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| COURSE CODE: | PCP 501 |
| COURSE TITLE: | METHODS OF FIELD EXPERIMENTATION |
| NUMBER OF UNITS: | 2 UNITS |
| COURSE DURATION: | Three hours per week |

## COURSE DETAILS:

**Course Coordinator:** ***Prof. Victor Idowu Olugbemiga Olowe*** MSc., PhD
**Email:** ***owebaba@yahoo.com***
**Office Location:** ***IFSERAR office, Research & Extension building***
**Other Lecturers:** ***P****rof. P.O. Adetiloye/ Prof D.K. Ojo*

## COURSE CONTENT:

*Logic, scientific methods, deductive and inductive reasoning. Essential steps in experimentation: definition of problem, objectives, treatments, experimental material selection. Guides in outlining a proposal on applied research project. Title, problem definition, objectives, materials and methods, plot layout diagram, work schedule, data sheet, yield sample diagram, log frame. Sources of variation in field experimentation. Experimental designs: Completely randomized, randomized complete block, latin square, split plots, single and factorial experiments. Analysis of variance from such designs. Data interpretation and conclusions based on the F-test on data analyzed. Mean and standard deviations, standard error, Least significant difference, Duncan's Multiple range test. Correlation and Regression. Non-parametric statistics and their application: Chi-square, normal curves and T-test. Writing reports of experiments (project report and journal articles)*
***Practicals****: Visit to selected farms and cropping system experiments. Identification of*

## COURSE REQUIREMENTS:

*This is a compulsory course for all final year students in COLPLANT. In view of this, students are expected to participate in all the course activities and have minimum of 75% attendance to be able to write the final examination.*

## READING LIST:

1. Finney., D.J. and Harper, J.L. (1994). *Presentation of Statistical Data*. Experimental Agriculture 30: 377-380.
2. Riley, J. (2001). *Presentation of Statistical Analysis*. 37:115-123.
3. Steel, R.G.D & Torrie, J.H. (1980). *Principles and Procedures of Statistics: A Biometrical* approach. 2nd ed. McGraw-Hill International Book Company, New York.
4. Wahuwa., T.A.T. Applied Statistics for Scientific Studies. Afrika-link Press, Abia. 1999.

## LECTURE NOTES

***INTRODUCTION***

*In general, statistics deals with the collection, analysis and interpretation of data. Statistics is the science of application of qualitative and quantitative techniques for making inductive inference. Statistics is concerned with the development of application of methods and techniques for collection, analysis and interpretation of numerical information to achieve defined objectives.*

***USE OF STATISTICS***

*Statistics can be useful in several situations. These include:*

1. Description of situation e.g. tables and graphs to describe the yield of different crop varieties.
2. Used in decision making i.e. sampling of a handful of products from large number of random sample to determine if the quality is good or bad.
3. Accessing variability in quality e.g. Seed planter used to plant seed of different sizes
4. Degree of association between factors or variables
5. Prediction – statistics can be used to predict the yield or a crop based on the nutrient in the soil or the amount of irrigation water applied, or the yield at different planting densities
6. Statistics is the tool for carrying out scientific experiments.

***ESSENTIAL STEPS IN EXPERIMENTATION***

*The correct choice of a statistical procedure for any experiment must be based on sound knowledge of statistics and the subject matter of the research. Thus, a good experiment can be designed by:*

1. A subject matter specialist (SMS) with some training in experimental statistics
2. A statistician with some background and experience in the subject matter under experimentation
3. A joint effort and cooperation between a statistician the SMS

*Problem definition*

- You begin by asking questions from what you have observed over the years personally or in literature
- Establish if there is truly a problem
- After identifying the problem there is need to do a comprehensive literature review to know how far other scientists have gone on the subject matter and then identify the missing gaps in knowledge. This procedure is very important because it avoids duplication of efforts.

***Definitions of Objectives***

*There would be one of more objectives in a research study. The objective should be very brief or concise, self explanatory and achievable.*

***Objective**: To evaluate the yield potential of new soyabean varieties. You can have broad objective or general objective and (specific objectives) which always address the specific topic.*

*Avoid rewriting your project title as your objective e.g. Project title: Study of the effect of fertilizer on maize varieties cassava and rewriting that as objective is wrong. The objective in this case is to determine the effect of fertilizer on yield and yield component of maize.*

***Choice of Treatments***

*Before a researcher can define experimental treatment a very good knowledge of the subject matter is needed. An experimental treatment is any process/procedure whose effect is to be measured and compared with others. The quantitative or qualitative component of a treatment is called the **treatment levels.** When there are two or more types of treatments, then each treatment is referred to as **factor**. For example, in the study of the effects of*

*insecticide on the control of insect pests on tomato varieties, there are two factors here, namely: the insecticides to be used and the number of tomato varieties in the study.*

***Definition of Experimental Material***

*Any object or element of the environmental on which treatment is applied and observation made is called experimental material. The portion of unit of experimental material receiving the application of treatment is called the experimental unit or experimental plot in a field experiment.*

*The minimum requirements for a valid experimental design are:*

***Replication:*** *It is the application of a treatment more than once in an experiment. This is done*

1. To provide an estimate of experimental errors
2. To improve the precision of an experiment
3. To increase the scope of inference
4. To reduce or control error variance

***Randomization:*** *Every treatment must be given equal chance of being placed within and experimental plot or a sample unit. Randomization of treatments means that the experimental error is randomly distributed, that is the residual error is not clustered. Random distribution of error is important in order to measure the level of statistical significant of effects of treatments or factors. Randomization is done to avoid bias in the allocation of treatments to plots.*

***Blocking:*** *This is accomplished by blocking or subdividing the experimental area or experimental material to more or less homogenous groups.*

***Question***

*What is the meaning of the following?*

1. Adaptive Research
2. Basic Research
3. Applied Research

***POPULATION PARAMETERS AND SAMPLE STATISTICS***

*Statistics is process of obtaining information about a population. Statistical information is used to make inferences about the population. Statistics deal with taking samples. Samples must be a representative of the population and the information obtained from the sample is called statistics. In order for statistics to be a representative of a population it must give a good estimate of the population parameters. Statistics provide the tool for obtaining information from samples that can apply to a whole population.*

*Parameters are the actual values or information obtained from a population and statistics are information obtained from samples to provide estimates of the real population parameters. There are two ways obtaining data (1) sampling/survey (2) Experimentation.*

***Survey:*** *Survey is carried out in order to describe what is happening about a large population. Survey is carried out when you go out to farmers and obtained information. One of the beauties of survey is that the problems that need research interventions can be identified from field surveys.*

***Experimentation:*** *This involves using definite procedures of asking questions, formulating hypothesis, setting up an experiment to test the hypothesis, (usually called null hypothesis), collection of data, analysis and interpretation of the data followed by a test of hypothesis during which the hypothesis is affirmed or rejected.*

*Each observation make from a sample is called a variable. Examples of variables are germination percentage, plant height, leaf area, dry matter yield and seed yield. The variables from samples may be discrete or continuous. A continuous variable has decimal places and should not be rounded up to whole numbers or integers. Examples are weight and height of the plant. Discrete variables are whole numbers or integers. Examples are days of emergence, leaves per plant and seeds per pod.*

*Various Statistics are used in the analysis of agricultural experiments or agricultural data. These include: Mean, mode, media, variance, standard deviation, analysis of variance (ANOVA), correlation, regression, t-test, Z-distribution, chi square and covariance analysis.*

***POLULATION AND SAMPLING***

*Population refers to a defined group that is of interest for study. It could be population of farmers in Ogun State, population of cassava growers in Ogun State or population of orange growers in Ogun State. It could be the number of women farmers in Nigerian or Number of student offering PCP501 course. A defined population or a specified population must be fairly homogenous in some respect but may be heterogeneous in other aspects. That means the population has sub populations. If the class of student in PCP501 is a defined population, its sub-populations will be the number of male and female students. Another sub-population will be the number of students taking the course from different departments. When we measure the characteristics of an entire population, we use the term population parameters for the population data summary.*

*Such parameters are population mean, population variance population standard deviation (S.D.). It is expensive time consuming and cumbersome to obtain parameters for a large population in the process of studying the population. Consequently, there is the need to take samples from the defined population for measurement and for estimating population parameters. When population parameters are estimated from samples, the estimates are called STATISTICS.*

*Statistics therefore deals with sampling techniques, method of collecting data and analyzing the interpreting the data.*

*To get a good estimate of the population parameters, it must have the following characteristics:*

1. It must be large enough to cover the various populations and therefore the range of variance. If otherwise a sample may not give a good estimate of the population characteristics.
2. Representative: A sample is representative when it covers the strata of the population as well as the strata variation
3. The sample must be random. Random sampling avoids bias. Random samples must be large enough and must be representative of the population.

***TECHNIQUES FOR OBTAINING SCIENTIFIC DATA***

1. Survey 2. Experiment

*Surveys are measurement taken from nature without imposing your own conditions or treatment. Surveys provide reasons why the population behave the way it is or explain the characteristics of the data from nature. Surveys are very important agricultural data. For instance a survey can be carried out on the weed spectrum and weed control methods on farmers' field in Ogun State and the kind crops farmers grow. In an experiment, we want to impose our condition on nature and measure the effect of the treatments imposed. For example in an attempt to investigate how to reduce malnutrition in children, in Ogun State, we can decide to fortify the food of children with soymilk and see how the children will grow or respond to the treatment. We can also try to use different rates of fertilizer to increase yield.*

*Scientists carry out experiments in various fields. Scientific experiments share the following features:*

- A review of facts, theories and proposals
- Formulation of logical hypothesis that can be subject to testing by experimental methods. A hypothesis is a proposition about a situation. The proposition may be true or not be true. An improved variety of maize will perform better than local variety in all locations. An experiment can be conducted to determine whether the hypothesis is true or not.

- Objective evaluation of the hypothesis on the basis of experimental results.

*Therefore, statistics is a tool used in scientific research to determine the validity or otherwise of a scientific hypothesis.*
*Statistics applied to agriculture can have a variety of names such as Biostatistics, Biometrics, Field Plot Technique. Experimental Designs or Methods of Field Experimentation. The differences are subtle depending on where emphasis is placed in the course.*

***PRINCIPLES OF FIELD EXPERIMENTATION***

*An experiment is a planned investigation that is carried out to obtain additional knowledge in order to solve identified problems and to obtain solutions to the problems. The problems can be identified from a survey, personal experience and literature search. The identified problem must be state in unambiguous term.*

- After identifying the problem, the next step is to carry out literature review – to find out how other scientists in other locations or countries had tried to solve the problem. What experimental procedure they used and the results obtained in order to ensure that your proposed experiment is properly conducted. Literature review is made easy by electronic search, library, e-mail correspondence etc.

- Clearly state the objective of the work. The objective must be straight forward and simple. It must be specified to ensure that the study is properly focused and the right results are obtained.

- Setting up of hypothesis: The hypothesis is state in the negative. This null hypothesis (Ho) states for instance that there are no differences in the yield of the varieties to be evaluated. The alternate hypothesis (Ho), will be accepted if the experiment shows otherwise.

- Designing of experiment: To be able to answer the problem, the scientist will

- Conduct the experiment

- Collect data

- Statistically analyse the data

- Interpret the data and Report the results obtained

***FIELD EXPERIMENTATION PRACTICES***

- Field preparation
- Choice of treatment and factors
- Choice of design and number of replications
- Plot labeling
- Treatment randomization and layout of the experiment
- Planting and application of treatments in the field
- Handling of experimental material
- Experimental unit and sampling unit
- Size of guard or border row

- Data collection, handling and processing

*Filed preparation must be timely including ploughing, harrowing, leveling and removing the entire stump.*
*Choice of design depends on the location, homogeneity of the site. It depend on the number of factors to be investigated.*
*Treatment randomization is very important to avoid bias in allocation of treatment to experimental plots. Randomization is important to correct and minimize residual error. The smaller the experimental error, the better is the precision of the experiment.*
*Field layout: In the field lay out the site, location, orientation relation to N.S.E.W. or road, the number of plot, replicate, the treatment number must be clearly shown. It must be typed and printed and given to all participants in the experiment.*
*Planting and application of treatments in the field has to be done at the right time. The treatment number must be put on label and place on the plot.*
*Handling of experimental material: Experimental materials must be carefully handled to avoid spoilage, leakage, overdose or under dose during measurement, transportation and application on the field. Also, contamination of contaminable materials must be avoided.*
*Experimental unit and sampling unit: The experimental unit is usually called the Gross plot size. It is the smallest unit in the experiment. Each experimental unit receives a treatment. The sampling unit is a portion of the experimental unit. It defines the portion from where sample is taken for measurement.*
*Size of guard/border row: The size of an experimental unit or plot must be large enough to avoid border effect. That is there must be guards rows. The advantages of border row include:*

1. It gives protection or shield or break when applying different fertilizer rates or pesticides from one plot to the other plot.
2. It helps to reduce border effect because border plants grow better than other plants within the plot.

***DATA COLLECTION***

- Collect the data in a log book
- Summarize data the same day that you collect the data
- Avoid using loose paper to collect data
- It must be readable by other persons
- Where sample has to be weighed or dried, it should be labeled and properly packed in a paper bag.
- Counting and weighing procedure must be adequate
- Summarized data must carry sampling date, name of variable, unit of measurement and location of the experiment
- The summarized data must be neatly presented for statistical analysis

***CONTENTS OF A RESEARCH***
*Title*
*Problem definition*
*Objectives*
*Material and Methods*
*Plot layout diagram*
*Work plan*
*Data sheet and Data collection*
*Gross and net plots*
*Data analysis*
*Presentation of experimental results*

*Log frame*

*The objective of a field experimental is to find scientific means of enhancing the quality and quantity of physical resources for crop production e.g. solar radiation, water, lands, fertility. Various practices and factors affect or determine crop performance and yield in the field. Such practices and factors include: tillage practices, fertilizer management, water management, pests and diseases management. Field experiments are carried out to determine the best practices that will increase the efficiency of crop production.*

*A title is formulated from the focus of the subject matter i.e. How can the efficiency of fertilizer be increased in order to get more better crop growth and yield? Title has to be brief, concise and clear. The title should reflect the objectives and the materials or factors being investigated.*

**Introduction***: The introduction provides information on the nature of the problem being addressed, the purpose, scope and justification of the experiment. There is no standard format in writing the introduction. The problem being addressed in the experiment must be clearly identified. How the problem was found out should be stated. What and where attempts have been made to solve such problem, if any and why it is still important to carry out the experiment. The scope of the experiment is the extent to which the identified problems for which the experiment being proposed will be tackled. It is important state what had been done or achieved by similar experiments in the past and what remains to be done. The introduction should also state why this study is important or what will be the importance of the solution to the problem that is being addressed.*

**Objectives***: The objective or objectives of the experiment are stated at the end of the introduction. It is still a part of introduction. It cannot be omitted in good report writing. The objective spells out briefly and accurately the specific focus of the problem that the experiment wants to solve. In order words the objective states the question the experiment wants to answer.*

**Literature Review***: This is the process of searching for information on previous studies on the topic and materials under investigation. The most important source of research information is Journal Publication, followed by books and then the internet. In reporting an experiment it is always vital to provide a review of literature to ensure that the investigator or researcher is familiar with progress and most recent developments in the chosen field of research. Literature review also prevents the duplication of research efforts. It also helps to improve the choice of materials and experimental methods.*

**Material and Methods** *The area, location and duration of the experiment must be stated. It is very important to describe the location, the climatic conditions of the site and the soil type. The type of land preparation, the plot size, description of treatments and factors used as well as the experimental design and number of replications used should be stated. The duration of the experiment must be stated.*

*Material: Information must be provided on the general cultural practices, such as land preparation, fertilizer application and control of weeds, insects and other pests that my interfere with the experiment. The rate per hectare of blanket applications of fertilizer, insecticides, herbicides and others used should be stated. The name of crop varieties used and the source of the seeds or planting materials should be stated.*

*Experimental design*

*Randomization and Field Orientation: State the specific design you want to used including number of factors, treatments and the number of replicates. It is important to state the dimension of the net plot and the gross plot size.*

*Treatment: State the number of treatments and how the treatments were applied. The treatments must be described e.g. crop varieties or fertilizer levels or plant populations or different concentrations of insecticides or chemical used.*

*Land preparation: Mention how the land was prepared. Hand clearing, bush burning or ploughing and harrowing or with the use of herbicide.*

*Fertilizer management: You have to state clearly the kind, the time, the rate and how it will be applied.*

*Weed management: You must describe fully the method of weed control. If herbicides are use, the kind, rate and time and how the herbicide is to be applied, the number of time and the stage of cultivation must be stated.*
*Insect and Disease Control: State time, rate, kind and how to apply chemical to control pest and disease. It is important to include target insect to be controlled.*
*Data Collection: Data to be collected must be stated and the intervals or growth stages when the data will be collected should also be stated before the experiment starts. In some experiments, unexpected situations may warrant taking additional data than what was contained in the project proposal.*
*Harvesting: This must be done at the approximate time. The method of harvesting, sampling procedure, sample size, method of sampling should be stated where necessary. The entire plant stands in a plot from GROSS PLOT size. The proportion of the gross plot size to be sampled is referred to as NET PLOT. The discard or border rows surround the plot to prevent injuries or other form of interferences with the gross plot size. Harvest is done anytime after physiological maturity.*
*POST HARVEST HANDLING: Indicates whether the samples will be weighed fresh or dry. If dry state whether it is sun dried or it is going to be oven dried. If it is to be oven dried, at what temperature?*
***DATA ANALYSIS**: State the statistical methods to be used in analyzing the data e.g. analysis of variance, mean separation, correlation or regression.*
***SOURCES OF VARIATION IN FIELD EXPERIMENT***
*This is can be called variation or variability*

- *Variability in biological material: Agricultural experiments. Involve biological materials. Biological materials are highly variable in size, weight and response to the same environmental resources e.g. a given seed lot, a variety of cowpea or maize. A seed lot from the same variety can't have the same weight for every seed. The seed size, seed weight, germination date, germination rate are different among seeds within the same seed lot.*
- *The soils on which plants grow are also not homogenous in texture, nutrients content and organic matter etc. All these will increase variability of the growth of the plant and therefore the data to be collected.*
- *Lack of uniformity in treatment application: Some treatments can't be completely uniform e.g. you can't have the same size of yam tuber.*
- *Uncontrollable factors: There are uncontrollable or unforeseen problems that arise in field experiment which can increase variability in the data or distort the result from the experiment e.g. stealing, attack by rodents, pests, diseases, nematodes infestation.*

*These above sources of variation introduce what is called experimental error or residual effect in field experiments. Residual effect is due to the normal variation in biological materials and other causes outlined above.*
*In order to minimize residual error there is the need to increase the precision of an experiment.*

1. Problem of soil heterogeneity (slope of the land) you must look at the vegetation of the land on which the experiment is going to be carried out before it is ploughed. After ploughing and harrowing, look at the soil texture in terms of the proportion of sand, silt and clay and you may carry out chemical analysis of the plots. Through the understanding of the vegetation or soil heterogeneity, the experimental plot can be stratified, such that each replicate of the experiment can be placed on different but relatively homogenous soils.
2. Uniformity trial is a trial or experiment that is carried out or run before the real experiment. The purpose is to even out the soil fertility by planting a crop that can take up all the nutrients in the soil prior to the implementation of the real experiment. Uniformity trial is usually carried out prior to setting up a fertilizer trial or

experiment. Uniformity trial can be statistically analysed as if real treatments have been imposed.

3. Choice of appropriate design. Different designs can be used to carry out different experiments. The choice of experimental design depends on the heterogeneity or otherwise of the soil. Some designs can be used to correct the defects in the field. Such defects like soil heterogeneity. The field environment is not so homogeneous. Unlike the green house. Your design must be able to capture the variability on the field.
4. Randomization: Can be defined as giving all treatments equal chance of falling into any plot in the field. There are different methods of randomization e.g. testing different kinds of herbicides on maize plot. You can use card, disc and table of random numbers etc to carry out randomization. You can randomize (n-1) which is called the degree of freedom. The extent to which you can randomize is 0-1. A disc which four side is called tetrahedron.
5. Ensuring uniformity of experimental materials e.g. Yam cuttings, cassava cuttings.
6. Collection of additional data: This is data that was not planned to be collected. If or instance some plots were attacked by rodent or insect, you have to do is to score the damage of the rodent or insect attack e.g. the scores can be attack, low attach, severe attack, very severe attack with scores of 1,2,3,4,5 respectively. In co-variance analysis, you use the additional date (score) to adjust or correct your actual data. The co-variate (addition data) can be used to correct your actual data (yield) with covariance analysis.
7. Treatment Levels: In selecting treatment levels, ensure the treatment levels are as wide as possible.
8. Plot Size: Sizes or experimental unit or plot must be large enough to overcome heterogeneity in the field and to accommodate destructive sampling.
9. Replication: In an experiment it's good to have 1-8 replicates.

*Merits of Replication*

1. Helps to remove the problem of soil heterogeneity by calculating and removing what is called block effect from the sources of variation
2. It reduces the value of the error. The smaller the residual error, the more it's easy to recognize the significant differences and vice-versa.

***Methods of Reducing Experimental Error***

1. Choice of appropriate design
2. Randomization
3. Replication
4. Uniformity trial
5. Collection of additional data
6. Co-variance analysis
7. Careful selection of treatments
8. Selection of correct experimental unit.

***DIFFERENCE BETWEEN ACCURACY AND PRECISION***

*Experiments are conducted to obtain specific information as an addition to knowledge e.g. how will new varieties of cowpea respond to nitrogen fertilizer. These questions require setting up experiment to get specific answer to such question.*

*An experiment that was badly planned or poorly implemented will not give the right answers.*

*Badly implemented experiment lacks the precision required to detect treatment effect e.g. whether, 90kg of Nitrogen applied to maize is not as good as 120kgN applied to maize. Inaccuracy and lack of precision are problems in poorly conducted experiment.*

***PROBLEM OF PRECISION (ACCURACY/INACCURACY***

*Accuracy refers to the ability of a scientist/student to carry out or measure precisely what is intended to be measured.*

*To collect data in the field you need to prepare a data sheet like the one below:*

*Name of experiment: Cowpea/maize intercropping*

*Observation: Cowpea dry matter yield*

*Date: Nov. 24, 2005*

| *Treatment* | *Rep 1* | *Rep 2* | *Rep 3* | *Rep 4* | *Xn* |
|---|---|---|---|---|---|
| *0KgN* | | | | | |
| *4.5KgN* | | | | | |
| *9.0KgN* | | | | | |
| *120KgN* | | | | | |

*You must keep accurate records. Accuracy is about how you carry out your weighing and measurements without any systematic error. When you weigh, there must be no systematic error in the weight (make sure the balance is not faulty). Another source of systematic error occurs when you approximate your figures.*

*Accuracy also means that when you are planting, the planting and treatment must be carried out accurately. Such inaccuracies will affect the result of your data and the results from the experiment.*

*Inaccuracies introduce large variability in experimental data. Variability that was not due to treatment or factor under study. Such large and undesirable variation will increase experimental/residual error.*

*Inaccuracy will increase experimental error and decrease precision. Precision in experimentation means getting the experimental procedure right such as choice of right design make sure that there is correct randomization, replication etc . to minimize experimental error.*

*It is important to differentiate between accuracy and precision.*

*Accuracy: is the ability of a student to carry out or measure precisely what is intended while precision is the ability of a student to get the experimental procedure right, such as choice of right design.*

***EXPERIMENTAL DESIGNS***

- Completely Randomization Design (CRD)
- Randomized Complete Block Design (RCBD)
- Latin square
- Split plot design
- Split-split plot design
- Split block design

*For each of the above designs it is very important to be:*

- Randomize the treatments or factors within each design
- Label the plots in the field
- Know the advantages and disadvantages of each design
- Able to collect the data correctly on the field
- Know the sources of variation
- Assign correct degrees of freedom for sources of variation

- Able to calculate Sum of Squares for each variation
- Calculate Mean Squares
- Compute error or Error Mean Square
- Calculate F-Ratio
- Test for Significance
- Separate Means

***COMPLETELY RANDOMIZATION DESIGN (CRD)***

*It is the simplest design. It is good for laboratory, green house and pot experiments. It is therefore suitable or efficient where conditions are homogenous. In the design, as many treatment can be used because of its simplicity and flexibility.*

*Disadvantages: It doesn't give a very good measure of experimental error i.e. it has low error precision where experimental material or environment is heterogeneous.*

*Randomization in CRD*

*Rhizobium strains*

| | | | | |
|---|---|---|---|---|
| *USDA 1* | *1* | *6* | *11* | *16* |
| *USDA 33* | *2* | *7* | *12* | *17* |
| *USDA 44* | *3* | *8* | *13* | *18* |
| *USDA 75* | *4* | *9* | *14* | *19* |
| *Control strain* | *5* | *10* | *15* | *20* |

*The randomization of treatments in a 4 x 4 Latin square is as shown:*

| *Rep I* | *Rep II* | *Rep III* | *Rep IV* |
|---|---|---|---|
| *D* | *C* | *B* | *A* |
| *A* | *B* | *D* | *C* |
| *C* | *D* | *A* | *B* |
| *B* | *A* | *C* | *D* |

*The heterogeneity that Latin square can control in two directions could be in the environment (soil) or planting material or both soil and planting material.*

*e.g. (1) Soil that slopes in two directions*

*(2) Slope*

***LATIN SQUARE DESIGN***

*Advantages*

1. Takes care of heterogeneity in 2 directions
2. Has more precision than CRD and RCBD

*The Disadvantages*

1. The number of rows must be equal to the number of blocks (columss and equal to number of treatments).
2. Therefore it becomes cumbersome to analyse when the number of treatments exceed five or six.

*The Design*

*Because of the number of rows and columns must be equal i.e. square the design could be a 3 x 3 or 4 x 4 or 5 x 5 0r 6 x 6 Latin square in one direction and water table in another direction.*

3. Only slope in one direction but the other heterogeneity in the planting material e.g. cassava cutting or yam tuber cut into different maturity stages and different stages put into different blocks.

***SPLIT PLOT DESIGN***

*This is strictly spreading an arrangement of treatments rather than a design. The slip plot arrangement is in RCBD. The number of replication can be as many as desirable. Usually between 3 or 4 or 5.*

*Advantages*

1. The split plot design is very useful for a two-factor trial or experiment particularly where special consideration is given on the ease or convenience of arranging the factors and treatments in the field. In such situations RCBD will not be a convenient design.
2. Because of its flexibility the randomization and application of treatments in the field is much earlier and more convenient that for standard RCBD.

*The Main Disadvantages are:*

1. It is commonly used for two factors only. Although an expert in biometrics can use it for trials involving 3 or four factors
2. The precision for testing the significance of treatment differences as main plot and sub plot levels are different. The precision being higher for subplot treatments than for main plot treatments.
3. The calculation of missing plot values can be more cumbersome.

*Assuming you want to evaluate the effectiveness of three contact insecticides on four varieties of cowpea in the control of flower and pod eating pests.*
*If you have a 3 x 4 factorial arrangement of treatments, how do you randomize this is a split plot design.*
*The factorial combinations could be 2 x 3, 2 x 4, 3 x 4, 3 x 5 etc. The number of replicates could be 3 or 4.*
*The decision about what factor to put in the main plot or in subplot is determined by:*

(1) Ease of assignment of treatments e.g. performance of maize varieties on two different land preparation methods will require putting land preparation method in main plot because it will be easier to do so.
(2) Put the more important factor in subplot with higher precision so that treatment differences can be easily detected.

*Before any experiment we must state the null hypothesis which will apply to every observation or variable measured in the experiment (Plant height, leaf area, dry matter yield, grain yield, score of pathogen infection etc).*

$$\frac{208^2 + 224^2 + 272^2 + 224^2}{4} - CF$$

$$= \quad 576$$

*ANOVA Table*

| | | | | | Require F | |
|---|---|---|---|---|---|---|
| *SV* | *D.f* | *SS* | *MS* | *Obs.F* | *5%* | *10%* |
| *Total* | *15* | *854* | | | | |
| *Block* | *3* | *576* | *192.0* | *24.69*** | *3.86* | *6.99* |
| *Treat* | *3* | *208* | *69.3* | *8.91*** | | |
| *Error* | *9* | *70* | *7.78* | | | |

*Compare the precision, error value (FMS) in CRD (53.8) with RCBD 7.78 and the effect on F-ratio.*
*Also the residual is obtained by sweeping Treatment mean and then Block means.*
*It is wrong and unacceptable to use a design that you did not use to implement a trial to analyse the data.*

*Mean Square for Error or Error Mean Square*
*MSE represents variability among capital units that remains after removal of other sources of variation.*
*This Residual effect or MSE can be seen by removal or sweeping technique if block effect and then removal of treatment effect.*
*Block 1 effect is block means – GM: $X_b$ - $X_g$*
*52 58 -b: which should be subtracted from each variety in BL 1*
*I*
*47 – (-6) 53*
*50 – (-6) 56*

*57 – (-6) 63*
*54 – (-6) 60*
*Block II effect 56 – 58 = -2*
*Block III effect 68 – 58 = +10*
*Block IV effect 56 – 58 = -2*
*Varieties with Block effect removed*

| | *I* | *II* | *III* | *IV* | *Total* | *Mean* |
|---|---|---|---|---|---|---|
| *$V_1$* | *53* | *54* | *53* | *53* | *212* | *53* |
| *$V_2$* | *56* | *56* | *57* | *59* | *218* | *57* |
| *$V_3$* | *63* | *55* | *59* | *59* | *236* | *59* |
| *$V_4$* | *60* | *67* | *64* | *61* | *252* | *63* |
| | ***232*** | ***232*** | ***232*** | ***232*** | | |
| *Mean* | ***58*** | ***58*** | ***58*** | ***58*** | | |

*Removal/Sweeping Away of Treatment effects*

| | | | |
|---|---|---|---|
| *$V_1$* | *53* | *58* | *-5* |
| *$V_2$* | *57* | *58* | *-1* |
| *$V_3$* | *59* | *58* | *+1* |
| *$V_4$* | *63* | *58* | *+5* |

*Removal of Treatment effects from the above table to get the next table corrected now for block or treatment effects*

| | *I* | *II* | *III* | *IV* | | *X* |
|---|---|---|---|---|---|---|
| *$V_1$* | *58* | *59* | *57* | *58* | *232* | *58* |
| *$V_2$* | *57* | *57* | *58* | *60* | *232* | *58* |
| *$V_3$* | *62* | *54* | *59* | *58* | *232* | *58* |
| *$V_4$* | *55* | *62* | *59* | *56* | *232* | *58* |
| *X* | ***58*** | ***58*** | ***58*** | ***58*** | ***58*** | |

*Mean square for error is the*
*Square of each residual*
*4(4) – (4 – 1) – (4 – 1)*
*Total (Treat) (Block)*
*$(58 – 58)^2 + 59 – 58^2$ …….. ‘ $(56 – 58)^2$*
*1(4) (4) - 1[ -4 -1 – (4-1)]*
*= 70/9*
*= **7.78***
*ANOVA in Latin Square 4 x 4 LS*

| *Rep I* | *Rep II* | *Rep III* | *Rep IV* | *Total X* |
|---|---|---|---|---|
| *D54* | *C65* | *B67* | *A51* | *237* |
| *A47* | *B54* | *D74* | *C57* | *232* |

| | | | | |
|---|---|---|---|---|
| *C57* | *D53* | *A62* | *B57* | *229* |
| *B50* | *A52* | *C69* | *D59* | *230* |
| *Total 208* | ***224*** | ***272*** | ***224*** | ***928*** |

*ANOVA*

| *S.V.* | *D.F* | *SS* | *EMS* | *Feal* | *F Tab* | |
|---|---|---|---|---|---|---|
| *Total* | *15* | *854* | | | *0.05* | *0.01* |
| *Column* | *3* | | | | | |
| *Row* | *3* | | | | | |
| *Treatment* | *3* | *208* | | | | |
| *Error* | *6* | | | | | |

***ANALYSIS OF FACTORIAL EXPERIMENT***

*What is very important in factorial experiments or even single factor experiment is that:*

(1) The total for each factor and the totals for the interactions must be clearly identified

(2) The number of varieties that add up to give the totals for each factor or interaction should be used as the division for the square of the variable before the C.T. is subtracted.

(3) Otherwise the sum of squares will be wrong (larger or smaller in value or negative)

(4) The SS is **never** negative for any source of variation because it is the square of deviations from the mean or sum of square.

*Assuming I have the following*

*2 x 3 factorial mean A at 2 levels, B at 3*
*3 x 2 factorial mean A at 3 levels, B at 2*
*3 x 2 factorial mean A at 3 levels, B at 3*

*The null hypothesis for this experiment is that none of the four varieties is in anyway better or superior to the other*

*Ho: Xv1 = Xv2 = Xv3 = Xv4*
*Ho: Tv = V2 = 0. Treatment positive if is zero*
*Ho: Ti = Vi / 0*
*Ho: Xv1 = Xv2 = Xv3 = Xv4*

*The linear Model for CRD*

*The values Xy = have a mean, a treatment effect and a residual variation.*

*Xy = Xy + Ti + Ei*

*Where Xy is any of the values in the sixteen experimental plots.*

*The Linear Model for CRD*

*Xy = Xy + Ti + Bi + cy*

*Xy = is the mean – or Grand mean*
*Ti is Treatment effect*
*Bj is Block effect*
*Eij is error term or residual effect*
*Linear Model for Latin Square*
*Xijk = Xijk + Ti + Rj + Ck + eijk*
*Take any value 67 = 58 + 5 + 1+ 2 + 3*
*Ti = Treatment effect*
*Rj = Block or Column effect*
*CK = Row effect*
*Eijk = is error term*
*Plant height (cw) or maize varieties to 60 DAP in four replicated + CRD*

| | *I* | *II* | *III* | *IV* | *Total* | *X* |
|---|---|---|---|---|---|---|
| *V1* | *47* | *52* | *62* | *51* | *212* | *53* |

| | | | | | | |
|---|---|---|---|---|---|---|
| *V2* | *50* | *54* | *67* | *57* | *228* | *57* |
| *V3* | *57* | *53* | *69* | *57* | *236* | *59* |
| *V4* | *54* | *65* | *74* | *59* | *252* | *63* |
| | | | | | *928 (Grand Total)* | *58 (Grand mean)* |

$$(X - X)2 = \frac{x/t2 - (x)2}{n}$$

$$\frac{(x - 1)}{n - 1}$$

| *Sources of variation* | *D.f* | *SS* | *MS* | *F-ratio* | | *F-Tab* |
|---|---|---|---|---|---|---|
| *Total* | *15* | *854* | | | *%* | *%* |
| *Treatment* | *3* | *208* | *69.3* | *1.29* | *3.49* | *5.95* |
| *Error* | *12* | *646* | *53.8* | | | |

*SST = 472 + 522 ----------592 - cf*

*CF = $\frac{9282}{16}$ = 53824*

*SST = 54678 - 53824 = 854*

*SSt = $\frac{2122 + \ldots\ldots 2522}{4}$ - CF*

*= 54032 - 53824 = 208*

*SS is always positive if – ve, it means cf is not correct or X2 is not correct*

*SSe = 854 - 208 = 646*

*Residuals = Sweep the means from each value*

*Square the residuals and subtract Cf = SSe*

*Interpretation of data*

*Data is taken on growth and yield so that growth data can be used to explain yield data. Does the improved variety have more vigorous growth (plant height) or more leaf no, or layer leaf area or are the leaves more upright to explain why the yield is significantly better than that of other varieties.*

*Plant height of maize at 60 DAP in your replicated in RCBD*

| | *I* | *II* | *III* | *IV* | *Total* | *X* |
|---|---|---|---|---|---|---|
| *V1* | *47* | *52* | *62* | *51* | *212* | *53* |
| *V2* | *50* | *54* | *67* | *57* | *228* | *57* |
| *V3* | *57* | *53* | *69* | *57* | *236* | *59* |
| *V4* | *54* | *65* | *74* | *59* | *252* | *63* |
| | *208* | *224* | *272* | *224* | *928* | *58 = XGM* |

$$SSB = \frac{Bt2}{4} - CF$$

*3 x 4 factorial mean A at 3 levels, B at 4*

*4 x 3 factorial mean A at 4 levels, B at 3*

*2 x 2 x 4 factorial mean that A, B & C are at 2, 2 & 4 levels respectively.*

*For A at 3 level and B @ 2 levels, the treatments for the experimental units are generated as follows:*

*A1 B1 = A1 B1*

*B2 = A1 B2*

*A2 B2 = A2 B1*

*B2 = A2 B2*

*A3 B1 = A3 B1*
*B2 = A3 B2*
*Note that simple effects can be algebraically calculated. This is not part of ANOVA.*
*B Effect A1 B1 + A2 B1 + A3 B1 - A1 B2 - A2 B2 - A3 B2*
*A2 effects A2 B1 + A2 B1 - A1 B1 - A2 B2*
*A3 effects A3 B1 + A3 B2 - A2 B1 - A2 B2*
*2 x 3 factorial in split plot with 3 replicates*
*18 plots*
*ANOVA Table*

| *S.V.* | *D.F.* | *SS* | *EMS* | *Fcal* | *FTab* | |
|---|---|---|---|---|---|---|
| | | | | | *0.05* | *0.01* |
| *Total* | *(17)* | | | | | |
| *Fact A* | *1* | | | | | |
| *Block* | *2* | | | | | |
| *Ea* | *2* | | | | | |
| *Fact B* | *2* | | | | | |
| *A x B* | *2* | | | | | |
| *Error b* | *8* | | | | | |

*Grain yield of varieties of maize with and without manile tons ha-1 and fertilizer*

| | | *I* | *II* | *III* |
|---|---|---|---|---|
| *A1 B1* | | *1.4* | *1.1* | *1.1* |
| *A1 B2* | | *1.3* | *1.4* | *1.2* |
| *A1 B3* | | *1.5* | *1.5* | *1.4* |
| *A2 B1* | *2.1* | *2.0* | *1.8* | |
| *A2 B2* | *2.6* | *2.3* | *1.9* | |
| *A3 B3* | *2.8* | *2.6* | *1.9* | |

*Note that when the treatment are arranged by the side the values are for collected*
*Calculate the totals and sum of square the Anova.*

*2 x 3 factorial in RCBD with 3 Replicated*
*No of plots 18*
*ANOVA Table*

| *S.V* | *D.F* | *SS* | *MS* |
|---|---|---|---|
| *Total* | *17* | | |
| *Blocks* | *2* | | |
| *Treatments* | | *(5)* | |
| *A* | *1* | | |
| *B* | *2* | | |
| *A x B* | *2* | | |
| *Error* | *10* | | |

*Calculate the SS.*

## *MEASURES OF CENTRAL TENDENCY*

*Central tendency means average performance, while dispersion of a data is how it spreads from a central tendency. He measures of central tendency are: mean, mode and media.*
*The mean is the sum of observations divided by the number of observations*

$$\frac{X1\ X2\ X3\ X4 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Xn}{N}$$

*X (pronounced as X bar) is the mean from sample where n is the mean from population. X is the estimate of n e.g.*

*0.9g, 1.2g, 1.4g, 1.6g, 1.8g*
*X 0.9 1.2 1.4 1.6 1.8 6.9*
*X = 6.9/5 1.38g/plot*

*N*

*The mean is a very good measure of central tendency where samples show what is called* ***Normal distribution.***

*Data is normally distributed when it has equal spread around the mean. It is not always the case that a set of data will be normally distributed. When the data is not normally distributed the mean is not a good measure of the central tendency*

*Mean / mode / median.*

*In the case of the skewed distribution the mean is located away from the central tendency*

*SAMPLE MEDIAN*

*Where data doesn't have a normal distribution mean doesn't represent the central tendency in such a situation, the median gives a better picture of central tendency which is defined as the central value when the data is arranged in ascending/descending numerical order.*

*e.g. 0.15g, 0.45g, 0.87g, 0.99g, 1.02g, 0.38g, 0.98g 1.00g Calculate the median of the data.*

*Solution: 0.15, 0.38, 0.45, 0.56, 0.87, 0.98, 0.99, 1.00, 1.02*

*0.87 = 0.71*

*Mode*

*This is very useful in determining central tendency when a very large data is involved. Given that the scores of 20 students in statistics examination are given below. Find the mode.*

*66.60.61.45.45.80.80.77.72.43.55.60.60.60. 98.40.80.62.41.42 he*

*Mode 60.*

*If a data is normally distributed the mode medium mean*

*MEASURES OF DISPERSION*

*The measures central tendency of a sample: Mean, median and mode do not tell us how value varies from the central tendency. This measurement of how values deviate from the mean is known as a measure of dispersion.*

*For instance, if the mean of ages of 1001 student in the University is 19 years. This could be 3 which means that the age range is 16 - 22 years in which the positive sign indicate the upper limit and the negative indicate the lower limit.*

*X - 19 years 3 i.e. Range 16 - 22*

*For every statistics that we measure there is a corresponding population parameter. Therefore the statistics/parameter for measuring dispersion are as foolows*

*Measures of Dispersion*

*Parameter/Statistics Population Samples*

*Variance*

*Standard deviation*

*Range*

*Range provides the lower and upper values of a set of data e.g. if the dry matter yield of soyabean plant inoculated with strains of nitrogen fixing bacteria (Rhizobium) are given as follows:*

| *Bacteria strains* | *Dry matter yield (x)* | *x - x* |
|---|---|---|
| $R_1$ | *10.2* | *10.28* |
| $R_2$ | *11.1* | *1.18* |
| $R_3$ | *9.8* | *-0.12* |
| $R_4$ | *8.7* | *-1.22* |
| $R_5$ | *12.2* | *2.28* |
| $R_6$ | *13.1* | *3.18* |
| $R_7$ | *9.4* | *-0.52* |
| $R_8$ | *10.6* | *10.08* |
| $R_9$ | *6.9* | *-3.02* |
| $R_{10}$ | *7.2* | *-2.72* |

*The sum of deviations for the mean is 0*
*Calculate the mean, the range and the S.D.*
*Mean = x – 99.2 = 9.92*
*10*

$\frac{x_1}{n} = x$

*x = mean*
*x – x = deviation from the mean*
*(x – x)2 = square of deviation from the mean*
*Variance S2 (x – x) while S = (x –x)2*
*n – 1 n - 1*
*Range x*

| *Bacteria strains* | *Dry matter (x)* | *X - x* | *(x – x)2* | *X2* |
|---|---|---|---|---|
| $R_1$ | *10.2* | *0.28* | *0.0784* | *104.04* |
| $R_2$ | *11.1* | *1.18* | *1.3924* | *123.21* |
| $R_3$ | *9.8* | *-0.12* | *0.0144* | *96.04* |
| $R_4$ | *8.7* | *-1.22* | *5.1984* | *75.69* |
| $R_5$ | *12.2* | *2.28* | *5.1984* | *148.84* |
| $R_6$ | *13.1* | *3.18* | *10.1124* | *171.61* |
| $R_7$ | *9.4* | *-0.52* | *0.2704* | *88.36* |
| $R_8$ | *10.6* | *0.68* | *0.4624* | *112.36* |
| $R_9$ | *6.9* | *-3.02* | *9.1204* | *17.61* |
| $R_{10}$ | *7.2* | *-2.72* | *7.3984* | *51.84* |
| | *X = 9.92* | *= 0* | *35.5360* | *1019.6* |

*X = 99.2*
*X2 = 1019.6*
*(x –x)2*
*n i.e. if you are dealing with a population*

*S2 = (x - x)2 i.e if you are dealing with sample*
*n - 1*
*Variance S2 = 35.5360 = 3.9484*
*9*
*S.D = S = 3.9484 = 1.987*
*Mean = 9.92 = 10 Range = 10.42*
*Variance = 1.987 2 or*
*Therefore the range is 9.92 1.987 i.e. 8 – 12 or 7.92 - 11.92*
*S = (x – x)2*
*n – 1*
*S = x2 - x2*
*n - 1*
*x2 = sum of square of x*
*x2 = sum of x squared*
*n – 1 = degree of freedom*

*(x)2 = correction factor which must be less than sum of square*
*N*
*1019.16 – (99.2)2*
*10*
*9*
*S 1019.6 - 98.064*
*9*

$S = \frac{35.536}{9}$

$S = 3.9484$

$S = 1.987$

$(x - x)2$ $\qquad$ $\frac{x2 - \frac{(x)2}{n}}{n - 1}$

## *COMPARISONS AMONG TREATMENT MEANS*

*In the analysis of variance, the null hypothesis (Ho) that is tested is always that all means are equal. If the F statistic is not significant then this Ho is not rejected and there is nothing more to do, except possibly try to make the experiment itself more precise/sensitive. If the Ho is rejected then at least one mean is significantly different from at aleast one other one. However, the limitation of the F-test is that it does not locate the specific difference(s) among the treatments.*

### *FOUR BASIC ASSUMPTIONS UNDERLYING ANOVA*

1. *Error terms are randomly, independently and normally distributed*
2. *Variances of different samples are homogenous i.e. they must not deviate from each other.*
3. *Variances and means of different samples are not correlated*
4. *The mean effects are additive (non-addivitivity results in heterogeneity of errors)*

### *Specific comparisons*

1. *between pairs of treatments*
2. *between 2 groups of treatments*
3. *tend comparisons*

*1. The first comparison is the simplest and most commonly used*

*2. The second comparison involves classifying the treatments into meaningful groups. A group may consist of one or more treatments and comparisons is made between aggregate means e.g. fertilized plots vs control; exotic varieties vs local varieties.*

*1 and 2 can be applied to any set of treatments.*

*3. The third comparison is limited to only treatments that are quantitative e.g fertilizer rates, distances of planting*

*The two basic procedures for testing the differences between treatment means are the least significant difference method (Lsd) and duncan's Multiple Range Test (DMRT).*

***LSD Method***

*This is the most commonly used and misused method of mean sesapartion. LSD is the most effective or valid test when there are only two means. The precision decreases as the number of means of treatments increases.*

**Rules for effective use of Lsd test**

a. *Use the lsd test only when the F test in the ANOVA is significant.*
b. *Do not use the lsd when the possible pairs of means in the experiment exceeds five*
c. *Use the lad for pre-planned comparisons even if the treatments are more than 5*

*To determine whether a difference between the treatments means is statistically significant, compare the observed difference with the computed lsd value. If the observed difference is larger than than the lsd value, the two treatment means are significantly different at alpha level of significance. If the difference between any pair of means is smaller than the lsd value, the two treatments are not significantly different.*

**Limitations of lsd test**

a. *Lsd assumes that the error is homogenous*
b. *It is often used to make many unplanned comparisons*
c. *It is not satisfying for all possible paired compatisons*

***Duncan's Multiple Range Test (DMRT)***

*DMRT was developed to alleviate the deficiencies of lsd. It is identical to lsd for adjacent means, but requires progressive higher values necessary for comparison. The use of DMRT should be limited to very specific situations where no prior knowledge is available about the performance of the treatments e.g selection of new varieties being compared*

***Advantages of DMRT***

a. *It takes into consideration the number of treatments*
b. *It permits decisions as to which differences are significant and which are not*
c. *F-test does not need to be significant before one can proceed*

d. *It uses a set of significant ranges, each range depending upon the number of means in that comparison*

***OUTLIER TEST***

*Outlier is the term used to denote the results of a replication which deviates greatly from the mean of all other replications of a specific treatment. They have an adverse and undesirable effect on trial results. They may be due to errors in plot measuring, tillage, application of the treatments, damage to plants during hoeing or by animals, robbery, mistakes in calculation e.t.c*

*N-fertilizer trial with 4 replicates*

*Yield: 31, 24, 8 and 25 kg/ha*

*SD of the 3 other means should be calculated and it must be determined if the SD of the presumed outlier is >4 times this SD*

$\frac{31+24+25}{3} = 26.7\ (\bar{x})$

$SD = \frac{(31-26.7)^2+(24-26.7)^2+(25-26.7)^2}{3-1} = 3.8$

*SD outlier = 8-26.7= 18.7*

*Since 18.7 is 4 times > 3.8, it is a true outlier*

***Coefficient of variation (CV)***

*When analyzing the trial, the magnitude of the experimental error permits us to assess the precision with which the trial has been conducted.*

*CV is the SD expressed as a percentage of the mean. It is a measure of the degree of repeatability of an experiment. It is said to be low of high in relation to a reference point.*

$CV = \frac{SD}{Mean} \times 100, \%$

*In field experiment, the CV should not exceed 10 -15%, otherwise it can be assumed that the trial has not been carried out satisfactorily. The results can only be used if reasons are stated in the Results and discussions Sections.*

**MEASURE OF LOCATION**

Mean is also known as average. For example the mean of 4, 5 6, 7 and 3 is 25/5 = 25. For a large data set, we normally make use of frequency distribution.

Example 1. Mean of a frequency distribution

| Variable (x) | Frequency (f) | (xf) |
|---|---|---|
| 4 | 2 | 8 |
| 5 | 1 | 5 |
| 6 | 3 | 18 |
| 7 | 4 | 28 |
| 8 | 1 | 8 |
| 9 | 1 | 9 |
| | **12** | **76** |

Mean = $\frac{\Sigma xf}{\Sigma f} = \frac{76}{12} = 6.33$

Mode = 7 because it is the number with the highest frequency

**Types of mean**

***a) Arithmetic mean*** = $\frac{\textit{sum of all variable}}{\textit{number of variable}}$ = $\frac{\Sigma x}{n} = \frac{\Sigma x}{\Sigma f}$

=

***b) Geometric mean***

The geometric mean of 2 numbers is the square root of their products e.g. geometric mean of 4 & 5 = $\sqrt{4} \times \sqrt{5} = \sqrt{20}$

For three numbers 2, 3, 4, it is the cube root.

Geometric mean = $\sqrt[3]{2 \times 3 \times 4} = 2.884$

= $\sqrt[3]{24} = (24)^{1/3}$ = 24 shift [$x^y$] [3] [=] 2.884

:. Geometric mean of 1, 2, 3, 4, 5 = $\sqrt[5]{120} = 2.605$

***c) Harmonic mean***

*This is the reciprocal of arithmetic mean of sum of reciprocals.*

*Consider 5 numbers 1, 2, 3, 4, 5*

*Sum reciprocals* $= \frac{1}{1} + \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \frac{1}{5}$

$= 1 + 0.5 + 0.333 + 0.25 + 0.2 = 2.28$

*Arithmetic mean of sums (am)*

= *1/5 of 2.28*

= *0.456*

*Reciprocal of arithmetic mean* $= \frac{1}{0.456} = 2.19$

Please note very well that harmonic mean is lower in value than the geometric mean.

Median: This is the number (or numbers) in the middle of a set of data after re-arranging the set of figures in ascending or descending order, or in the order of magnitude.

Example: 5, 6, 4, 7, 6, 6, 7, 8, 7, 7, 9, 4 can be re-arranged as 4, 4, 5, 6, 6, 6, 7, 7, 7, 7, 8, 9

Median = $= \frac{6+7}{2} = 6.5$

**Median of a large population**

When the number of measurements (N) is large i.e we have a large population, median of that population is taken as ½N$^{th}$ measurement. i.e.

Median may be defined as the 50$^{th}$ percentile, with half of the population above and the other half below it. Median divides the area of a histogram into two equal parts.

**PERCENTILES**

From the cumulative frequency graph (Ogive) given, 50$^{th}$ percentile correlates with cumulative frequency of ½ x 108 = 54

The Ogive gives the number of plots per plant that is not more than 14

Therefore the 50$^{th}$ percentile = 14 which is about the **median**

75$^{th}$ percentile = 81 ≈ ¾ of 109 of Ogive

The number that corresponds to this is 17 if you trace the ogive vertically down

75$^{th}$ percentile = ¾ (N + 1)$^{th}$ number

25$^{th}$ percentile = ¼ (N + 1)$^{th}$ number

**RELATIONSHIP BETWEEN MEAN, MEDIAN AND MODE**

Mean - mode = 3 (mean – median) ( 1 )

Mean – mode = 3mean – 3 medain ( 2 )

- mode = 2 mean – 3 median ( 3 )

:. Mode = 3 medain -2 mean ( 4 )

**Example 2**

| Weight (kg) (x) | Freq (f) | xf |
|---|---|---|
| 73 | 1 | 73 |
| 72 | 2 | 144 |
| 71 | 3 | 213 |
| 70 | 2 | 140 |
| 69 | 4 | 276 |
| **Total** | **12** | **876** |
| | ∑f | ∑xf |

Mean = $\frac{\Sigma xf}{\Sigma f} = \frac{846}{12} = 70.5kg$

Median = (71 + 70)/2 = 71.5 kg because we have 69, 69, 69, 69, 70, 70. 71, 71, 71, 72, 72 and 73

Mode = 69 kg because it has the highest frequency

**Example 3** Mean using a variable as origin

| (x) | (deviation) | f | xf |
|---|---|---|---|
| 73 – 70 | 3 | 1 | 3 |
| 72 – 70 | 2 | 2 | 4 |
| 71 – 70 | 1 | 3 | 3 |
| 70 – 70 | 0 | 2 | 0 |
| 70 – 69 | -1 | 4 | -4 |

Mean weight = $70 + \frac{\Sigma fx}{\Sigma f}$

$= 70 + \frac{6}{12} = 70 + 0.5 = 70.5kg$ as in Example 2

**Example 4**

| Number of insects | Freq | Deviation 15 as origin | (fx) |
|---|---|---|---|
| 8 | 1 | -7 | -7 |
| 9 | 1 | -6 | -6 |
| 10 | 2 | -5 | -10 |
| 11 | 5 | -4 | -20 |
| 12 | 9 | -3 | -27 |
| 13 | 15 | -2 | -30 |
| 14 | 19 | -1 | -19 |
| 15 | 20 | 0 | 0 |
| 16 | 16 | 1 | 16 |
| 17 | 10 | 2 | 20 |
| 18 | 5 | 3 | 15 |
| 19 | 3 | 4 | 12 |
| 20 | 1 | 5 | 5 |
| 21 | 0 | 6 | 0 |
| 22 | 1 | 7 | 7 |
| Total | **108** | | **75** |

Mean $= 15 + \left[\frac{\Sigma fx}{\Sigma f}\right] = 15 + \left[\frac{75-119}{108}\right] = 15\left[\frac{-44}{108}\right] = 15 - 0.4 = 14.6$

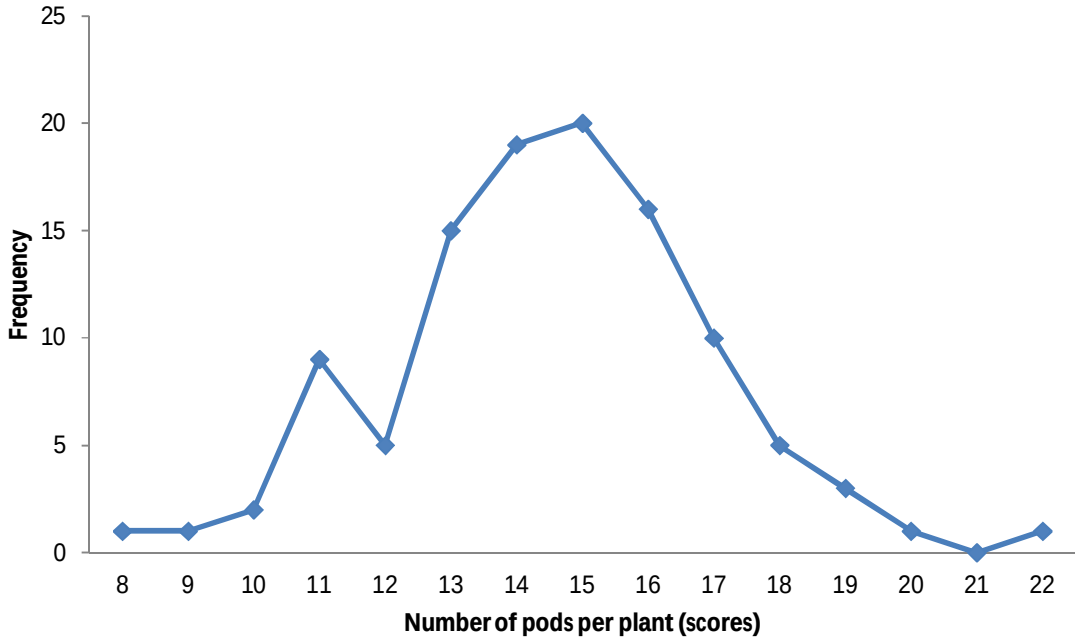
**QUESTION 1** Try the above using 14 as origin

Table 1. A frequency distribution table

| Number of pods/plant | | Frequency |
|---|---|---|
| 8 | 𝍸 | 1 |
| 9 | 𝍸 | 1 |
| 10 | 𝍸𝍸 | 2 |

| | | |
|---|---|---|
| 11 | 𝍸 | 5 |
| 12 | 𝍸 𝍸 | 9 |
| 13 | 𝍸 𝍸 𝍸 | 15 |
| 14 | 𝍸 𝍸 𝍸 𝍸 | 19 |
| 15 | 𝍸 𝍸 𝍸 𝍸 | 20 |
| 16 | 𝍸 𝍸 𝍸 𝍸 | 16 |
| 17 | 𝍸 𝍸 | 10 |
| 18 | 𝍸 | 5 |
| 19 | 𝍸 | 3 |
| 20 | 𝍸 | 1 |
| 21 | - | 0 |
| 22 | 𝍸 | 1 |
| Total number examined | | 108 |

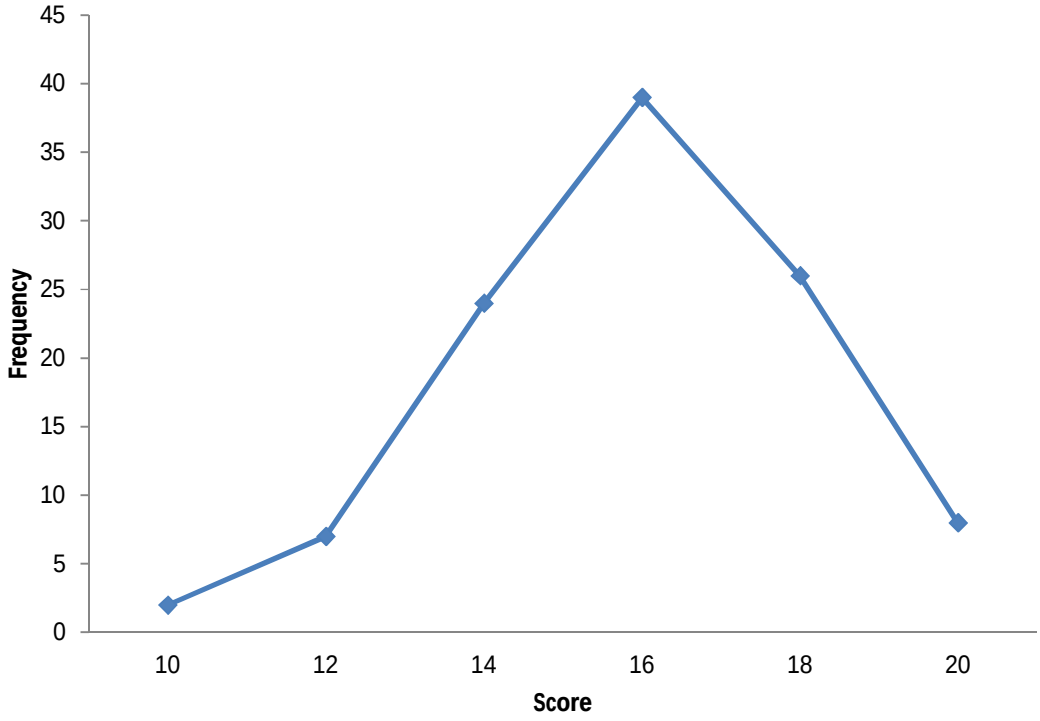
**Frequency polygon**




*(a) Modal group - Equal grouping*

| Under 10 | | Frequency |
|---|---|---|
| 10 – 11 | 𝍸 | 1 |
| 12 – 13 | 𝍸 𝍸 | 1 |
| 14 – 15 | 𝍸 𝍸 𝍸 𝍸 | 2 |
| 16 – 17 | 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 | 5 |
| 18 – 19 | 𝍸 𝍸 𝍸 𝍸 𝍸 | 9 |

| | | |
|---|---|---|
| 20 – 22 | ++++ ++ | 15 |

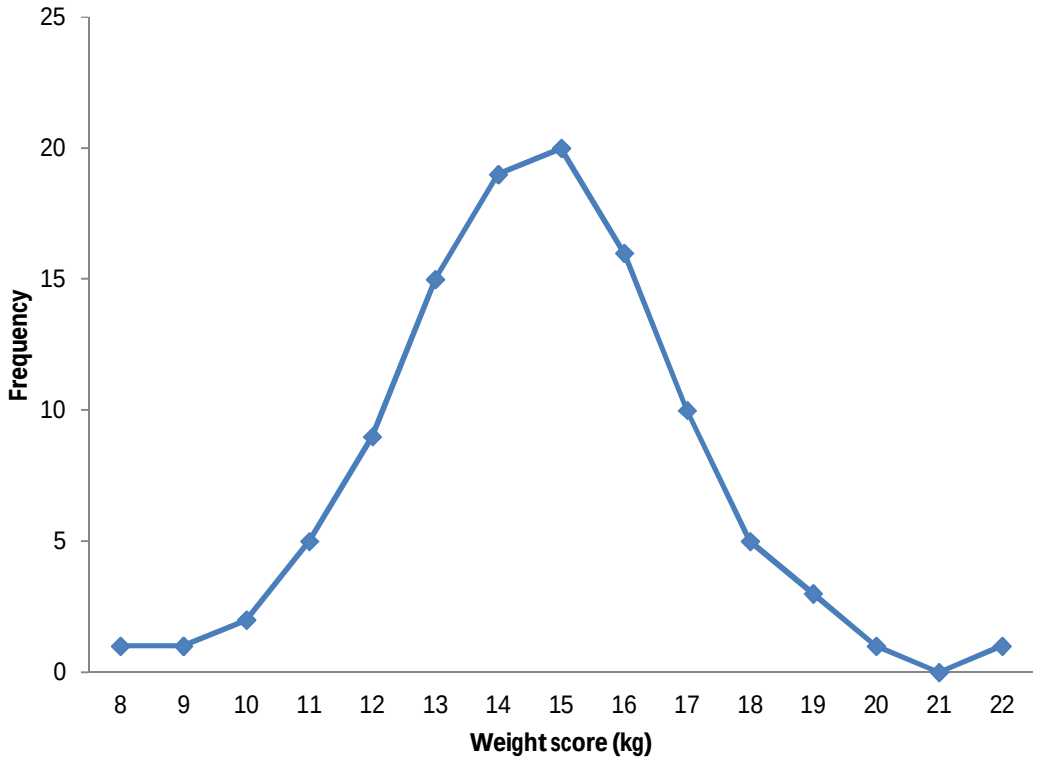



| Unequal grouping | Frequency |
|---|---|
| Under 10 | 2 |
| 10 - 11 | 7 |
| 12 – 14 | 43 |
| 15 – 17 | 46 |
| 18 – 20 | 9 |
| 21 - 22 | 1 |
| | 108 |

Modal group = 15 - 17

**HISTOGRAM OF WEIGHT DISTRIBUTION**

| Weight score (kg) | Frequency |
|---|---|
| 8 | 1 |
| 9 | 1 |
| 10 | 2 |
| 11 | 5 |
| 12 | 9 |
| 13 | 15 |
| 14 | 19 |
| 15 | 20 |
| 16 | 16 |
| 17 | 10 |
| 18 | 5 |
| 19 | 3 |
| 20 | 1 |
| 21 | 0 |
| 22 | 1 |



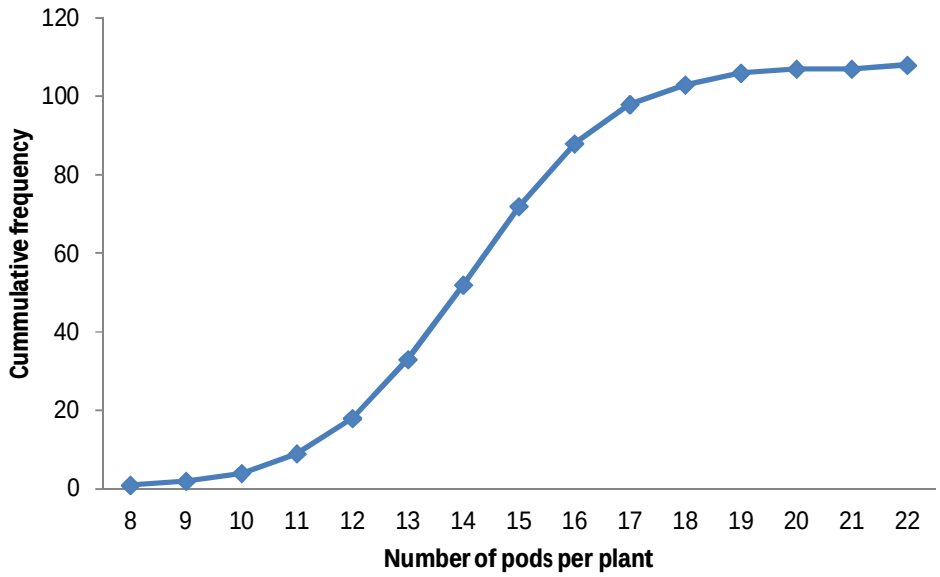

**CUMULATIVE FREQUENCY DISTRIBUTION OF NUMBER OF PODS PER PLANT**

| Number of pods per plant | Frequency | Cumulative frequency |
|---|---|---|
| 8 | 1 | 1 |

| | | |
|---|---|---|
| 10 | 2 | 4 |
| 11 | 5 | 9 |
| 12 | 9 | 18 |
| 13 | 15 | 33 |
| 14 | 19 | 52 |
| 15 | 20 | 72 |
| 16 | 16 | 88 |
| 17 | 10 | 98 |
| 18 | 5 | 103 |
| 19 | 3 | 106 |
| 20 | 1 | 107 |
| 21 | 0 | 107 |
| 22 | 1 | 108 |
| | 108 | |

**THE CUMULATIVE FREQUENCY GRAPH**

The cumulative frequency graph is also called "Ogive" It is a graphical way of representing the frequency distribution.




**MEASURE OF DISPERSION**

The various statistics used for the measurement of dispersion or spread are variance.

Standard deviation

Variance of the mean

Standard error of the mean

Coefficient of variability

( a ) The sample variance ($S^2$) is given as $S^2 = \frac{\left[\Sigma x^2 - \frac{\Sigma x^2}{n}\right]}{n-1}$

Where

$(\Sigma x^2)$ = Sum of squares of variable x obtained by squaring each variable

$(\Sigma x)^2$ = Square of sum of variable x

n = number of variables

$\frac{(\Sigma x)^2}{n}$ is called the correlation term

Let us consider the following six variables 5.0, 5.5, 7.0, 8.0, 10.0, & 2.5

Where n = 6

| Variable | $x^2$ |
|---|---|
| 5.0 | 25.0 |
| 5.5 | 30.25 |
| 7.0 | 49.0 |
| 8.0 | 64.0 |
| 10.0 | 100.0 |
| 2.5 | 6.25 |
| **Sum ∑38.0** | **274.5** |

$\Sigma x^2$ = 274.5

$\Sigma x$ = 38.0

:. $(\Sigma x)^2$ = $(38.0)^2$ = 1444

$(\Sigma x)^2)/n$ = 1444/6 = 240.67

Variance ($S^2$) = $\frac{\Sigma x^2 - \left(\frac{\Sigma x)^2}{n}\right)}{n-1}$

= $(274.5 - 240.67)/5$

= $33.83/5$ = 6.77

(b) Standard deviation is the square root of variance i.e. the square root of variance gives standard deviation.

*Square root of* $S^2 = \sqrt{S^2} = S$

*∴ Standard deviation* $S = \sqrt{S^2}$

*From the example above* $S = \sqrt{6.77} = 2.60$

*(c) Mean of the samples* ($\bar{x}$) *is*

*given as* $(\bar{x}) = \frac{\Sigma x}{n} = \frac{38}{6} = 6.33$

Coefficient of variability (CV) = $\frac{\text{Standard deviation}}{6.33} = 2.60/6.33 = 0.410$

Expressed as a percentage CV = 0.41 x 100 = 41.0%

(d) Variance of the mean ( $S^2\bar{x}$) is given as variance divided by the number of variables

n = 6

$S^2\bar{x} = S^2/n$

$= 6.77/6 = 1.128$

(e) Standard error of the mean simply called standard error is the square root of the variance of the mean

Standard error = √variance of the mean

$= \sqrt{S^2} = \frac{\sqrt{S^2}}{n} = \sqrt{1.128} = 1.062$

Note that Standard error = $\sqrt{\frac{S^2}{n}} = \frac{S}{\sqrt{n}} = \overline{Sx}$

Where S = Standard deviation

## TEST OF HYPOTHESIS

An hypothesis is an assumption about a parameter or population which may or may not be true.

Type of Hypothesis

1. *Null hypothesis* ($H_O$)
2. *Alternative hypothesis (Ha)*

Ho is the hypothesis to be tested for acceptance or rejection depending on the result of an experiment. It usually contains an equality statement or sign so that a confidence interval can be constructed around the parameter e.g.

Mean value of the two soil samples ($\mu_1$ & $\mu_2$) are the same or similar

Ho : $\mu_1 = \mu_2$ means are equal soils are similar.

Ha is the hypothesis taken as true when the Ho is false.

Ha : $\mu_1 \neq \mu_2$ means are not equal soils are not similar

Where there are more than two means we say

Ho : $\mu1 = \mu2 = \mu3 = \mu4$ …….

In the alternative.

Ha : $\mu1, \neq \mu2 \neq \mu3 \neq \mu4$

**Test Statistics**

- *The basis for any scientific experimentation is to set up a hypothesis – the Null hypothesis and when the null hypothesis is disputed, we accept the alternative hypothesis.*
- *However, the rejection or acceptance of any hypothesis must be done on an objective and rational basis and not what we think about the outcome of our investigation.*
- *Therefore, the use of appropriate test statistic will provide the rational and objective acceptance or rejection of hypothesis under various circumstances. It is very important to note that each test statistic is based on certain assumptions rather than the mathematic calculations.*
- *The assumptions must be known and fulfilled because any conclusions based on the test results will be meaningless if the assumptions are not fulfilled.*

The most useful and commonly used test statistics for testing hypothesis are

1. *The t test, which compares the means of two samples and tests the null hypothesis that the two means are the same*
2. *The (Chi square) $X^2$ test, which compares how well some data fit a model or an idea situation you already have.*

3. *The F-test, which compares the variances or standard deviations of two samples to see if they come from the same population.*
4. *Correlation coefficient, which measures the association between two variables.*

Before we go into specific examples of the above, let us see what we understand by the following term.

**Significant Levels**

- *Each of any of the test statistics above has the percentage point (probability) at which the null hypothesis can be accepted or rejected i.e. 20%, 10%, 5%, 1%, and so on.*
- *The use of the probability level will allow us to know how likely it is that we would have obtained our results, if the null hypothesis is true.*
- *The point at which we reject the null hypothesis has to be decided on the basis of the penalties for being wrong. The question is "What is the penalty for rejecting the null hypothesis when we should have accepted it?, or the penalty of accepting when we should have rejected? This decision on the percentage point or the significant level is very important.*

In agricultural and biological experiments, 5% is normally taken as the significant level.

If the chance (probability) of getting results that are different from those predicted by null hypothesis is greater than 5% ($P > 0.05$), then we say that there is no significant difference between the observed and the predicted and thus, we accept the null hypothesis.

On the other hand, if the chance of getting results is less than 5% ($P < 0.05$), we say that the observed and predicted are significantly different at 5% level and thus, we reject the null hypothesis and accept the alternative hypothesis.

Generally the smaller the probability or chance (say 0.01 or 0.001), the more likely it is that our results are due to some realistic biological phenomena and not due to random chance. The corollary is that the larger the value, the less likely it is that our results are due to a real biological effects and the more likely they are due to chance

| **P Value** | **0.20** | **0.10** | **0.05** | **0.01** | **0.001** |
|---|---|---|---|---|---|
| Accepting the Null hypothesis | | | Rejecting the null hypothesis | | |
| P > 0.05 | | | P < 0.05 | P < 0.01 | P< 0.001 |
| Not quite significant (Lack of Confidence) | | | Significant | Highly significant | Very highly significant |
| Repeat of experiment may be necessary | | | Fairly confident | Very confident | Almost certain |

**The Student's t test**

The test is not particularly reserved for students. If was first developed by William Gosset in 1908 who at that time was not allowed by his employer (Guinness) to publish under his own name. He therefore referred to himself as "Student"

The t test is used to compare the means of two samples or sets of data to see whether they come from the same population or not. The null hypothesis is that the two means come from the population and that any difference between them is due to sampling error or chance.

The assumptions of a t test are

1. *The populations from which samples are taken are normally distributed.*
2. *The samples have similar standard deviations.*
3. *The samples were collected independently.*

The test statistic is given as $t = \frac{(\bar{x}_1 - \bar{x}_2)}{S\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}} = \frac{(\bar{x}_1 - \bar{x}_2)}{S\bar{x}}$

$x_1$ and $x_2$ are the two means

S is standard deviation of the population

$S\bar{x}$ is called standard error.

$n_1$ and $n_2$ are the number of observations

thus, $sx = \frac{\sqrt{S^2}}{n} = \frac{S}{\sqrt{n}}$

The t test is very robust because the conclusions based on it has some level of validity even if the assumptions on which it is based are not completely fulfilled.

t test can be used in a number of ways

1. *To compare two sample means as above*
2. *To compare a sample means with a standard when the mean and variance of the population are known.*

**Example 1**

The mean yield of maize in Nigeria is 5 ton\ha (a standard). However, a new maize variety with a yield of 7.6 tons\ha is introduced.

Test if the two means are similar or not.

$H_0 : \mu_1 = \mu_2$ i.e. $5.0 = 7.6$

$Ha : \mu_1 \neq \mu_2$ i.e. $5.0 \neq 7.6$

Assuming that the mean yield of the improved variety is obtained from 64 samples i.e n = 64 with 6.77 as variance

$$t = \frac{\bar{x} - \mu}{S\bar{x}}$$

s = Standard deviation

n = Number if observation

$x$ = *Mean of new (improved) variety = 7,6 kg/ha*

$\mu$ = *Standard mean = 5.0 kg/ha*

$S\bar{x}$ = *Standard error* = $\frac{\sqrt{S^2}}{n} = \sqrt{\frac{6.77}{64}} = \sqrt{0.1058}$

t = (7.6 – 5.0)/0.325 = 7.69

Thus, $t_{cal} = 7.69$

Tabulate t value at 63 df = 2.0

Ho : $\mu = \mu$ makes the test a 2-tail test

$\alpha$- level = 0.05/2 = 0.025 and from the above, $t_{cal} > t_{tab}$

We can then conclude that the two means are significantly difference at 5% probability i.e.

Ho $7.60 \neq 5.0$ $(P < 0.05)$

We reject the null hypothesis and conclude that the two means differed significantly.

**Example 2**

Sample vs Standard - When the means and sample variance are not known.

When the samples are given, one can calculate the mean of samples and then the variance of the sample. Then the sample means can be compared with the Standard

$\overline{X}$ yield of cassava = 10 ton/ha (Standard)

Another eight samples 8, 10, 12, 11, 9, 14, 8, 10 are taken

Sample mean = 10.25

Sample variance = 4.21 and n = 8

$$\therefore \quad Sx = \sqrt{\frac{4.21}{8}} = \sqrt{0.527} = 0.725$$

$$t = \frac{x-\mu}{Sx} = \frac{10.25-10.00}{0.725} = 0.344$$

Thus, $t_{cal} = 0.344$

Number of samples (n) = 8 and $\alpha$ – level is 0.05/2 = 0.025

Therefore, $t_{0.025}\, df_7 = 2.365$

Also, $t_{0.05}\, df_7 = 3.97$

$t_{cal} < t_{tabulated}$

Therefore, we accept the null hypothesis and conclude that there is no significant difference between the two means i.e. $P > 0.05$ ($\mu_1 = \mu_2$)

**Example 3**

Expected or standard mean = 10.29

Samples are (x) 8, 10, 7, 6, 9, 10, 8 $\quad \therefore \Sigma x = 58$

Squares ($x^2$) 64, 100, 49, 36, 81, 100, 64 $\quad \therefore \Sigma x^2 = 49.4$

$$\text{Observed Mean } (x) = \frac{\Sigma x}{n} = 8.29$$

$$\text{Variance} = \frac{\left[\Sigma x^2 - \frac{(\Sigma x)^2}{7}\right]}{6} = \frac{494-480.6}{6} = 2.24$$

Standard error = $\sqrt{\frac{\delta^2}{n}} = \frac{\delta}{\sqrt{n}} = (2.24)^{\frac{1}{2}} = 0.566$

t = (10.29 – 8.29)/0.566

= 3.54 = $t_{cal}$

$t_{tabulated}$ = 4.39

Thus at 5% probability level

$T_{cal} < t_{tab}$

We accept the null hypothesis (P> 0.05) and conclude that there is no significant difference between 10.29 and 8.29 i.e $\mu_1 = \mu_2$

**The F tests**

F-tests are tests of variances that make use of the ratio of two variances particularly in the analysis of variance (ANOVA) table to determine whether or not two samples come from the same population.

In some instances, standard deviations, are not necessarily the variances, of the samples are used. Thus, F tests can be used to test if two populations have equal variance. i.e they are used to compare variances.

Usually, the larger the F ratio, the greater is the difference between the means that connect the variances.

Assuming that we want to consider an experiment with seven samples using a t test at 0.05 significant level. There will be just 1 in 20 chances of concluding that the samples come from populations with different means when in fact they do not. It will also mean that we shall have 21 ($7C_2$) different comparisons to be able to decide that the two means from the population differ significantly even though in reality they come from the same population.

Therefore the use of F-tests in the analysis of variance is both safer and more efficient. They are used to test the significance of mean squares of different source of variation in the ANOVA tables. In fact, it is good to make use of t-tests only when the F-tests are significant.

F-tests are based on one-tail tests and the test statistic is given as

$$F = \frac{\delta_1^2}{\delta_2^2}$$

Where $\delta_1^2$ and $\delta_2^2$ are variances or mean squares.

The table below is a typical ANOVA table involving four genotypes of cowpea in four replicates in a given environment.

| Source | df | Mean square | Observed F-ratio | Expected F-ratio |
|---|---|---|---|---|
| Replication | 3 | 2299.25 | 1.43 | 3.86 |
| Genotype | 3 | 11024.18 | 6.87 | 3.86 |
| Error | 9 | 1605.34 | | |
| Total | 15 | | | |

Note that the mean square (MS) is the ratio of Sum of Square (SS) to the degree of freedom (df).

Thus SS = df x MS

Note also that the expected F-ratio was taken at 5% probability level taking cognizance of the df for genotype in the horizontal part of the F table and df of error in the vertical column.

From the ANOVA table one can conclude that there is significant difference among the four cowpea genotypes because the observed F-ratio is larger than the expected. However, there was no effect of replication suggesting that replications were virtually similar.

**The chi-square ($X^2$) test**

($X^2$) is used in agriculture to test whether the observed values in an experiment agree with the expected values in a set of quantitative data.

It is also used to test whether the effect of a set of treatment depends on another effect or factor. When used to test treatment effects, there is need to construct a 2 – way contingency table.

Thus, $X^2 = \frac{\sum (\text{Observed} - \text{Expected})^2}{\text{Expected}}$

**Example 1**

A breeder postulates that the phenotypes of the progeny of a certain di hybrid ratio are 9:3:3:1 in the $F_2$ generations.

Examination of 800 members of the $F_2$ generation revealed that 439, 168, 133 and 60 values were observed for the four phenotypes. He would suspect linkage if the ratio does not agree with 9:3:3:1.

Ho: Observed value = expected value

Ha : Observed value ≠ expected value

Note that n = 4 and thus, number of phenotypes degree of freedom (df) = 3

$X^2_{0.05}$ df 3 = 7.81 from the table

| Phenotype | Expected ratio | Observed Number (O) | Expected number (E) | 0 - E | $(0 - E)^2$ | $(0 - E)^2/E$ |
|---|---|---|---|---|---|---|
| **1** | 9/16 | 439 | 450 | -11 | 121 | 0.27 |
| **2** | 3/16 | 168 | 150 | 18 | 324 | 2.16 |
| **3** | 3/16 | 133 | 150 | -17 | 289 | 1.93 |
| **4** | 1/16 | 60 | 50 | -10 | 100 | 2.00 |
| **∑ (sum)** | **1** | **800** | **800** | | | **6.36** |

$X^2_{cal}$ = $\sum (0 - E)^2/E = 6.36$

$X^2_{cal} < X^2_{tab}$

$X^2_{tab}$ = 7.81

Since the calculated (observed) chi-square value is less than the tabulated or expected value, one can conclude that there is no significant difference between the observed and expected ratio i.e.

$H_O$: Observed = expected ratio is true

There is no linkage as there has been no deviation from the expected ratio.

**Example 2**

| | Observe | Expected | O – E | $(O - E)^2$ | $(O - E)^2/E$ | |
|---|---|---|---|---|---|---|
| 1 | 10 | 15 | 5 | 25 | 5/3 | = 1.666 |
| 2 | 35 | 30 | 5 | 25 | 5/6 | = 0.833 |
| 1 | 15 | 15 | 0 | 0 | 0 | |
| **4** | **60** | **60** | | | | **2.499** |

$X^2ob$ = *2.5*

$X^2_{tab}$ = *5.991*

$X^2ob < X^2_{tab}$

There is no significant difference between the observed $X^2$ and expected $X^2$

We conclude that null hypothesis ($H_o$) is rejected