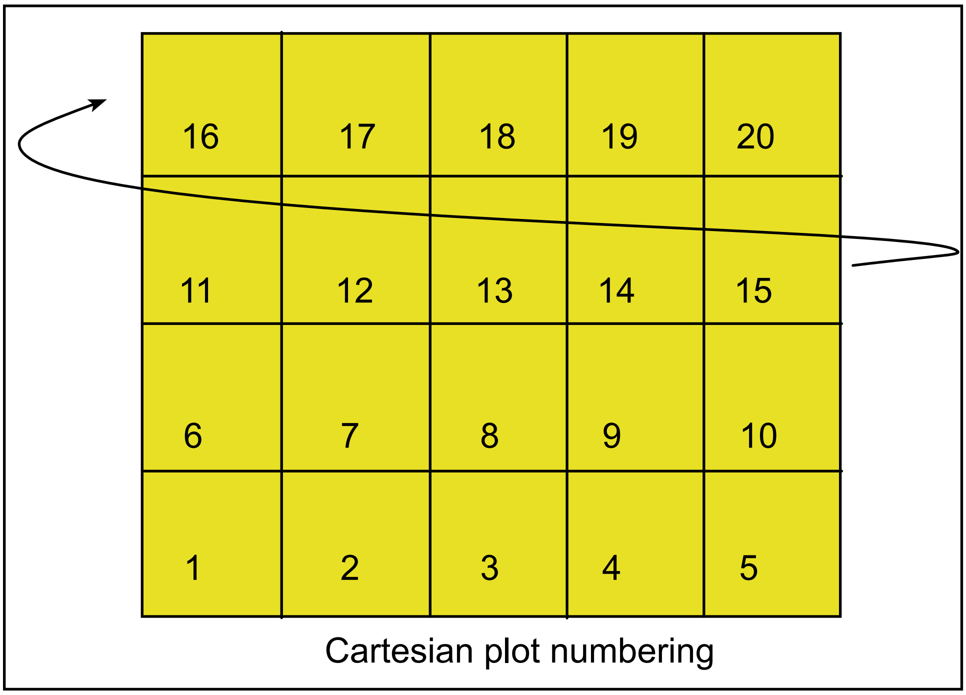


Figure 12. Cartesian plot numbering.

- Choosing appropriate checks
  - Each trial should have at least one appropriate local check.
  - The local check is the best available variety nominated by each trial collaborator.
- Border rows
  - Each variety trial should have a number of border rows surrounding the experiment, so that the varieties on the edge of the experiment do not have any advantage over the varieties in the centre of the experiment. Border rows may also help to reduce attack of vertebrate pests on the test varieties.
  - A minimum of two rows is required as a border.

5 Agronomic practices in maize variety trials

Good management practices are essential for the production of a high yield in maize variety trials. The management practices include seed dressing, thinning, the filling of vacancies in plant stands (supplying) and cultivation, control of weeds, diseases, insects, and vertebrate pests, fertilizer application, and timely harvesting.

Seed dressing–The plant stand/unit land area has a positive correlation with grain yield to an appreciable extent. Therefore, it is essential to ensure that the plant stand is as near-perfect as possible. There are many soil-inhabiting organisms – fungi, bacteria, and insects – that attack seeds and seedlings under the soil, thereby reducing emergence and seedling survival, leading ultimately to poor plant stand (missing stands) and low grain yield. Seed dressing is used to control such organisms and is done pre-planting, in some cases as a slurry, and in others as a dry powder. The chemicals are generally toxic and must be handled with caution. This includes the proper disposal of their containers. Respect all the rules established for using chemicals, including the wearing of gloves and nose-masks when the chemicals are being applied.

Thinning, filling of vacancies in plant stand, and cultivation–It is common to over-plant maize variety trials to ensure a near-perfect plant stand, and then to thin the emerged plants to the desired plant density at the 2–4 leaf stage. The process of removing plants that have emerged in excess of the target density is called thinning. Field staff have a tendency to remove more than the target number of plants/hill and thinning must, therefore, be done with the utmost care. During thinning, remove the less vigorous plant/hill and ensure the remaining plants are standing firmly. In the savanna zone where animal power is used for land preparation, cultivation is done as soon as possible after thinning to (1) create furrows for water conservation, (2) provide more topsoil around the maize stands, and (3) control weeds. Cultivation may also be done manually with the African hoe.

Thinning has the disadvantage of being wasteful of seeds and may not be necessary if highly viable seeds that have been chemically treated are planted, in which case over-planting may not be necessary. Over-planting of experiments on farmers' fields is not advisable if it will be difficult to get to the field at the right time for thinning.

To ensure near-perfect-to-perfect stands, missing stands may be replanted in some cases, such as breeding nurseries and crossing blocks. This process is termed supplying. This is not advisable in maize variety trials because of differences in plant age which may confound the results obtained from the trials. For example, there could be differences in the times of flowering and maturity of the plants within a plot and between plots containing the same variety.

Weed control–Weeds have been defined as plants growing out of place. Weeds compete with crop plants for environmental factors and usually out-compete the crop plants, depriving them of the much-needed growth-promoting factors. Weeds thrive better than crop plants under marginally available environmental factors, including moisture. A crop field may be infested with broad-leaf or narrow-leaf weeds, or with a mixture of both. There could also be noxious weeds which are difficult to control. Seeds may remain viable after many years in the soil, thus making it easy for weeds to infest the crop field when the conditions are favorable.

Maize is particularly sensitive to competition during the early vegetative growth stage and weeds must, therefore, be controlled effectively. Good land preparation is the first step in effective weed control in maize variety trials. Planting must be done as soon as possible after land preparation. Pre-emergence herbicides may then be sprayed after the experiment has been planted, usually before the maize seedlings emerge. This may be supplemented with manual weeding or the spraying of contact herbicides later during the growing season. In the latter case, a shielded nozzle may be used to prevent the herbicide from falling on the maize plants.

In situations where noxious weeds such as spear grass (*Imperata cylindrica*) exist, systemic herbicides, such as glyphosate may be applied 2–3 weeks before land preparation. Before planting, manually uproot the stumps of noxious woody species such as *Chromonena odoratum*. The control of parasitic weeds, *Striga hermonthica* in particular, is a special case. Except for maize trials involving *Striga* tolerant materials, *Striga*-infested fields should be avoided. However, *Striga* infestation may be minimized by planting legume crops in rotation with maize.

The general rule is: keep the maize trial weed-free until flowering. Weed infestation after flowering has little or no adverse effect on maize performance.

Control of diseases, insects, and vertebrate pests–Various diseases and insects attack maize in the field. The collaborative efforts of international and national program scientists have resulted in the successful incorporation of host-plant resistance to several maize diseases. For example, screening for MSV resistance is routinely done at IITA and since about the 1980s, varieties developed at the Institute are streak resistant. Similarly, breeding maize for insect resistance, especially the corn borers, has been ongoing at IITA for many years, and has been an important component of the Africa Maize Stress (AMS) project.

Most variety trials sent to collaborators have specific instructions concerning the agronomic practices to be used. The instructions must be followed strictly. Where there are no specified instructions, diseases and insects may be controlled with the application of the appropriate chemicals. Some seed dressing chemicals, such as Apron Plus, contain both fungicide and insecticide and are systemic. This may be sufficient to control most common pests and diseases. However, for some general feeders, such as the grasshopper (*Zonocerus variegatus*), additional control measures may be necessary.

Vertebrate pests, especially rodents and weaver birds, are a problem in fields surrounded by bush or tall grassland. Fencing with wire mesh is an effective way to control rodent pests; bird scarers are needed to control the birds.

Fertilizer application–Fertilizers promote the vigorous growth and high productivity of maize. N, P, K, and some micro-elements are required by maize plants and must be supplied by the soil. Therefore, where soil tests indicate inadequate levels in the soil, fertilizers must be applied externally.

Fertilizer should be applied immediately after planting or not later than the 2/3 leaf stage after thinning has been completed. Usually, the total amount of P, K, and micro-elements is applied at this stage, but N application may be in two splits; the larger dose at this stage and the balance top-dressed at about 1–2 weeks before flowering.

The field may be subdivided into smaller and manageable units to facilitate the application of the needed quantity of fertilizer/unit area. Fertilizer application should be done when the soil is sufficiently moist and it may be necessary to cover the applied fertilizer with soil, especially the second dose of N.

Although the source of fertilizer may not be important, the researcher should ensure that the required amount of the element in the fertilizer is actually applied. Therefore, a working knowledge of calculating the elemental composition of fertilizers is essential. This is applicable to both inorganic and organic fertilizers. In addition, if and when organic fertilizers are to be applied, the researcher must keep strictly to the additional rules, such as the stage of decomposition before application and the distance from the maize plant at which the fertilizer is to be applied. Inorganic N-fertilizers are acidic; therefore, they should be well monitored, especially in acidic soils. Liming may be necessary in such situations.

Fertilizer application in trials involving *Striga* tolerant maize varieties is a special case and must be handled with extra care. High doses of N reduce *Striga* infestation; therefore, low rates of about 30 kg N ha^{-1} are usually recommended for such trials. In situations where soil tests show that the native soil-N reaches this amount, external application is not necessary. It has been observed that certain soils in the savannas of WCA have the capacity to release a nitrogen flush at the beginning of the rainy season. This residual N may add up to the applied N to make available a significant amount of N to the maize plant, leading to an increase in the N levels and hence causing a dramatic response of maize to N. This should be taken into consideration in the low-N trials.

Timely harvesting–Harvest the maize crop as soon as possible after the plants seem to be sufficiently dry. Where possible, grain moisture may be used to determine the stage to harvest. Timely harvesting reduces disease infection, infestation by field-to-store pests, such as weevils, the lodging of plants, damage by vertebrate pests, and seed germination on the cob.

6 Data collection in maize variety trials

The usefulness of maize variety trials is dependent on the type, accuracy, and precision of data collection. The time of collecting data depends on the kind of trait. For flowering data, observations must begin when the earliest varieties begin to tassel, shed pollen, or extrude silks, and must be done daily so as to make the most accurate estimate of when each plot reaches 50% tasseling, anthesis, or silking. Observations must continue until the latest flowering varieties have been recorded. Foliar disease scoring must be timed to the epidemiology of the disease. If observations are made too early, records may give a false indication of disease resistance, and if too late, it may be difficult to differentiate between normal leaf senescence and disease incidence. For most leaf diseases, scoring at the middle of the grain-filling period is appropriate.

Data should be collected only on competitive plants and, in a 4-row plot for example, from the middle of the two central rows only, leaving the two outside rows as borders. The objectives of each experiment will determine the type of data to be collected. In general, the researcher requires varieties with a high yield, disease and insect resistance, good ear aspect, good standability (little root and stalk lodging) and a few other traits. Maize researchers generally record most of the following traits:

Plant stand (PLST). Total number of plants/plot obtained soon after thinning.

Days to tasseling (DYTS). Number of days from planting to the date when 50% of the plants in a plot have emerged tassels.

Days to anthesis (DYANTH). Number of days from planting to the date when 50% of the plants in a plot have tassels shedding pollen.

Days to silking (DYSK). Number of days from planting to the date when 50% of the plants in a plot have emerged silks.

Plant height (PLHT). Average height of plants in centimeters (cm) from the base of the plant to where tassel branching begins. Alternatively, you can estimate plant height by placing a meter stick in the center of the row and determine the average visually.

Ear height (EHT). Average height in cm from the base of the plant to the node bearing the upper ear (or estimate the distance visually for the whole plot using a meter stick).

Plant aspect (PASP). Take plant aspect after silking, before harvest, when plants are still green but ears are fully developed. This is a general score for the appearance of the plants in the plot, considering factors such as relative plant and ear heights, uniformity, reaction to diseases and insects, lodging, etc. PASP is rated on a scale of 1 to 5 where 1 = excellent overall phenotypic appeal and 5 = poor overall phenotypic appeal. (A 1– 9 rating scale may also be used.)

Husk cover (HUSK). Take these data when ears are fully developed and husk leaves are drying out (1–3 weeks before harvest). Score 5–10 plants in the plot and find the average. Hold the husk leaves above the ear tip in your hand to determine how far they extend beyond the ear. Avoid plants with ears that are not well developed, since the husk leaves on small ears will tend to extend further than those on well-filled ears. Use a 1 to 5 rating scale where 1 = husks tightly arranged and extend beyond the ear tip and 5 = ear tips exposed. (You can also use a 1–9 rating scale.) Increase the score if husks leaves are very loose, and reduce slightly if the leaves are very tight.

Rust *polysora* or *sorghi* (RUST). Record data on rust, *Puccinia polysora* or *P.sorghi* within the 2–4 week period after 50% silking. Use a score of 1–5 or 1–9 where 1 = no rust and 5 or 9 = severe rust. Ideally, you should score about 10 plants in each plot.

Blight *maydis* or *turcicum* (BLT or BLIGHT). Record data on *maydis* leaf blight, *Bipolaris maydis*, or on *turcicum* leaf blight, *Exserohilum turcicum,* within the 2–4 week period after 50% silking. Use a 1–5 rating scale, as indicated below. Ideally, score about 10 plants in the central part of the plot and take an average. However, to save time, you may subjectively estimate the average by considering both the incidence of the disease (number of plants that show symptoms) and severity of infection (on a scale of 1–5 or 1–9). For a 1–5 rating scale:

1 = slight infection	Very few lesions on leaves, usually only on the lower leaves of the plant.
2 = light infection	Few to moderate lesions on leaves below top ear, no lesions on leaves above the top ear.
3 = moderate infection	Moderate to large number of lesions on leaves below the top ear, few lesions on leaves above the top ear.
4 = heavy infection	Large number of lesions on leaves below the top ear, moderate to large number of lesions on leaves above the top ear.
5 = very heavy infection	All leaves with large number of lesions leading to premature death of the plant and light ears.

***Curvularia* (CURV) and MSV (STREAK).** Use a 1–5 rating scale based on the proportion of the ear leaf that is covered with lesions. Ideally, score about 10 plants in the central part of the plot and take an average. However, to save time, you may subjectively estimate the average by considering both the incidence of the disease (the number of plants that show symptoms) and the severity (on a scale of 1–5 or 1–9) of infection.

1 = slight infection	Less than 10% of the ear-leaf covered by lesions.
2 = light infection	10–25% of the ear-leaf covered by lesions.
3 = moderate infection	26–50% of the ear-leaf covered by lesions.
4 = heavy infection	51–75% of the ear-leaf covered by lesions, leading to premature death of the plant and light cobs.
5 = very heavy infection	76–100% of the ear-leaf covered by lesions, leading to premature death of the plant and light cobs.

MSV is transmitted by leaf hoppers and so it is not uniformly distributed in a field. Look for symptoms of the disease before rating a plant. If there are no visible symptoms, skip the plant, because it is likely to be an escape.

Downy mildew (DM). Number of plants in a plot showing infection by the disease.

Termite damage (TERM). Termite damage rating is scored on a scale of 1–5 or 1–9 where 1 = no termite damage and 5 or 9 = severe termite damage.

***Striga* emergence counts and damage rating**. These data are collected twice, at 8 and 10 weeks after planting, and are referred to as *Striga* count 1 (STR CO1 or STR CO8), *Striga* count 2 (STR CO2 or STR CO10) and *Striga* rating 1 (STRRA1), *Striga* rating 2 (STRRA2). *Striga* emergence count is the number of *Striga* plants thriving on the maize root system. *Striga* damage rating is done by rating the maize for symptoms of the damage caused by the parasite. The symptoms include a greyish leaf color and leaf scorching after the initial leaf wilting, usually accompanied by a poor development of the stalk and ear, resulting in lodging. Rating is done on a 1–9 scale, with 1 = highly tolerant and 9 = highly intolerant or sensitive.

Root lodging (RL or RLRAT). This is the number or percentage of plants that are leaning more than 45 º from the upright position.

Stalk lodging (SL or SLRAT). This is the number or percentage of plant stalks broken below the ear. A plant may be both root lodged (leaning from the base) and stalk lodged (broken below the ear). Data for root and stalk lodging should be taken no earlier than a week before harvest.

Plants at harvest (PHARV). This refers to the total number of plants/plot at harvest. Include barren plants as well as plants with ears. It is important to obtain accurate counts, because the data will be used in calculating the percentage lodging and ear number/plant. The data will also be used to determine if adjustments are needed for plant stand.

Ear number (EHARV). This is the total number of ears at harvest that bear kernels. Include the second ears as well as the top ears.

Field weight (FWT). This is the weight in kg (to the nearest tenth of a kg) of all dehusked ears (cobs) in the plot.

Ear aspect (EASP). Use a score on the 1–5 rating scale (or 1–9) or the general appearance of all ears in the plot. Factors to consider may include ear size, grain filling, disease and insect damage, and uniformity of size, color, and grain texture. The scale is relative for a given trial, so that:

1 = best, 3 = average, 5 = poorest ear aspect.

Ear rot rating (EROT). The score is based on the proportion of the ears showing rot. Consider both the number of rotten ears and the degree of ear rot. For a 1–5 scale, 1 = little or no rot, 5 = most of the ears rotten.

Ear borer damage (EBORER). Based on the extent of tunneling observed on the ears at harvest: 1 = little or no damage, 5 = extensive damage. Consider both the number of damaged ears and the extent of damage on each ear.

Moisture percentage (MOIST). The grain moisture content is taken by a moisture tester at harvest. Grain should be sampled from a minimum of five representative ears, either by breaking the ears in half and sampling rows at the center of each ear, or by using a standing or hand-held sheller which samples entire rows from the base to the tip of the ear. Mix the sample well before determining the moisture. Grain moisture may be determined with an electronic moisture tester or by the oven method.

Grain hardness (GHARD). Score 1–5 (or 1–9): 1 = very flinty, 5 (or 9) = very soft (dent) or floury.

Post-harvest characteristics. Improved varieties are sometimes not adopted by farmers in spite of their high yield potential because they lack the desired storage, and processing characteristics, or palatability. Measurements which indicate consumer preferences for particular varieties are not well established. As a general rule, flintier types are preferred for industrial dry milling and for traditional processing which includes the removal of the pericarp. A softer grain type is preferred for traditional dry milling of the whole grain and for traditional wet milling.

An important characteristic which is difficult to assess is the recovery rate, i.e., how much final product is actually obtained/kg of maize grain. For green maize consumption, a high sugar content and low chaff are desired. Although the total demand for white grain in the region is much greater than that for yellow grain, yellow varieties are preferred for human consumption in some countries and for the poultry industry.

Other important trial management data to be recorded

- Location (latitude, longitude, altitude)
- Type of trial management applied (e.g., low-N, optimal, etc.)
- Soil type and fertilizer applied
- Plot size (number of rows, row width, number of hills, hill spacing, and plants/hill).
- Planting date
- Weed, pest, and disease control measures applied
- Rainfall received and irrigation applied (dates and amounts)
- Harvest date

Recording data in field books

- It is best to record the data directly into the field books at the time of collection.
- Avoid the practice of collecting data on rough sheets of paper and then transferring these into the field books at a later time.
- Any copying of data records increases the chances of errors.
- Be on the lookout for outliers in the data.

Recording data in field books and computers

- Ideally, data should be recorded in an electronic format on hand-held computers at the time of collection, but then always ensure that backups of electronic files are made and stored in a secure place.
- When sending field books to the trial originator, it is wise to retain a copy of the original as a backup.

7 Harvesting, shelling, and determination of grain yield of varieties in a trial

The determination of the grain yield potential is the ultimate goal of most maize variety trials. Harvesting marks the end of the field work for each trial. In most cases, all ears in a designated portion of the plot (for example, the two middle rows in a 4-row plot) are dehusked and removed from the stalk manually. All the harvested ears from a plot are packed in front of the plot for the determination of relevant ear data, such as number of ears, weight of harvested ears, number of rotten, diseased, and insect-damaged ears, ear aspect, shelling percentage, and ear or grain moisture at harvest.

Harvesting is normally done by a large number of casual laborers, mostly unskilled and with little or no education. Consequently, harvesting must be supervised thoroughly to ensure that the plots are cleanly harvested and ears from one plot are not mixed with those from nearby plots. The latter is particularly important for single- and 2-row plots. Similarly, the determination of ear weight, shelling percentage, and grain moisture requires careful handling. Balances used in the field are usually mounted on a tripod placed on uneven surfaces. The field assistants in charge of weighing must ensure that the pointer on the balance is at the exact starting point (e.g., zero point) for each plot to be weighed; otherwise some bias would be introduced into the data inadvertently. This should also be done for the grain to be used for moisture determination by the oven method.

Ideally, grain yield should be determined by shelling and taking the grain weight of all ears harvested from each plot. Plot-size shelling machines may be used for this purpose, otherwise the ears may be shelled by hand or by using hand-held maize shellers that handle one ear at a time. The conversion of grain yield to grain moisture-standardized yield is as follows:

Yield (at 12.5% grain moisture) = Grain yield × (100 – actual grain moisture %)/87.5

Note that the 12.5% in the formula is not constant. It is the moisture to which the grain is converted in this example. The value is subtracted from 100 to give 87.5% in the right-hand side of the equation. If the researcher desires to convert the grain to 15% moisture, the denominator becomes 85%.

For trials with few entries, shelling all the ears is achievable within a reasonable timeframe, but for trials with a large number of entries, such as progeny trials, it is cumbersome, burdensome, and time consuming to shell all ears. One way around the problem is to shell a sample of ears (for example, five) from each plot and apply the shelling percentage to the whole plot. Another possibility is to assume an equal shelling percentage for all plots in the trial. IITA Maize scientists assume 80% shelling for all plots. In a study involving many types of field trials (n = 900), Fakorede and Oluwaranti (unpublished) found that the grain yield determined by shelling the ears had a correlation coefficient (r-value) of 0.97 with that determined by assuming a shelling percentage of 80 for all plots. The shelling percentage had low r-values with grain yield in the study.

The use of grain weight plot^{-1} to estimate the grain yield ha^{-1} has also been controversial. If a uniform shelling percentage is applied to all plots, then the variation in grain yield among the plots is determined only by ear (cob) weight and percentage moisture at harvest. Therefore, the use of ear weight as the estimate for yield potential seems justified. In Fakorede and Oluwaranti's study, the correlation coefficient between ear weight and grain yield was 0.96.

8 Summarization and preparation of maize variety trial data for statistical analysis

Advances in electronic computer technology have greatly eased data analysis. The development of improved hardware along with user-friendly software has resulted in fast, accurate, and efficient data analysis by researchers. That notwithstanding, the saying *garbage in, garbage out* is still very much a reality in the computer analysis of data from maize variety trials. The computer program or package relieves the researcher from the burdens of computation, but the results and interpretation depend on the data entered into the computer and how well the researcher understands and has control of the materials in the study. The researcher must therefore ensure that the data fed into the computer are real and entry must be done correctly.

Preparation of data for computer packages

The researcher should check the data for errors in transcription before data entry as well as afterwards. Very likely, some outliers will be detected and, where possible, these must be corrected, otherwise they should be deleted. Presently available statistical packages generally accept data in spreadsheet format. Excel in Microsoft Office suite is a readily available spreadsheet that is compatible with most statistical packages commonly used by researchers in WCA.

Most statistical packages also have data entry mode in spreadsheet format. Characteristically, the default format is displayed but the analyst or data entry clerk can change the specification as needed and within the restrictions of the package.

Following are some guidelines appropriate for the computer analysis of maize trial data.

1. Each experiment should have a unique identification number which may be used as the file name for the purposes of data analysis. Similarly, variable names should be well spelled out. One common practice of maize researchers is the use of shortened forms of variable names. Since such names are not standardized, the researcher should give the names in full if the statistical package makes provision for it. Most packages make provision for variable labels apart from variable names. Statistical Analysis Systems (SAS) enters variable names into the spaces for variable labels unless the analyst supplies the variable labels.
2. Each data point should be entered to the accuracy with which the measurement was made. In other words, do not truncate or round off the original values. Spreadsheets are formatted in such a way that the number of decimal places can be fixed for each variable at the beginning of data entry. However, the decimal point for each row may not necessarily align with those in the other rows for data analysis.
3. A *missing value* (that is, an observation which was not obtained or was lost) is better left as a blank rather than coded zero because the program may treat zero as a value, and this may greatly distort the values of the statistics computed from such data. Statistical packages can handle missing values if requested by the analyst. In certain types of analyses, correlation and regression, for example, some packages have options for pair-wise deletion of missing data. In some others, such as ANOVA and t-test, the computer package does the analysis using the available data and the degrees of freedom are calculated appropriately.
4. Assign numbers rather than letters to measurements made on the nominal or ordinal scale (discrete variables); for example, male may be coded 1, female 2. Here also, the use of 0 as one of the codes should be avoided.
5. Except for special cases, such as frequency distribution, do not change ratio or interval data (continuous variables) to ordinal scale. For example, data on plant height should not be coded as 1 = < 80 cm, 2 = 81–100 cm, etc. This could sacrifice some of the useful information in the original measurements.
6. The order of data entry is not important in statistical analysis. The analysis of data entered as typified in the two tables below will produce exactly the same outputs provided there are no mix-ups in the values of the factors (year, location, rep, and variety) in relation to the corresponding variable values (ear number, grain yield, etc.). However, it is easier to check through the data for errors in transcription, outliers, and missing values in Format A.

Format A

Year	Location	Rep	Variety	Ear number	Grain yield
1	1	1	1	18	4.5
1	1	1	2	14	3.7
1	1	1	3	7	1.2
1	1	2	1	15	4.0
1	1	2	2	21	5.3
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
4	4	4	3	20	4.9

Format B

Year	Location	Rep	Variety	Ear number	Grain yield
1	1	1	1	18	4.5
4	4	4	3	20	4.9
1	1	1	3	7	1.2
1	1	2	1	15	4.0
1	1	2	2	21	5.3
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
1	1	1	2	14	3.7

Therefore, if data are entered using Format B, the program may be instructed to sort the data into Format A and a hard copy is then printed for checking.

9 Statistical analysis for access to and use of the information from maize variety trials

Once the data from all the trials have been collated, the trial coordinators analyze the data and publish the results through the media or even at the local agricultural meetings, workshops, and conferences. IITA's maize scientists collate and analyze the regional and international trial data on the basis of individual sites, by country, and combined across all sites. The data are subjected to various forms of statistical analysis, including ANOVA, AMMI, and, more recently, GGE Biplot, which facilitates the process of identifying the best variety for specific sites and agro-ecological zones. The outputs are collated and published as booklets (hard copy) and in electronic form (CDs) and made available free of charge to all collaborators as well as to anyone interested in the information. The information is useful to participating farmers for identifying which varieties performed best and were most appealing to other farmers in their community. Similarly, seed companies use the results to determine where to target the sales of the varieties they produce. In addition, because the trials are conducted in a large number of locations, the varietal release committees of WCA countries accept the results in the process of approving recommended varieties for release.

The intention here is not to duplicate the mechanics of the various statistical methods taught in statistics textbooks as well as in colleges and universities. Presumably, those who would be using this book have taken one or two courses in statistics or biometrics and/or experimental designs. Also, with the widespread availability of computers and user-friendly statistical packages, the users of this book are not expected to be analyzing maize data manually. That era is forever gone, even from the so-called developing world. However, the users of the book are expected to be capable of (1) preparing data for computer analysis, (2) determining the most appropriate statistical method to use for analyzing their data, (3) reading and understanding the computer printouts of the statistical analysis, (4) correctly interpreting the statistical analyses of their data, and (5) carrying out further analysis to aid the interpretation and application of the results to real- life, practical problems. The issues related to the preparation of data for computer analysis have been thoroughly discussed in Section 8. Issues related to analysis, interpretation, and the practical application of the results, are discussed briefly in the rest of this section.

Statistical analysis

The statistical analysis method for maize variety trials depends on the type of trial, the objectives of the researcher, and the experimental design. Normally, the analyses are done using some type of statistical package loaded on the computer. Packages used by the Maize Program at IITA have changed over time, including MSTAT, GENSTAT, AGROBASE-4, and SAS. Presently, SAS is the main package in use and several training courses on the package have been organized for collaborating scientists from NARS in recent years. Examples of computer printouts from SAS are presented and discussed here for some of the more commonly used designs in maize research.

Examples

A. The Completely Randomized Design (CRD)

Following are four samples of grain yield (t/ha) obtained from 5 maize varieties:

Var 1: 2.5, 3.0, 2.7, 2.6
Var 2: 2.9, 2.6, 2.9, 2.8
Var 3: 3.2, 3.2, 3.5, 3.7
Var 4: 2.9, 3.4, 3.2, 3.3
Var 5: 3.2, 2.6, 3.1, 2.7

The objective here is to test the Null hypothesis: Var 1=Var 2=………=V5 at α= 0.05.

The data were analyzed using SAS and the computer printout is reproduced as follows:

```
ANALYSIS OF COMPLETELY RANDOMIZED DESIGN DATA
08:19 Tuesday, August 19, 2008

The ANOVA Procedure
Class Level Information
Class           Levels          Values
VARIETY         5               1 2 3 4 5
Number of Observations Read      20
Number of Observations Used      20
```

```
ANALYSIS OF COMPLETELY RANDOMIZED DESIGN DATA
08:19 Tuesday, August 19, 2008

The ANOVA Procedure
Dependent Variable: YIELD
                                 Sum of
Source            DF             Squares          Mean Square      F Value      Pr > F
Model             4              1.36000000       0.34000000       6.54         0.0030
Error             15             0.78000000       0.05200000
Corrected Total   19             2.14000000

R-Square          Coeff Var      Root MSE         YIELD Mean
0.635514          7.601170       0.228035         3.000000

Source            DF             Anova SS         Mean Square      F Value    Pr > F
VARIETY           4              1.36000000       0.34000000       6.54         0.0030
```

```
ANALYSIS OF COMPLETELY RANDOMIZED DESIGN DATA
08:19 Tuesday, August 19, 2008

The ANOVA Procedure
t Tests (LSD) for YIELD
NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.
Alpha                           0.05
Error Degrees of Freedom        15
Error Mean Square               0.052
Critical Value of t             2.13145
Least Significant Difference    0.3437

Means with the same letter are not significantly different.
t-Grouping              Mean          N       VARIETY
        A               3.4000        4       3
        A
B       A               3.2000         4      4
B
B       C               2.9000        4        5
        C
        C               2.8000        4       2
        C
        C               2.7000        4       1
```

Comments – The F-test showed highly significant differences among the five varieties thus leading to the rejection of the Null hypothesis and acceptance of the Alternative hypothesis. For any source of variation having 2 or more degrees of freedom (df), the significant F-test in the ANOVA cannot tell the researcher which treatments are different from the others. Some further analysis must be done to compare the means and this is referred to as *means separation* or *multiple comparison*. The statistical package prints out the square root of the error mean square, which the researcher could use to compute some values to be used for means separation, such as the standard error and the least significant difference (LSD). But the program also computes the LSD at a specified level of probability and uses the value to separate the means for varieties. Another statistic that may be used for means separation, although not presented here, is Duncan New Multiple Range Test (DNMRT). For the purpose of interpretation, the means of varieties that have the same letter are not statistically different and are, therefore, classified into the same group. For the five varieties in this example, there appears to be three groups: Var. 3 with the highest yield, Vars 2 and 1 with the lowest yield, and Vars 4 and 5 in the middle. However, Var. 4 did not differ significantly from Var. 3 while Var. 5 overlapped with Vars 2 and 1.

If the experiment had been conducted as a Randomized Complete Block Design (RCBD), the error df would have been reduced to 12 because it would have been possible to isolate the replication effects as 3 df. The analysis is presented below.

ANALYSIS OF CRD DATA AS RANDOMIZED COMPLETE BLOCK DESIGN

```
08:19 Tuesday, August 19, 2008
-------------------------------------------------------------------
The GLM Procedure
Class Level Information
Class            Levels           Values
REP              4                1 2 3 4
VARIETY          5                1 2 3 4 5
Number of Observations Read        20
Number of Observations Used        20
-------------------------------------------------------------------
```

ANALYSIS OF CRD DATA AS RCBD

```
08:19 Tuesday, August 19, 2008  18
-------------------------------------------------------------------
The GLM Procedure
Dependent Variable: YIELD
                  Sum of
Source            DF            Squares         Mean Square      F Value    Pr > F
Model             7             1.42000000      0.20285714       3.38       0.0311
Error             12            0.72000000      0.06000000
Corrected Total   19            2.14000000

R-Square          Coeff Var     Root MSE        YIELD Mean
0.663551          8.164966      0.244949        3.000000

Source            DF            Type I SS       Mean Square      F Value    Pr > F
REP               3             0.06000000      0.02000000       0.33       0.8015
VARIETY           4             1.36000000      0.34000000       5.67       0.0085

Source            DF            Type III SS     Mean Square      F Value    Pr > F
REP               3             0.06000000      0.02000000        0.33       0.8015
VARIETY           4             1.36000000      0.34000000       5.67       0.0085
-------------------------------------------------------------------
```

```
ANALYSIS OF CRD DATA AS RCBD
08:19 Tuesday, August 19, 2008

The GLM Procedure
t Tests (LSD) for YIELD

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha                           0.05
Error Degrees of Freedom        12
Error Mean Square               0.06
Critical Value of t             2.17881
Least Significant Difference    0.3774

Means with the same letter are not significantly different.

Grouping      Mean        N        VARIETY

   A          3.4000      4        3
   A
B  A           3.2000     4        4
B
B  C          2.9000      4         5
   C
   C          2.8000      4        2
   C
   C          2.7000      4        1
```

B. The Randomized Complete Block Design (RCBD)

Data in the table below are grain yield (g/plant) of 8 maize varieties evaluated in an experiment replicated 4 times. Here, also, the objective of the researcher is to determine whether differences exist among the varieties for the trait. In other words, the Null hypothesis is: Var 1=Var 2=………=Var 8. In addition, the researcher has the opportunity to test the replication effect if he so wishes.

Variety	Rep 1	Rep 2	Rep 3	Rep 4	Xi.
1	104.9	84.3	77.0	76.5	342.7
2	88.0	106.5	89.8	108.7	393.0
3	80.0	71.3	77.5	69.5	298.3
4	80.8	106.5	83.3	95.9	366.5
5	60.0	52.5	53.0	51.0	216.5
6	96.4	98.8	99.1	107.2	401.5
7	91.4	99.7	83.3	89.5	363.9
8	91.8	84.8	70.0	81.5	327.7
X.j	693.3	704.4	633.0	679.8	

X.. = 2710.5

```
ANALYSIS OF RCBD DESIGN
07:25 Tuesday, August 19, 2008

The ANOVA Procedure
Class Level Information

Class          Levels          Values
Rep            4               1 2 3 4
Vty            8               1 2 3 4 5 6 7 8

Number of Observations Read     32
Number of Observations Used     32
```

```
ANALYSIS OF RCBD DESIGN
07:25 Tuesday, August 19, 2008

The ANOVA Procedure
Dependent Variable: YLDPP
                                 Sum of
Source            DF             Squares          Mean Square      F Value    Pr > F
Model             10             6618.208125      661.820813       9.17       <.0001
Error             21             1515.501563      72.166741
Corrected Total   31             8133.709688

R-Square          Coeff Var      Root MSE         YLDPP Mean
0.813676          10.02927       8.495101         84.70313

Source            DF             Anova SS         Mean Square      F Value    Pr > F
Rep               3              369.840938       123.280313       1.71       0.1959
Vty               7              6248.367187      892.623884       12.37      <.0001
```

```
ANALYSIS OF RCBD DESIGN
07:25 Tuesday, August 19, 2008

The ANOVA Procedure
t Tests (LSD) for YLDPP

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.
Alpha                              0.05
Error Degrees of Freedom           21
Error Mean Square                  72.16674
Critical Value of t                2.07961
Least Significant Difference       12.492

Means with the same letter are not significantly different.

t-Grouping     Mean          N       VARIETY

   A           100.375       4       6
   A
   A           98.250        4       2
   A
B  A           91.625        4       4
B  A
B  A           90.975        4       7
B
B  C           85.675        4       1
B  C
B  C           82.025        4       8
   C
   C           74.575        4       3

   D           54.125        4       5
```

Comments – In this analysis, replications were not significantly different whereas the varieties showed highly significant differences, thus leading to the rejection of the Null hypothesis. The means separation clearly identified the groups to which the varieties belonged for this trait. Note that there are also overlaps here in the grouping of the means.

C. Factorial Experiments

In maize research, a factor is a treatment that has two or more levels of application. Examples are fertilizer rates, spacing, plant density, varieties, date of planting and season, year or environments. Experiments in maize research that have more than one factor are referred to as factorial experiments. Depending on the objective and level of precision expected on the factors, factorial experiments may be designed as randomized complete blocks with factorial arrangement or as split plot or split-split plot arrangement.

Following is the analysis of an experiment involving three factors: 2 seasons, 5 varieties, and 3 densities. The experiment was replicated twice. Note that replication is not considered as a factor in field experiments because the researcher does not normally desire to have any information on replications as in the real factors of the experiment. The primary purpose of replication is to enable the researcher to estimate the error or residual variance in the experiment without which the variation among the levels of each factor cannot be tested statistically.

```
ANALYSIS OF FACTORIAL DESIGN DATA
08:19 Tuesday, August 19, 2008
--------------------------------------------------------------------------
The GLM Procedure
Class Level Information

Class               Levels        Values
season              2             1 2
rep                 2             1 2
Variety             5             1 2 3 4 5
Density             3             1 2 3

Number of Observations Read    60
Number of Observations Used    60
--------------------------------------------------------------------------
```

```
ANALYSIS OF FACTORIAL DESIGN DATA
8:19 Tuesday, August 19, 2008
--------------------------------------------------------------------------
The GLM Procedure
Dependent Variable: Yield
                                Sum of
Source             DF           Squares        Mean Square     F Value   Pr > F
Model              23           10964.81450    476.73107       7.47      <.0001
Error              36           2296.03533     63.77876
Corrected Total    59           13260.84983

R-Square           Coeff Var    Root MSE       Yield Mean
0.826856           35.64985     7.986160       22.40167

Source             DF           Type I SS      Mean Square     F Value   Pr > F
season             1            7425.937500    7425.937500     116.43    <.0001
rep(season)        2            574.161667     287.080833      4.50      0.0180
Variety            4            876.480667     219.120167      3.44      0.0177
season*Variety     4            654.720000     163.680000      2.57      0.0546
Density            2            371.934333     185.967167      2.92      0.0670
season*Density     2            425.433000     212.716500      3.34      0.0469
Variety*Density    8            636.147333     79.518417       1.25      0.3013
--------------------------------------------------------------------------
```

```
Source            DF        Type III SS      Mean Square     F Value    Pr > F
season            1         7425.937500      7425.937500     116.43     <.0001
rep(season)       2         574.161667       287.080833      4.50       0.0180
Variety           4         876.480667       219.120167      3.44       0.0177
season*Variety    4         654.720000       163.680000      2.57       0.0546
Density           2         371.934333       185.967167      2.92       0.0670
season*Density    2         425.433000        212.716500     3.34       0.0469
Variety*Density   8         636.147333       79.518417       1.25       0.3013
```

```
ANALYSIS OF FACTORIAL DESIGN DATA
08:19 Tuesday, August 19, 2008
```

```
The GLM Procedure
Least Squares Means

season   Yield LSMEAN
1        33.5266667
2        11.2766667

Variety    Yield LSMEAN
1          19.2416667
2          18.2666667
3          28.9833333
4          21.6666667
5          23.8500000

season    Density       Yield LSMEAN

1         1             32.9833333
1         2             24.7666667
1         3             44.7833333
2         1              5.5000000
2         2             11.7666667
2         3             13.1833333
```

Comments – For factorial experiments, SAS performs two types of ANOVA: Type I (Fixed Model) and Type III (Mixed Model). The Type II, which is not performed here, is the Random Model. In the Fixed Model, it is assumed that the researcher determined the levels of the factors involved in the experiment, whereas for the Random Model, the levels are beyond the control of the researcher. The Mixed Model has the levels of some factors determined by the researcher and the levels of other factors beyond the researcher's control. In factorial experiments, the researcher is interested in the effects of the factors per se (referred to as the *main effects*) as well as their interactions. The ANOVA clearly brings out the main effects as well as the interactions. In this example, season may be considered as a random factor whereas variety and density are fixed. Analyzing the data using the two models gave exactly the same outputs in this study. Using $P \leq 0.05$ as the acceptable limit for statistically significant levels, only season and variety as main effects were statistically significant and only season × density interaction effect was significant among the possible interactions. Consequently, only these statistically significant effects need be considered in any further analysis, such as means separation.

In factorial experiments, the interest of the researcher is often beyond establishing significant treatment effects. Rather, the researcher looks for an opportunity to establish trends in response to the application of each factor. An example of such opportunity exists in the significant season × density interaction in this study. The response may be graphically displayed as shown in the next figure. This graph more clearly explains the interaction than the means separation or multiple comparisons.

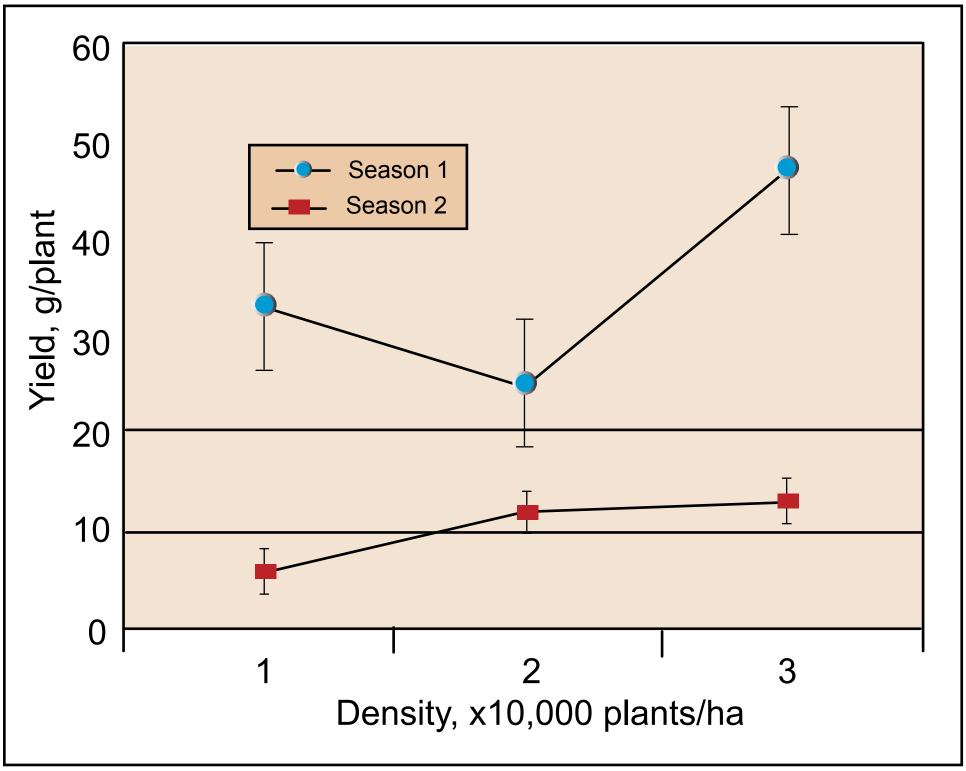


Figure 13. Effect of plant density on grain yield of maize in two planting seasons.

D. Contrasts

A statistically significant source of variation may be partitioned into as many single dfs as there are for the source of variation and the mean squares associated with each df tested against the pooled error in an F-test. The sum of squares for each df is obtained by a procedure termed *contrasts*. A contrast is a linear combination of two or more factor level means with coefficients that sum to zero. Two contrasts are orthogonal (independent or non-overlapping) if the sum of the products of corresponding coefficients (i.e., coefficients for the same means) adds to zero. By definition, contrasts (C) may be expressed as shown below, using the notation μ_i for the *i*-th treatment mean:

$$C = c_1\mu_1 + c_2\mu_2 + \cdots + c_j\mu_j + \cdots + c_k\mu_k$$

where

$$c_1 + c_2 + \cdots + c_j + \cdots + c_k = \sum_{j=1}^{k} c_j = 0$$

Simple contrasts includes the case of the difference between two factor means, such as $\mu_1 - \mu_2$. If one wishes to compare treatments 1 and 2 with treatment 3, one way of expressing this is by:

$\mu_1 + \mu_2 - 2\mu_3.$

Note that

$\mu_1 - \mu_2$ has coefficients +1,– 1

$\mu_1 + \mu_2 - 2\mu_3$ has coefficients +1, +1, –2.

These coefficients sum to zero.

As an example of *orthogonal contrasts,* note the three contrasts defined by the table below, where the rows denote coefficients for the column treatment means.

	μ_1	μ_2	μ_3	μ_4
C_1	$+1$	0	0	-1
C_2	0	$+1$	-1	0
C_3	$+1$	-1	-1	$+1$

Note and verify from the table that the following statements are true:
1. The sum of the coefficients for each contrast is zero.
2. The sum of the products of coefficients of each pair of contrasts is also 0 (orthogonality property).
3. The first two contrasts are simply pair-wise comparisons, the third one involves all the treatments.

As might be expected, contrasts are estimated by taking the same linear combination of treatment mean estimates. In other words:

$$\hat{C} = \sum_{i=1}^{r} c_i \overline{Y}_{i.}$$

and

$$Var\left(\hat{C}\right) = \sum_{i=1}^{r} c_i^2 Var\left(\overline{Y}_{i.}\right) = \sum_{i=1}^{r} c_i^2 \left(\frac{\sigma^2}{n_i}\right) = \sigma^2 \sum_{i=1}^{r} \frac{c_i^2}{n_i}$$

Note: These formulas hold for any linear combination of treatment means, not just for contrasts.
An example of SAS printout involving ANOVA and contrasts is provided below.

```
ANALYSIS OF VARIANCE AND CONTRASTS
08:04 Monday, August 18, 2008
```

```
The GLM Procedure

Class Level Information

Class       Levels     Values
REP         10         1 2 3 4 5 6 7 8 9 10
VTY         4          A B C D

Number of Observations Read      40
Number of Observations Used      40
```

```
ANALYSIS OF VARIANCE AND CONTRASTS
08:04 Monday, August 18, 2008
```

```
The GLM Procedure
Dependent Variable: YLD
                                 Sum of
Source             DF            Squares        Mean Square      F Value    Pr > F
Model              12            969.700000     80.808333        20.45      <.0001
Error              27            106.700000     3.951852
Corrected Total    39            1076.400000
```

```
R-Square    Coeff Var    Root MSE     YLD Mean
0.900873     22.59007     1.987927     8.800000

Source          DF          Type I SS       Mean Square     F Value     Pr > F
REP             9           34.9000000      3.8777778       0.98        0.4771
VTY             3           934.8000000     311.6000000     78.85       <.0001

Source          DF          Type III SS     Mean Square     F Value     Pr > F
REP             9           34.9000000      3.8777778       0.98        0.4771
VTY             3           934.8000000     311.6000000     78.85       <.0001

Contrast        DF          Contrast SS     Mean Square     F Value     Pr > F
A vs B          1           72.2000000      72.2000000      18.27       0.0002
C vs D          1           88.2000000      88.2000000      22.32       <.0001
A+B vs C+D      1           774.4000000     774.4000000     195.96      <.0001
```

Comments – Note the following facts for this example:

a. The sum of squares for variety in the ANOVA was partitioned into single degrees of freedom (df) for three sources of variation whose sum of squares added up to the same value as the variety sum of squares.
b. Each contrast showed a highly significant F-test.
c. The contrast involving (A+B) vs (C+D) made the largest contribution to the variation among varieties, accounting for about 83% of the variation.

In conclusion, contrasts are by far more powerful for means separation than the multiple comparison technique.

Practical application of the results of maize field trials

In an attempt to determine the new variety to adopt/release, the researcher compares the performance of an existing (reference or check) variety with the test varieties in the trial using the LSD or twice the standard error as the yardstick. For example, if in a variety trial the yield of the reference variety is 15 Mg ha^{-1} and the standard error = 0.445, only varieties with a yield of 15 ± 2(0.445) are significantly different from the reference variety; that is, varieties that have grain yield < 14.11 Mg ha^{-1} are inferior to the reference variety while those with grain yield >15.890 Mg ha^{-1} are superior. The yield range 14.11 to 15.890 Mg ha^{-1} is termed *confidence limit* or *confidence interval*. The LSD is used similarly except that it is not multiplied by 2, which is already built into its computational formula.

Typical summaries of trial analysis results by IITA maize scientists are presented in Tables 1 for Mali and 2 for Nigeria. Using the LSD 0.05 value, none of the varieties produced a higher grain yield than the reference entry in Mali but entries 11 (IWD C3 SYN/DT-SYN-1-W) and 12 (TZL COMP1-W C6/DT-SYN-1-W) were higher yielding than the local check variety. In Nigeria, entry 12 and three others were higher yielding than the local check and three of the four varieties out-yielded the reference check. In both countries, the outstanding varieties performed about as well as other varieties for the agronomic traits in the trials. Therefore, the outstanding varieties may be selected by the countries for immediate release, further testing especially on-farm, or as source germplasm for the extraction of inbred lines and improved varieties.

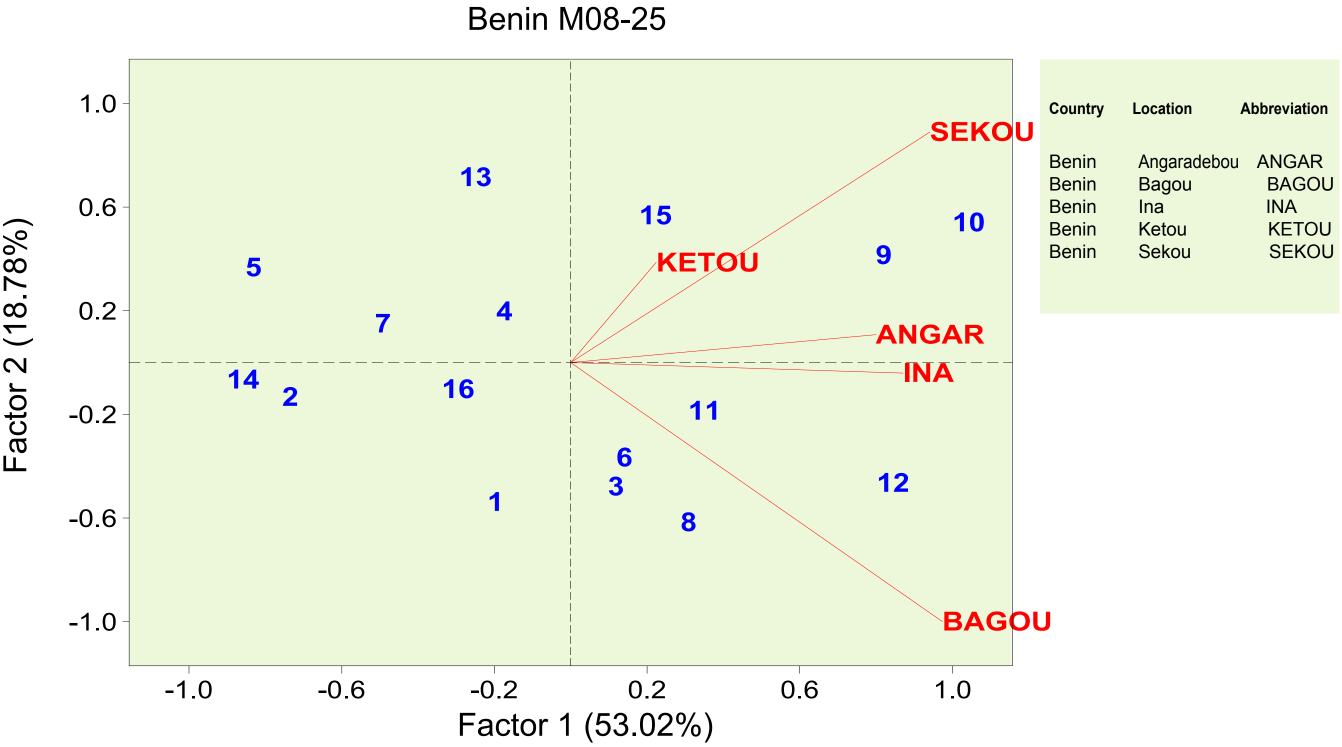
The GGE biplot summarizes the variety and variety × site analysis (Figs 14. and 15). The biplot is divided into four sectors by the horizontal and vertical dotted lines. The left side of the vertical line contains relatively poor yielding varieties and locations while the right side contains those that are high yielding. The further away a variety or location is from the horizontal line, the less stable it is in performance. The most stable varieties are located close to the horizontal line. In Bénin, varieties 9, 10, 15, and three locations (Sekou, Ketou, and Angara) were high yielding but only variety 11 had a stable performance (Fig. 14). Five varieties (Entry 3, 4, 8, 9, and 10) were found to be high yielding with a stable performance across locations in Ghana (Fig. 15)

Table 1. Means of Intermediate/Late Maturing DT varieties included in a regional trial averaged over two sites in Mali in 2008.

Entry	PEDIGREE	Grain yield (t/ha)	Grain yield as % of check (TZB-SR)	Anthesis (days)	Silking (days)	ASI (days)	Plant height (cm)	Ear height (cm)	No. ears per plant
1	DT-SR-W C0 F2	3.4	131	57	59	2.3	183	77	1.0
2	DT-SYN-1-W	3.0	115	58	60	1.9	169	74	1.0
3	TZLCOMP1-W C6 F2	3.4	131	58	60	1.8	192	84	1.0
4	IWD C3 SYN F2	3.6	138	57	59	2.5	197	81	0.9
5	SUWAN-1-SR-SYN	3.5	135	57	59	2.3	188	83	1.0
6	White DT STR SYN	2.6	100	58	60	2.1	170	71	0.9
7	TZUTSY-WSGY-SYN	3.5	135	57	60	2.5	188	77	1.0
8	(White DT STR Syn/IWD C3 SYN) F2	3.1	119	58	60	2.3	199	85	0.9
9	(White DT STR Syn/TZL COMP1-W) F2	3.4	131	58	60	2.0	189	85	0.9
10	DT-SR-W C2	3.7	142	57	59	2.4	193	80	1.0
11	IWD C3 SYN/DT-SYN-1-W	4.1	158	57	59	2.0	193	81	0.9
12	TZL COMP1-W C6/DT-SYN-1-W	4.0	154	57	60	2.5	196	88	1.0
13	S14DKD Medium DT	2.9	112	57	59	2.4	198	89	0.9
14	TZB-SR – *Reference entry*	3.4	131	59	61	2.1	206	98	1.0
15	Oba 98	3.7	142	56	59	2.4	204	89	0.9
16	Local check	2.6	100	56	58	2.5	195	84	0.9
	Mean	3.4		57	60	2.2	191	83	0.9
	Heritability	0.2		0	0	0.0	1	1	0.3
	LSD05	1.2		2	1	0.8	22	13	0.1
	LSD01	1.6		2	2	1.1	31	18	0.2
	CV	32.1		3	2	32.9	11	15	12.6

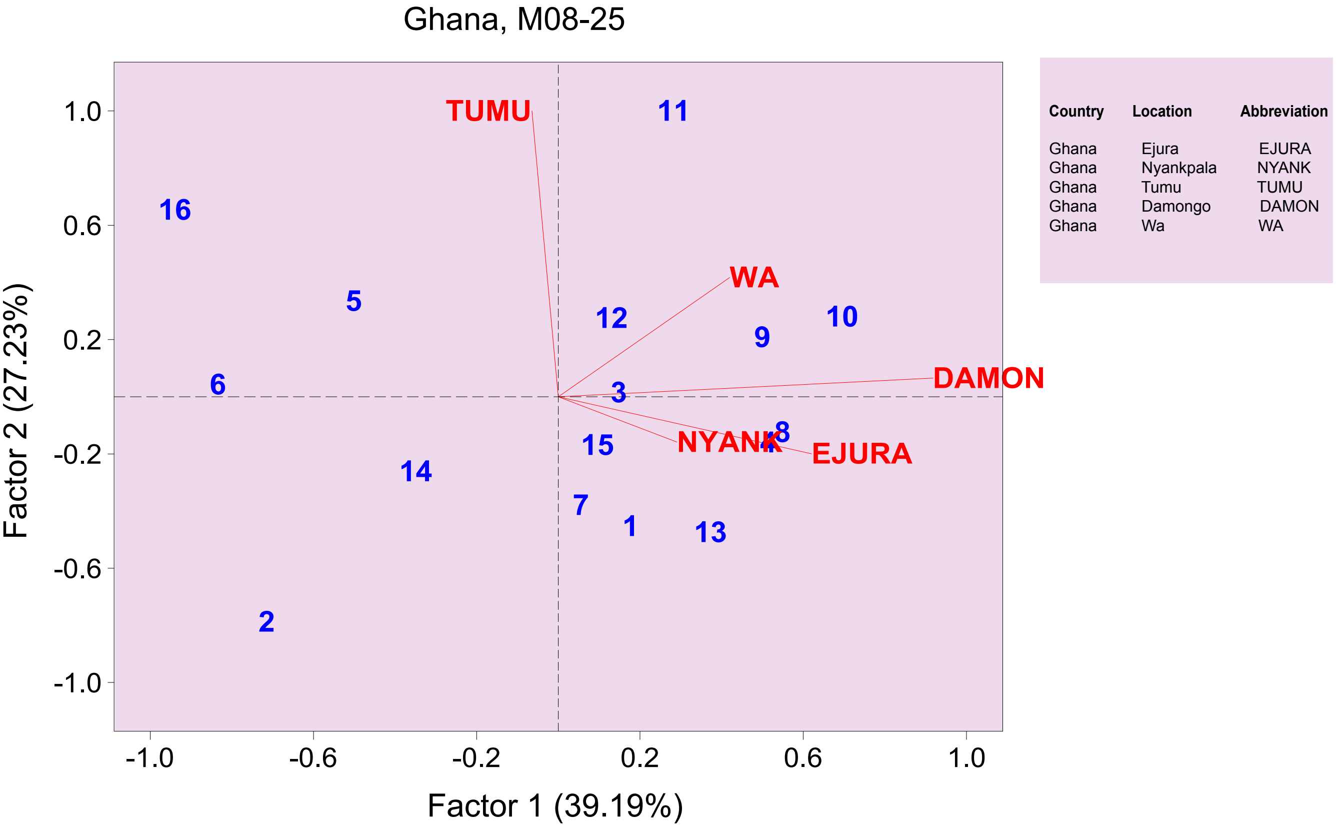
Table 2. Means of Intermediate/Late Maturing DT varieties included in a regional trial averaged over 24 sites in Nigeria in 2008.

Entry	PEDIGREE	Grain yield (t/ha)	Grain yield as % of check (TZB-SR) (%)	Anthesis (days)	Silking (days)	ASI (days)	Plant height (cm)	Ear height (cm)	No. Ears per plant
1	DT-SR-W C0 F2	3.3	118	60	63	3.4	173	72	0.9
2	DT-SYN-1-W	3.2	114	61	64	3.4	168	65	0.9
3	TZLCOMP1-W C6 F2	3.4	121	61	64	3.4	175	76	0.9
4	IWD C3 SYN F2	3.3	118	61	64	3.3	174	73	0.9
5	SUWAN-1-SR-SYN	3.0	107	58	61	3.8	166	65	0.9
6	White DT STR SYN	3.2	114	60	63	3.2	171	68	0.9
7	TZUTSY-WSGY-SYN	2.9	104	60	64	3.5	174	70	0.9
8	(White DT STR Syn/IWD C3 SYN) F2	3.7	132	60	64	3.4	173	71	0.9
9	(White DT STR Syn/TZL COMP1-W) F2	3.8	136	60	63	3.0	177	75	1.0
10	DT-SR-W C2	3.8	136	59	62	2.9	174	72	0.9
11	IWD C3 SYN/DT-SYN-1-W	3.5	125	60	63	3.3	176	72	0.9
12	TZL COMP1-W C6/DT-SYN-1-W	3.8	136	60	63	3.4	179	75	0.9
13	S14DKD Medium DT	3.2	114	59	63	3.6	176	74	0.9
14	TZB-SR – *Reference entry*	3.0	107	62	65	3.5	179	79	0.9
15	Oba 98	3.3	118	60	63	3.1	180	75	0.9
16	Local check	2.8	100	62	65	3.5	171	72	0.9
	Mean	3.3		60	63	3.4	174	72	0.9
	Heritability	0.9		1	1	0.4	1	1	0.4
	LSD05	0.8		2	2	1.1	20	13	0.3
	LSD01	1.1		3	3	1.4	26	18	0.3
	CV	24.6		3	3	32.5	11	19	28.1



Country	Location	Abbreviation
Benin	Angaradebou	ANGAR
Benin	Bagou	BAGOU
Benin	Ina	INA
Benin	Ketou	KETOU
Benin	Sekou	SEKOU

Figure 14. SREG Biplot of Intermediate/Late Maturing DT Variety Trial evaluated at 5 sites in Bénin in 2008.



Country	Location	Abbreviation
Ghana	Ejura	EJURA
Ghana	Nyankpala	NYANK
Ghana	Tumu	TUMU
Ghana	Damongo	DAMON
Ghana	Wa	WA

Figure 15. SREG Biplot of Intermediate/Late Maturing DT Variety Trial evaluated at five sites in Ghana in 2008.

10 Economic analysis of on-farm variety trials

This section focuses on the economic analysis of on-farm trials. The objective here is to underscore the importance of on-farm technology testing and acquaint the reader with the data required for the economic evaluation of on-farm trials. Since on-farm technology testing is an integral component of the process of assessing the impact of agricultural research, the section also aims to promote an "impact culture" among the training participants. Impact culture is used here to imply that impact assessment is an integral and important cross-cutting issue among disciplines in the agricultural research process.

Evaluation of on-farm technology

Improvement in production technology is necessary for agricultural development. Agricultural scientists develop new production technologies to help improve farmers' welfare. After research priorities have been set, researchers embark on technology development. This could involve the on-station development of new crop varieties, crop and natural resource management practices, or pest management practices. These technologies will then undergo on-farm testing with the farmers.

Farmers adopt a new production technology that is economically superior to the existing one(s). They are interested in net benefits and in protecting themselves against risk. To make good farm recommendations, scientists must keep these goals in mind and evaluate alternative technologies from the farmers' point of view.

On-farm testing is useful for evaluating technologies in a wider range of conditions than is available on-station. It is carried out to test, with farmers and on their plots, the acceptability and profitability of an innovation or technologies already available before they are promoted on a larger scale. Agronomists should be able to demonstrate, with little or no assistance from agricultural economists, the economic advantage of a proposed or an existing production technology. On-farm trials for technology evaluation are important for obtaining realistic input–output data for cost–benefit analysis in the process of impact assessment. On-farm testing provides important diagnostic information about farmers' problems, and enables researchers to identify the impediments to larger adoption of the research outputs. Studies carried out during on-farm technology generation also help researchers to have a better understanding of the early adoption processes involving the integration of farmers' indigenous knowledge into the scientific knowledge of researchers (Fig. 16).

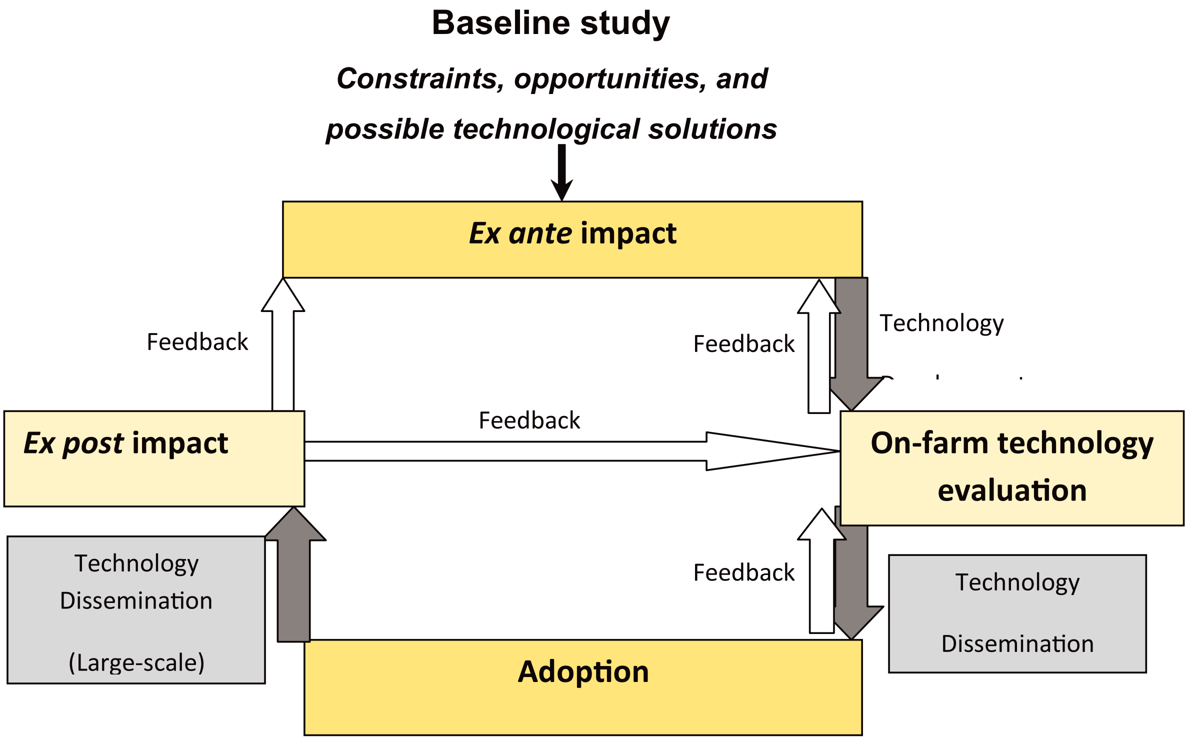


Figure 16. The impact assessment process.

Source: Alene, A.D., V.M. Manyong, J. Gockowski, O. Coulibaly, and S. Abele. 2006. A framework for conceptualizing impact assessment and promoting impact culture at IITA. ***IMPACT****, IITA-Ibadan, Nigeria.*

Before changing from one production method to another, farmers consider many factors, such as the agro-ecological requirements, the availability of additional production resources (farmland, credit, labor, skill, equipment, etc…), and the potential additional income resulting from the change. They also consider the compatibility of the new technology with socio-cultural circumstances, goals, and the whole farming system. A budget is a farm management method that is intended to assist researchers, extension agents, and farmers in the decision-making process. One of the tools in economics used to compare the economic benefits of technologies is partial budget analysis. The purpose is to organize data information from on–farm trials in such a way as to help make a particular management decision. The types of decisions with which agronomists and farmers will usually be concerned are the choice of fertilizer level, the choice of variety, and so on, or sometimes the choice among alternative packages of cropping practices.

Partial budget analysis

A partial budget is a tool that aims at quantifying and comparing the effects of a proposed technology on crop production with those of other, alternative technologies. Results assist agricultural scientists in identifying any weakness (i.e., high cost and/or low income) of the technology being developed and aid scientists and extension agents in deciding which technology to recommend to farmers. For example, farmers know that applying fertilizer is likely to increase maize yield, and thus the gross income. However, the use of fertilizer also results in additional costs. The decision whether to use fertilizer for maize production or not, requires a partial budget analysis. In general, a partial budget could be prepared to ascertain the effect on the net benefit of the following.

- Replacing one enterprise with another without any change in the entire farmland area; for example, replacing 1 ha of maize with 1 ha of soybean.
- Changing to different levels of a single technology; for example, estimating the effect on net benefit of changing from one level of N-fertilizer application to another in maize production.
- Changing to a different technology; for example, changing from a local variety to improved DT maize.

Developing a partial budget for on-farm maize research involves collecting, organizing, and analyzing experimental data to quantify the income, costs, and benefits of various alternative technologies. The assessment of profitability requires data on yields, labor, animal power, organic and inorganic fertilizer, pesticides, and the unit prices of all the inputs used and the output produced. Data should cover both the farmers' practices and all technologies tested. Accurate data can be obtained only if farmers manage the trials themselves. Thus, profitability assessment requires trials in which the researchers have considerable input in the design, but the farmers are responsible for field implementation. The objectives of assessing feasibility and acceptability require data on the farmers' assessments and adaptations of the technology. A sheet for the on-farm evaluation of data is provided (Fig.17).

A partial budget is based on a unit (for example, a 1 ha maize farm) and only variable input costs are considered. Income is the gross farm gate benefit. The net benefit is the difference between the gross farm gate benefit and the total variable input costs.

Table 3 shows an example of a partial budget and concerns the evaluation of different maize varietal technologies. This shows the level of profitability and helps the farmers to decide whether to adopt a new variety or not. In general, the objective of a partial budget in maize production is to recommend technologies that are agronomically different, economically superior, and socially acceptable to farmers.

Concepts in partial budget analysis

An agricultural researcher needs to be aware of common concepts to conduct a sound partial budget analysis.

Recommendation domain: A recommendation domain is a group of farmers in similar circumstances to whom the same recommendation(s) could be given for better farming practices. Similar circumstances can be a combination of biophysical, economic, and socio-cultural conditions. An example is a group of farmers not using improved varieties in maize production.

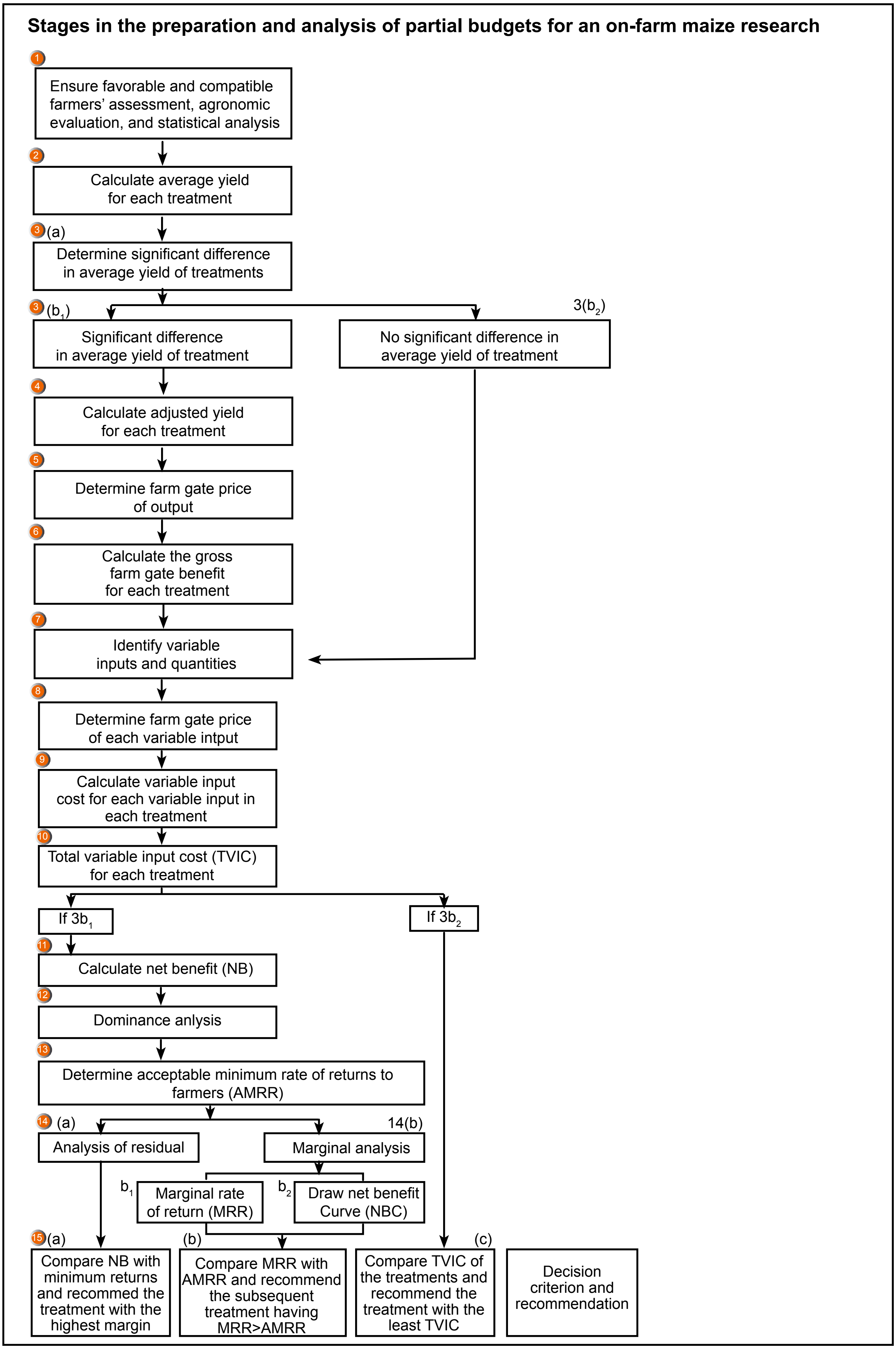

Stages in the preparation and analysis of partial budgets for an on-farm maize research

Figure 17. Stages of partial budget analysis.

Experimental variable: The experimental variable is the characteristic under study. The researcher is interested in how yield responds to a change in the quantity or quality of this variable. For example, in an N-fertilizer experiment, the experimental variable is nitrogen. The quantity of N-fertilizer varies; the quantities of other inputs (non-experimental variables) are constant.

Production: Production is the conversion or transformation of input(s) to output. Maize crop production is the transformation of land, maize seeds, labor, herbicide, management, and so on, to maize output.

Output/product: This is the item being produced. For example, grain and stover are the output of maize farms; mutton and wool are the output of sheep farms; and meat and milk are the output of dairy farms.

Inputs: Inputs are the resources used to produce outputs. Inputs used in the production of maize are land, maize seeds, herbicides, labor, planters, shellers, dryers, the farmer’s time and skill, and so on. The resources can be classified into land, labor, capital, and management.

Resources could also be grouped into:
- fixed inputs
- variable inputs

Fixed inputs: These are inputs that do not change in quantity with a change in the level of production. The quantity used of a fixed input remains constant regardless of the quantity of output and of other categories of inputs. In maize production, the quantity of any of the inputs used could be held constant. In partial budget analysis for an on-farm experiment, land can be cropped for more than one cycle of production, thus making land a fixed input.

Variable inputs: Variable inputs are used once to produce outputs. The quantity of variable inputs varies with the quantity of output, or treatments, or technologies. Examples for maize production are seeds and inorganic fertilizer.

Price: Price is the value of the resources that are exchanged to obtain the use of some other things. It is expressed in monetary terms/unit, for example, kilogram of maize seeds, liter of herbicide, person-day of labor, and kilogram of maize output. As a result of the market form of most agricultural inputs and outputs, it is assumed that individual farmers cannot influence their market price.

The price of each unit of input and each unit of output is constant, regardless of the quantity of input purchased and the quantity of output sold by the farmer. Thus, in a partial budget, the same price/unit of input and the same price/unit of output are used for all treatments and technology levels.

Price of purchased input: The price of a purchased input is the market price of a commodity. For example, ₦27 is the market price for one bag of N-fertilizer.

Price of owned input: Owned inputs are the personal possessions of the farmers which they do not have to buy. Examples of such inputs in maize production are inherited farmland and family labor. The price of such inputs is determined using the concept of opportunity cost.

Opportunity cost: The value of a forgone alternative or the price of the input in its best alternative use is the opportunity cost. For example, if a maize farmer spends five days weeding the 1 ha farm, the cost of labor is not zero although there is no outflow of cash (farmers do not pay themselves). If the farmer earns ₦100/day in an alternative job, the cost of weeding is ₦500/ha (₦100/day × 5 days/ha), since the farmer could earn that much in the alternative job.

Farm gate price (of an input): Often, farms are far from markets. Getting inputs to farms means that additional expenses (such as transportation cost) must be added to the market price of the input. The farm gate price is the price of an input at the farm gate. For example, the market price of a bag of N-fertilizer is ₦27, and transportation cost from the market to the farm gate is ₦3/ bag. The farm gate price of N-fertilizer is therefore ₦30 (i.e., 27 + 3).

Farm gate cost (of an input): The farm gate cost of an input is the product of its farm gate price and the quantity of the input required for a given area.

Total variable input costs: This is the sum of all the variable input costs for each of the treatments and varies from one treatment to another. If more than one variable input is used, the total variable input cost is the sum of the variable input costs for each treatment which varies with the quantity or quality (characteristics) of technologies (Table 3).

Fixed input cost: This is the cost of the fixed resources. Since the quantity of a fixed resource does not change from one treatment to another, the fixed input cost remains constant regardless of the level of input, treatment, or technology. Therefore, although the fixed input cost is not relevant in the preparation and analysis of a partial budget it should be included in the budget analysis of any enterprise..

Yield: The yield is the quantity of output (such as maize or milk) produced/unit area. The yield of field crops is usually expressed in kg/ha. For example, the yield of an improved maize variety in an on-farm experiment can be 3000 kg/ha.

Adjusted yield: The experimental yield is scaled down by a given proportion to approximate the yield that farmers can obtain on their farms in real cropping conditions. The scaling down is necessary to prevent an overestimation of the returns that farmers are likely to obtain from a treatment. Experimental yields are higher than farmers' yields because of a higher level of management (recommended number of stands, timely planting, weeding, application of fertilizer, application and recommended doses of chemicals, and so on), smaller plot size, precision in harvesting date, and better harvesting methods. The difference between yields from experimental fields and those from farmers' fields in similar cropping conditions will be the basis for the scaling down. For example, it may be necessary to scale down by 10% an experimental yield of 3000 kg/ha of maize.

Yield (kg/ha) = 3000

Adjusted yield (kg/ha) = 90/100 × 3000 = 2700

Scaling down may not be necessary in an on-farm experiment where the experimental design is very close to the farmers' practice.

Farm gate price of the output: Distances between farms and markets account for the difference between the farm gate price and the market price of the output. The farm gate price of the output is the value (price) farmers receive or can receive for their harvested crops. By this definition, it is the price farmers receive at the end of the production process.

Marketing agents (middlemen) responsible for getting the commodity to the market incur marketing costs. For example, the farm gate price of maize is the market price less the marketing cost (usually transportation cost). Alternatively, the farm gate price of the output is the price the marketing agents pay for the output at the farm gate.

For example, the market price of maize is ₦5.50/kg and the marketing cost from the farm to the market is ₦0.40/kg. The farm gate price of maize is:

		₦/kg
Market price of maize		*5.50*
Marketing cost	–	*0.40*
Farm gate price		*5.10*

Gross farm gate benefit: The gross farm gate benefit is the product of the farm gate price of the output and the adjusted yield. If the farm gate price is ₦5.10/kg and the adjusted yield is 2700 kg/ha, the gross farm gate benefit will be:

₦5.10/kg × 2700 kg/ha = ₦13,770/ha

Net benefit: The net benefit is the difference between the gross farm gate benefit and the total variable input cost. If the gross farm gate benefit is ₦13,770/ha and the total variable input cost is ₦300/ha, the net benefit is:

₦13,770–₦300 = ₦13,470/ha

Dominance analysis: The process of eliminating dominated treatments from further analysis is called dominance analysis. In a dominated treatment, a higher total variable input cost is incurred to earn the same or a lower net benefit when compared with other treatments. For example, in the table below, Treatment 3 is dominated by Treatment 2. Treatment 3 should be eliminated at this stage from further analysis.

Example of dominance analysis on four treatments

	Treatment			
	1	*2*	*3*	*4*
Total variable input costs (₦/ha)	*200*	*300*	*415*	*510*
Net benefit (₦/ha)	*2150*	*3750*	*3120*	*4190*

Marginal analysis: Marginal analysis determines the effect of a change in farming activities. In an on-farm experiment, marginal analysis shows the economic effect of changing from one treatment to another. It involves the calculation of the marginal rates of return between treatments.

Marginal rate of return: The marginal rate of return (MRR) is a ratio of the change in net benefits to the change in total variable input costs between treatments.

Net benefit curve: The net benefit curve shows the relationship between net benefits and total variable input costs. The MRR is estimated from the slope of the curve. The steeper the slope, the higher is the MRR.

Acceptable minimum rate of return: The minimum return which farmers expect to earn from an enterprise or technology is the acceptable minimum rate of return (AMRR). Returns below this minimum make the enterprise or technology a failure. AMRR is the sum of the return to management and the cost of capital.

Return to management: The return to management is the benefit which the maize farmer expects for managing a farm. In a new technology, it is the benefit which the farmer expects to receive for the time and effort spent in learning and using the new technology.

Cost of capital: This is the benefit forgone for tying up the working capital in one enterprise rather than in another. In the case of money, it is interest; it is called rent if the resources are land and equipment. The concept of the opportunity cost of capital is used if owned inputs are used in production. In areas where the formal credit system is weak and the informal credit system is very active, the opportunity cost of capital should use the high interest rates that are usually applied by moneylenders.

Working capital: The working capital is the value of resources (purchased or owned) used in production with the expectation of returns in future. In maize production, the working capital is the value of land, labor, and capital.

Acceptable minimum return: This is the product of the AMRR and the total variable input cost of each treatment. For the farmer to change to a new technology, it is the lowest acceptable minimum return required.

Residuals: The difference between the net benefit and the acceptable minimum return gives the residuals of each treatment. Residual analysis is used as a decision criterion to recommend a treatment with the highest residual.

Decision criterion: The decision criterion is the guideline for making a recommendation. An equal or a higher marginal rate of return above the acceptable minimum rate of return is a decision criterion.

Steps in partial budget analysis

Partial budget analysis goes through many steps before reaching a decision criterion. The stages in the preparation and analysis of partial budgets for on-farm maize research are shown in Figure 17.

An example

Two maize varieties that have been developed to escape or tolerate drought were evaluated on farmers' fields. The varieties are one extra-early maturing variety which matures in 80 days and a DT early maturing variety which matures in 95 days. The extra-early variety is able to escape drought. The early maturing variety matures 15 days later and has a higher yield potential than the extra-early variety. The varieties were evaluated on-farm with the active participation of the farmers. The farmers were each given the two varieties to test against their own local maize varieties.

The trials comprised the following treatments:

- Treatment 1: Local variety
- Treatment 2: Improved extra-early maturing
- Treatment 3: Improved early maturing

The objective of the research is to show the profits involved using the different maize varieties. Partial budget analysis for changing from local variety to improved maize is prepared from the information on that enterprise budget.

The result of the partial budget analysis is the net benefit of each variety (Table 3). Following the stages for partial budget analysis gives the steps, activities, and results below:

Step 1: Agronomic evaluation and farmers' assessment

The agronomic evaluation and farmers' assessment of the different improved varieties are favorable. There is no social sanction against the use of improved DT maize in the research area. Economic evaluation of each technology using partial budgeting is needed.

Step 2: Average maize yield

The average yield for each treatment is as follows.

	Treatment		
	1	*2*	*3*
Average yield (kg/ha)	*2592*	*3983*	*4331*

Step 3a: Mean yield difference

The average yields are assumed to be significantly different.

Step 3b: Differences in average yields of treatments

Significant differences are detected in the average yields of treatments

Step 4: Adjusted yield

The experimental yield of each treatment reduced by 10% gives the farmers' obtainable yield.

	Treatment		
	1	*2*	*3*
Average yield (kg/ha)	*2592*	*3983*	*4331*
Adjusted yield (kg/ha)	*2333*	*3585*	*3898*

Step 5: Farm gate price of maize output

The market price of the maize output is ₦5.50/kg and the marketing cost (transportation, etc.) from the farm to the market is ₦0.40/kg. Therefore, the farm gate price of the output is ₦5.10/kg.

Step 6: Gross farm gate benefits

The gross farm gate benefit of each treatment is the product of the farm gate price of output and the adjusted yield.

Step 7: Type and quantity of variable inputs used

The variable inputs are maize seeds, labor, and fertilizers.

Step 8: Farm gate price of variable inputs

The farm gate price of an input is its market price plus transportation cost.

Step 9: Variable input costs

The variable input cost for each treatment is a product of the quantity of the variable input and the farm gate price.

Step 10: Total variable input cost

This is the sum of variable input costs as shown above.

Step 11: Net benefits

Calculate the difference between the gross farm gate benefit and the total variable input cost. For the three treatments, the net benefits are given in Table 3.

Step 12: Dominance analysis

The treatments are arranged in ascending order of magnitude of the total variable input and the corresponding net benefit.

Net benefit	***Treatment***	***Variable cost***
17,495	*DT maize*	*2384*
16,671	*Extra-early variety*	*1611*
11,124	*Local variety*	*773*

There is no dominated treatment as increasing variable input costs correlate with increasing net benefits.

Step 13: Farmers' acceptable minimum rate of return

Farmers' AMRR is the sum of the cost of capital and returns to management. Most maize farmers have no access to formal loans which attract lower rates of interest. However, in rural areas, opportunities for informal loans exist.

Assume that the monthly interest rate of informal loans in the area of the experiments varies from 3 to 10% and the gestation period of the maize enterprise (that is, the period between preparation of land and realization of income from the output) is 6 months. If the interest rate is 3%, the cost of capital is 18% (3%/month × 6 months), and it is 60% (10%/month × 6 months) if the interest rate is 10%. Assume that the majority of farmers in the study area consider that a business is profitable only when it gives 100% returns to management. The AMRR will be 118% (100 + 18) for 3% and 160% (100 + 60) for 10% interest rate/month. Assume that a significant proportion of farmers obtain loans at 10%; then the AMRR of 160% is retained for further analysis.

From Step 13, move either to the step of analysis of residuals or to marginal analysis.
Consider the analysis of residuals first.

Step 14: Analysis using residuals

The maize farmers' AMRR of 160% is multiplied by the total variable input costs of each treatment to obtain the acceptable minimum returns of each treatment. The difference between the net benefit and the acceptable minimum returns of each treatment gives the residual of each treatment:

Analysis of residuals

		Treatment		
		1	***2***	***3***
1	*Net benefit (₦/ha)*	*11,124*	*16,671*	*17,994*
2	*Total variable input costs (₦ /ha)*	*773*	*1,611*	*1,885*
3	*AMRR (%)*	*160*	*160*	*160*
4	*Acceptable minimum return (₦/ha) (2 × 160/100)*	*1,237*	*2,578*	*3,016*
5	***Residuals (₦/ha) (1–4)***	***9,887***	***14,093***	***14,978***

Step 15a: Decision criterion and recommendation: analysis using residuals

The residual margin of each treatment is indicated above. According to this criterion the treatment with the highest residual (Treatment 3) is chosen and recommended.

Now let's proceed with marginal analysis.

Step 15b: Marginal analysis: marginal rate of returns by arithmetic process

		Treatment		
		1	***2***	***3***
1	*Net benefit (/ha)*	*11,124*	*16,671*	*17,994*
2	*Change in net benefit (/ha)*		*5,547*	*1,323*
	Change in net benefit between 3 and 1			*6,870*
3	*Total variable input costs (/ha)*	*773*	*1,611*	*1,885*
4	*Change in total variable input costs (/ha)*		*838*	*274*
	Change in cost between 3 and 1			*1,112*
5	***Marginal rate of return (%)***		***662%***	***483%***
	Marginal rate of return from 1 to 3 (%)			***618%***

From the above, note that the MRR of changing from Treatment 1 to Treatment 2 is:

(16,671 – 11,124) / (1,611 – 773) = 6.62 or 662%

A farmer's investment of ₦1 in the improved extra-early maize variety gives an additional ₦6.62.

Step 15c: Decision criterion and recommendation: analysis using marginal rate of return

A change from Treatment 1 to Treatment 2 gives an MRR of 662% which is higher than the acceptable minimum rate of return of 160%. Changing from Treatment 2 to Treatment 3 gives an MRR of 483% which is higher than the acceptable minimum rate of return of 160%, but lower than the MRR from Treatment 1 to Treatment 2. Furthermore, changing from Treatment 1 to 3 gives a MRR of 618% which is lower than the 662% generated with the change from Treatment 1 to Treatment 2. Therefore, the change from 1 to 2 is more lucrative. Treatment 2 of the adoption of the extra-early maize variety is recommended.

Sensitivity analysis

Scientists are aware that certain factors, usually beyond the control of the farmers, could negatively affect (= decrease) the net benefit and the MRR of shifting from the present practice to a proposed practice. Examples of these factors are technology failure and adverse conditions (drought, flood, insect infestation, etc…) which reduce yield. A change in the market situation, price policies, or inflation can increase variable input price(s), decrease output price, or both.

Researchers cannot accurately predict the occurrence of these factors and their effects on net farm benefits before committing resources to the proposed technology. The factors bring about risk or uncertainty associated with the proposed technology. Farmers, especially in developing countries, cannot afford to take risks because of their lack of resources. Therefore, researchers and farmers want to know the range of crop yields or prices for which the proposed practice may be recommended. Sensitivity analysis is used to test a proposed technology for its ability to withstand yield or price changes.

Sensitivity analysis uses different prices or yields to determine what would happen to the net benefits and the choice of proposed technology if it were to occur in price or yield conditions different from those expected.

Assume that the use of the improved maize variety was recommended when its farm gate price was heavily subsidized. Removal of the subsidy would result in an increase in the farm gate price of this input. The analysis may include the anticipated farm gate price to assess the effect of the potential input price increase.

Table 3. A partial budget for maize production comparing different maize varieties.

		Maize varieties		
		Local Var.	Imp. Var1	Imp.Var2
Gross farm gate benefits				
1	Average yield (kg/ha)	2,592	3,983	4,331
2	Adjusted yield (kg/ha) (1 × 0.9)	2,333	3,585	3,898
3	Price (₦/kg)	5.10	5.10	5.10
4	Gross farm gate benefits (₦/ha) (₦/ha) (2 × 3)	11,897	18,282	19,879
Variable input costs (₦/ha)				
5	Maize seeds	63	360	360
6	Planting	40	150	150
7	Fertilizer	100	450	450
8	Weeding	360	420	600
9	Harvesting	90	100	150
10	Shelling	40	45	75
11	Drying	80	86	100
12	Total variable input costs (₦/ha) (Σ5...11)	773	1,611	1,885
Net benefit				
13	Net benefit (₦/ha) (4 – 12)	11,124	16,671	17,994
14	Change in net benefits between two consecutive treatments* (₦/ha)		5,547	1,323
15	Change in total variable input costs between two consecutive treatments** (₦/ha)		838	274
Marginal rate of return				
16	Marginal rate of return (14/15)		6.62	4.83

*Change in net benefits between Treatments 2 and 1 is 16,671 – 11,124 = 5,547
Change in net benefits between Treatments 3 and 2 is 17,994–16,671 = 1,323
**Change in total variable input costs between Treatments 2 and 1 is 1,611 – 773 = 838
Change in net benefits between Treatments 3 and 2 is 1,885 – 1,611 = 274

Table 4. On-farm evaluation data sheet.

Description of variable/parameter	Data /Data source
Type of technology being evaluated (MV, CRM, PHM)	Example: MV
Description of the technology being evaluated	Example: Drought resistant maize
Yields with old technology (kg/ha)	Survey of all control plots
Yields with new technology (kg/ha)	Survey of all treatment plots
Family labor used with old technology (days/ha)	Survey of all control plots
Hired labor used with new technology (days/ha)	Survey of all treatment plots
Inorganic fertilizer used with old technology (kg/ha)	Survey of all control plots
Inorganic fertilizer used with new technology (kg/ha)	Survey of all treatment plots
Animal power used with old technology (days/ha)	Survey for all control plots
Animal power used with new technology (days/ha)	Survey of all treatment plots
Pesticide used with old technology (kg/ha)	Survey of all control plots
Pesticide used with new technology (kg/ha)	Survey of all treatment plots
Land allocation to crops	Surveys of all participating farmers
Crop-specific input uses and production	Surveys of all participating farmers
Adoption of other improved technologies	Surveys of all participating farmers
Input–output prices	Survey of nearby markets
Farm and household characteristics	Surveys of all participating farmers
Technology characteristics and farmers’ preferences	Surveys of all participating farmers
Production constraints	Surveys of all participating farmers

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Annexes

Annex 1. Table of random numbers from 0 to 9.

	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**M**	**n**	**o**	**p**	**q**	**r**	**s**	**t**	**u**	**v**	**w**	**x**	**y**	
Ra	8	2	0	3	1	4	5	8	2	1	7	2	7	3	8	5	5	2	9	0	6	3	1	6	4	***Ra***
Rb	0	8	7	3	3	3	2	4	5	2	1	1	3	1	2	0	6	2	1	1	1	3	6	7	9	***Rb***
Rc	3	3	3	8	7	5	5	6	4	3	2	0	4	2	3	5	5	1	6	3	6	3	2	5	6	***Rc***
Rd	5	7	5	5	4	2	6	2	7	7	4	9	9	4	4	4	7	2	8	1	2	4	6	1	2	***Rd***
Re	2	9	3	9	5	1	0	3	1	4	6	2	2	1	5	3	8	3	3	4	5	2	5	3	4	***Re***
Rf	1	8	7	8	7	6	9	3	5	4	9	3	8	7	6	9	9	2	4	1	7	0	1	6	5	***Rf***
Rg	6	4	8	5	9	1	1	5	9	5	5	8	7	9	7	2	3	4	6	4	9	7	3	7	8	***Rg***
Rh	7	3	8	8	0	9	3	2	6	3	7	7	4	0	8	0	4	5	2	6	0	4	3	0	9	***Rh***
Ri	8	5	3	1	1	8	6	1	5	7	0	3	5	5	9	8	2	6	7	7	8	9	1	9	8	***Ri***
Rj	9	4	5	9	3	2	0	6	9	9	9	4	6	4	0	1	1	7	9	9	7	0	3	6	7	***Rnj***
Rk	2	1	5	3	5	3	3	2	8	0	2	5	7	6	1	3	2	8	0	4	5	4	7	5	4	***Rk***
Rl	4	2	9	5	3	7	5	5	7	1	3	6	3	2	0	9	3	9	2	5	3	2	9	3	1	***Rl***
Rm	5	9	2	8	7	6	7	6	4	5	5	5	2	7	9	8	5	0	4	6	6	2	7	2	2	***Rm***
Rn	6	3	3	3	0	5	8	0	0	3	7	7	1	1	8	7	8	4	6	2	3	7	1	1	3	***Rn***
Ro	7	6	0	1	1	9	1	9	4	7	9	4	0	8	5	5	0	5	8	3	7	8	1	4	7	***Ro***
Rp	2	7	0	6	4	1	5	1	8	2	1	5	9	2	6	0	9	6	3	7	4	0	2	6	3	***Rp***
Rq	3	3	8	5	5	4	7	1	1	5	2	2	8	9	7	5	5	7	1	9	1	8	2	8	8	***Rq***
Rr	4	1	7	1	6	6	0	2	8	4	4	1	3	4	3	0	6	2	2	8	7	1	0	0	5	***Rr***
Rs	8	2	2	8	0	0	3	5	3	8	5	9	4	0	1	5	8	3	9	5	9	4	9	9	5	***Rs***
Rt	9	7	5	9	1	9	5	3	9	0	7	0	2	5	5	1	3	4	0	3	0	9	5	2	9	***Rt***
Ru	1	3	9	6	3	1	4	4	3	2	8	7	1	6	6	9	4	1	6	6	4	2	7	4	2	***Ru***
Rv	2	0	8	2	5	3	6	4	5	5	3	5	5	7	9	8	5	6	3	7	5	8	6	5	4	***Rv***
Rw	5	4	9	1	7	6	4	8	5	7	9	3	6	8	0	8	6	7	4	8	3	4	2	1	1	***Rw***
Rx	6	2	5	1	0	8	2	9	1	2	2	1	7	1	3	4	2	3	7	1	6	8	9	7	2	***Rx***
Ry	0	9	2	5	2	4	5	2	3	1	3	2	8	3	2	2	7	2	8	2	7	0	9	0	2	***Ry***
Rz	9	0	9	1	4	5	4	4	5	7	5	5	1	2	4	0	1	4	2	3	2	9	2	7	9	***Rz***
Raa	3	5	2	6	5	1	8	6	2	9	8	7	2	4	5	2	2	5	3	4	7	3	2	8	5	***Raa***
Rab	0	2	9	9	7	7	2	0	6	0	3	6	3	3	6	3	4	0	4	5	8	2	8	3	0	***Rab***
Rac	2	2	8	3	3	4	9	1	7	1	1	8	8	5	2	1	6	9	5	7	2	2	1	4	3	***Rac***
Rad	4	9	5	4	9	9	1	2	3	3	2	5	7	4	2	4	9	8	6	9	3	9	2	2	7	***Rad***
Rae	5	7	5	3	1	2	4	5	4	5	6	6	6	6	3	5	5	5	8	0	4	2	3	1	9	***Rae***
Raf	3	6	0	1	6	1	8	4	8	7	5	3	9	5	6	4	6	6	1	8	6	1	4	6	2	***Raf***
Rag	2	6	9	9	0	5	0	7	5	9	3	4	0	7	7	4	3	3	3	7	9	8	7	7	4	***Rag***
Rah	1	7	7	1	1	8	3	9	6	0	9	8	5	6	9	3	4	4	5	6	0	3	0	0	8	***Rah***
Rai	6	5	3	3	2	0	4	3	8	2	0	9	4	8	0	2	5	2	7	4	1	3	5	4	8	***Rai***
Raj	7	8	1	3	6	1	5	6	6	4	8	2	6	7	1	0	0	1	8	3	5	0	2	4	6	***Raj***
Rak	0	0	9	4	7	2	6	4	7	3	3	1	1	9	2	1	9	3	9	7	7	7	9	0	6	***Rak***
Ral	9	5	9	0	3	6	1	7	1	5	4	3	3	0	3	9	1	4	0	4	8	7	5	5	8	***Ral***
Ram	2	4	8	1	4	9	2	2	3	1	5	4	5	1	4	9	2	6	3	2	9	9	6	3	5	***Ram***
Ran	1	3	9	7	8	4	4	1	8	6	2	9	8	4	5	2	3	8	5	3	1	2	4	1	0	***Ran***
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**M**	**n**	**o**	**p**	**q**	**r**	**s**	**t**	**u**	**v**	**w**	**x**	**y**	

Annex 2. Objectives, expectations, and study materials for the hands-on training course on the conduct and management of field trials.

Objectives

On successful completion of this course, you will be able to:

1. State in clear terms the purpose of maize variety trials you conduct;
2. Distinguish the different types of maize variety trials;
3. Design, layout and conduct maize variety trials;
4. Apply agronomic practices in maize variety trials efficiently and effectively;
5. Collect appropriate and useful (usable) data from maize variety trials in the field;
6. Harvest, shell, and determine the yield of maize varieties in a trial;
7. Summarize and prepare maize yield trial data ready for statistical analysis.
8. Interpret correctly the computer outputs of the statistical analysis.
9. Correctly select the varieties for further testing and/or release.

Study materials

1. Seeds of different maize varieties
2. Seed envelopes
3. Planting ropes
4. Tapes
5. Pegs
6. Tags
7. Hand planters
8. Mechanical and manual (hand) shellers
9. Meter sticks
10. Permanent markers
11. Pencils and biros
12. Field notebooks
13. Portable balances

Practical

1. Prepare seeds for planting a variety trial.
2. Mark out the field ready for planting.
3. Prepare planting ropes
4. Plant the experiment.
5. Take data on agronomic traits from already established variety trials.
6. Summarize variety trial data ready for statistical analysis.
7. Analyze and interpret variety trial data.

Pretest questions

1. Distinguish variety from cultivar.
2. Why does maize have many varieties?
3. List five characteristics that may be used to distinguish maize varieties.
4. List three purposes of conducting field trials in maize research.
5. What type of field designs are used for progeny trials? Illustrate with a trial composed of 256 full-sib progenies.
6. Discuss the importance of progeny trials in long-term maize breeding programs.
7. What are the characteristics of national, regional, and international maize trials? List the challenges facing these trials in West Africa.
8. Mention and discuss an international maize trial coordinated by a national maize program in West Africa.
9. What is an on-farm trial? How does it differ from a demonstration? Describe in detail the mother–baby trial.

10. What is coefficient of variation (CV)? What is its relationship with maize yield in West Africa? Which one contributes more to CV, mean or standard deviation? Discuss with lucid examples.
11. What steps must a researcher take when planting variety trial of maize?
12. Describe how the Pythagoras Theorem may be used to advantage in planting maize trials.
13. A farmer planted maize into rows spaced 0.75 m apart with hills spaced 0.20 m apart and one seed/ hill. What is the plant density/ha? Show all calculations clearly. What type of maize variety is most appropriate for this spacing?
14. Discuss the following management practices in maize variety trials: (a) seed dressing (b) thinning (c) fertilizer application (d) weed control.
15. Mention one parasitic weed and two obnoxious weeds in maize farms. How may these weeds be controlled effectively?
16. What are check varieties in maize trials? Use hypothetical data to illustrate the use of standard error in identifying varieties that yield significantly more than the check in a variety trial.
17. With specific reference to flowering, foliar disease scoring, *Striga* emergence count and *Striga* damage rating, discuss the importance of timeliness in data collection in maize trials.
18. Why is it important to harvest maize as soon as it reaches harvest maturity? Enumerate the steps to take to prevent mixing one variety with another in maize yield trials.
19. In a yield trial consisting of 2-row plots, 5 m long with spacing of 0.75 m between rows and 0.25 m within rows at one plant/hill, ear weight from one of the plots is 8.5 kg with 20% grain moisture and 80 shelling percentage. What is the grain yield/ha adjusted to 15.5% moisture content?
20. Mention three categories of people that use the information generated from maize variety trials. Enumerate the specific usefulness to each group.