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Research Methodology: An Agricultural Perception

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Abstract

Research methodology is a combined principle that focuses on 'research' and 'methodology'. The term research was considered a systematic activity directed towards discovery and the development of an organized body of knowledge, whereas methodology was considered a concept that refers to the overall approach taken in a piece of research. This concept was viewed as a scientific procedure for solving various problems related to research objectives and questions. This paper discussed the concept of research methodology from an agricultural perspective as a qualified and supportive profession in an academic environment. The context has provided an advanced explanation of important subjects that focused on solving many simple and complex glitches in agriculture and sciences. The paper maintained that this research was a systematic and theoretical analysis with different scientific methods, different principles, and different applications. From a universal perspective, a logical scientific approach has been developed to help provide an advanced understanding of the general meaning and complex theories involved in the field of research and its scientific methodology. To expand this advanced understanding, different types and classes of research, farming system research (FSR), and theories related to research and experimental designs, steps involved in achieving the best scientific research, research hypotheses, statistical analysis, and research software, are covered. Soil testing techniques have been used as specialized examples to demonstrate the relevance of various laboratory research approaches and to allow researchers to ensure that findings and data information are valid and scientifically accurate.

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INTRODUCTION

Research methodology is a compound word that combines the general meaning of two important words, 'research' and 'methodology'. In agriculture and related sciences, research methodologies include specific research methods, which play key roles in conducting experiments in the areas of mixed cropping, weed control, fertilizer use, crop physiology, irrigation and trials on perennial crops, animal and poultry management, forest and fishery productivity, and soil and environmental analyses.

It is a scientific approach that also employs the use of statistical hypotheses and tests of significance, including a review of correlation studies (linear and quadric), experimental designs, partial and multiple regression analyses, analysis of variance, and descriptive analyses of different kinds (Govindasamy, 2023). Today, research methodology is advancing, as it becomes all-inclusive, inviting many different technologies into it. Computer applications in agriculture and other fields of science (Kumar & Sarkar, 2015; Borrelli et al., 2021), statistical analysis and software applications (Honfo et al., 2019), mobile apps and their procedures (Choudhary et al., 2022), and remote sensing and practical applications (Usman et al., 2020) are becoming increasingly popular research methodologies. Many research objectives have been achieved with the theories and practices of research methodology. This has emphasized the critical need to understand the true meaning of the words ‘research’ and ‘methodology’ in global academic clarifications. This is important because it can help researchers better plan studies by identifying the most suitable approaches and techniques involved in research (Kapoor, 2016; Kothari, 2019; Lau, 2023). At this junction, the two questions that need to be answered are ‘what is research’ and what is ‘methodology’. This paper is logical and based on the different opinions and contributions of several authors to help answer these two important questions. This is in addition to different types of research and research methods in relation to field and laboratory techniques for soil testing and soil data evaluation. The experimental design, statistical hypotheses and software used for the tests of significance are also covered. This section discusses the comprehensive meaning of what research is and how it is important for academic development, economic development and decision-making.

RESEARCH: *CONCEPT AND RATIONAL*

The concept of research is very broad and comprehensive because of its relevance to all areas of study, academically, as well as its original contribution to the existing stock of knowledge in various subjects. Research may be broadly defined as the systematic gathering of data and information and its analysis for the advancement of knowledge in any subject (Kothari, 1985). The term ‘research’ is believed to comprise defining and redefining problems; formulating hypotheses or suggested solutions; collecting, organizing and evaluating data; making deductions and reaching conclusions; and, at last, carefully testing the conclusions to determine whether they fit the formulating hypothesis (Clifford Woody, 1884-1948). This principle has included the manipulation of things, concepts or symbols for the purpose of generalizing to extend, correct or verify knowledge, whether that knowledge aids in the construction of theory or in the practice of an art (Slesinger & Stephenson, 1930). Thus, research can be regarded as an activity that leads us to find new facts and information, assisting us in verifying the available knowledge and in making us, question things that are difficult to understand as per existing data (UOU, 2010).

Waltz & Bausell (1981) considered research to be a systematic, formal, rigorous and precise process employed to gain solutions to problems or to discover and interpret new facts and relationships. John (2005) defines research as a systematic activity directed towards discovery and the development of an organized body of knowledge. Academic researchers are scientific and provide valuable information for knowledge propagation. Gilmor et al. (2023) noted that scientific research aims to answer questions and acquire knowledge concerning natural phenomena and to describe, predict, and explain these natural phenomena.

Through research, specific goals can be achieved by outlining an objective, deciding which discipline to study, and understanding which different lab techniques can produce data for a chosen hypothesis; this is important because the continual growth of knowledge drives development and new advances for a stronger future and better understanding of the global economy, food security, climate change, sustainability and human health development (Gilmor et al., 2023).

Methodology of research: *an overview concept*

Methodology can be defined as a concept that refers to the overall approach taken in a piece of research (Sim & Wright, 2002). It can also be defined as a scientific procedure for solving various problems related to research (Top4u, 2022). This finding indicates that the research methodology is a supportive profession in the academic research environment that focuses on solving many simple and complicated problems in agriculture and sciences. It is the systematic and theoretical analysis of the methods applied to a field of study and comprises the theoretical analysis of the body of methods and principles associated with a branch of knowledge (UOU, 2010). This means that the research methodology employed the use of many research methods and experimental designs, which help researchers, achieve objectives of great value in different fields of study. It has been considered a field of science that guides researchers in conducting studies in both the field and laboratory, both in situ and ex situ based, digital or computer based. Research methodology also consists of theories and practices that help researchers conduct assessments either practically or theoretically, and this has been the result of two major research papers – a review paper and a non review paper. Thus, the scientific method that is adopted for conducting any type of research either in agriculture or any field of science is called methodology (Kothari, 2019). It generally involves the reporting and interpretation of data, as well as guidelines for the detailed application of various methods and collection of results (Norris et al., 2015; Larson-Hall & Plonsky, 2015). The critical study of the methodology adopted in various laboratory and field techniques (Safdar et al., 2016; Lau, 2023) has involved the use of different advanced approaches and procedures, which support soil and plant analyses, animal studies, forest assessments, environmental observations, and medical health care systems (Harris et al., 2006; Kothari, 2019).The research methodology can be understood as a set of specific procedures or techniques used to identify, select, process, and analyse information about a topic (UOU, 2010).

Research: *its basic characteristics*

The characteristics of research determine whether the research is free of biases, partialities, prejudices, favouritism, preferences and subjective errors. They control the purity of the research and make it pure and original. These characteristics can be summarized as follows: (a) generalized (degree to which the result of a study can be applied to a larger population), (b) controlled (measured, defined and precise), (c) rigorous (relevant, appropriate and justified), (d) empirical (experimental, observed and realistic), (e) systematic (organized, efficient and logical), (f) ethical (abided by ethical standards), (g) reliability (repeatability of a study, tool, procedure, or instrument), (h) validity (suitability and efficiency of the research instrument or procedure), (i) hypothesis (assumption and formulation of theories), (j) analytical and accuracy (correctness of instruments, procedures and tools), (k) credibility (trustworthy of all the sources), and (l) critical (scrutiny of the procedures used and the methods employed, foolproof and free from drawbacks) (UOU, 2010; Top4u, 2022).

These wide ranges of research characteristics make the research unique and exceptional. They stand firm to assist and guide the researcher to achieve their set of objectives and purposes. They ensure that the research contributes to global scientific knowledge, economic development, and decision making.

Research on farming systems: ***a theoretical concept***

Farming system research (FSR) is aimed at verifying the technological options for ensuring food security and improving the welfare of a growing population worldwide. SRFs are considered by Upton (1987) to have four main characteristics, which can be described as scientifically focused on (a) farm households recognizing that rural changes and development ultimately depend on rural people whose existing practices are well adapted to environmental constraints and household objectives, (b) specific localities where large differences between these localities exist in the resource base and in the farming systems practiced, (c) holistic systems that are concerned with the whole farming system and its interdependencies rather than with individual elements, and (d) multidisciplinary systems that integrate the perceptions of both the technical and the social sciences to analyse existing systems and to identify options for improvement. A complete depiction of these four main characteristics of FSR is shown in Figure 1. However, four main stages are involved: description and diagnosis, design of improved systems, testing and evaluation of improved systems, and implementation and extension of promising alternatives (Upton, 1987).

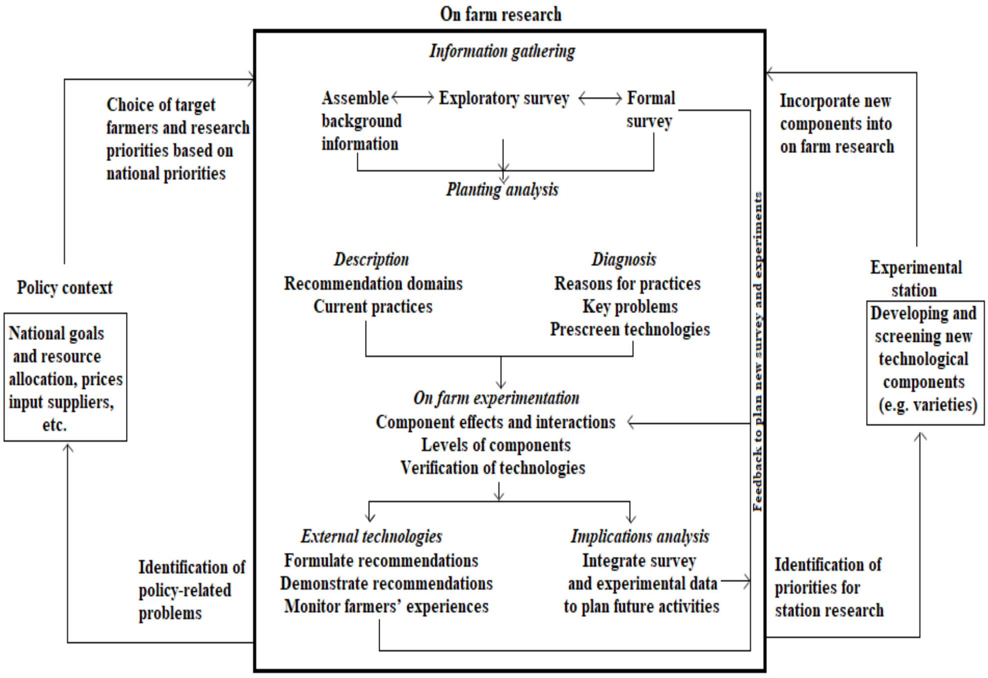

Figure 1. Farming system research cycles (reconstructed by S. Usman after Upton, 1987)

Research methodology: ***various types***

Different established research methodologies can be employed to explore a research problem or to help researchers validate hypotheses through clearly defined parameters, environments and assumptions (Physiopedia, 2023). However, these various types of research can be used for the detailed achievement of farming system research cycles, as depicted in Figure 1.

We described and modified them below based on the combined information obtained from different texts (Hedrick, et al., 1993; UOU, 2010; Kapoor, 2016; Suresh, 2016; Safdar et al., 2016; Kothari, 2019; Lau, 2023).

- ***Descriptive research:*** This research methodology entails conducting surveys and fact-finding investigations across various domains to elucidate the contextual factors pertinent to a specific study. Ex post facto research methodology has been utilized to expand upon this approach in diverse fields such as agriculture, environmental science, and biology. Its defining characteristic lies in the researcher's lack of direct control over variables, thus limiting them to reporting observed or past occurrences within the study. For instance, agricultural studies could be employed to examine the disparities in soil fertility decline and food security threats between the populations of northern Nigeria and north eastern Nigeria. In these two instances, the researcher observed that the soil fertility declined as a result of poor management and lack of good vegetation cover, and the high cost of rice was the result of production scarcity in the region. Researchers could further hypothesize that poor management practices and bare vegetation are the main reasons for the decline in soil fertility. Similarly, he could also hypothesize that production scarcity is a factor in the high cost of rice. The techniques to be employed in these hypotheses can be decided upon by the researcher based on the descriptive nature of these studies. Selection can be made from various techniques available and suitable for the environment where the research is to be conducted.
- ***Analytical research:*** This type of research employs the use of the facts, information and data that are already available and that can be restudied, observed and analysed by the sources to make a further detailed hypothesis for the evaluation of the materials involved. It involved more logical investigation and questioning. This is illustrated by methodological data on rainfall, temperature, and relative humidity, which can be analysed to determine why drought occurs, what factors are responsible for sudden climate change, why flooding increases, etc.
- ***Applied research:*** This type of research refers to finding a solution for a specific and practical problem that is faced by an individual, society or an industrial or business organization. A typical example is how to control erosion or deforestation, what are the most advanced soil and water conservation techniques for irrigation projects, what measures can be used to increase food production, etc. This means that the main aim of applied research is to determine a solution for some critical practical problems.
- ***Fundamental research:*** Fundamental research, also known as *basic research*, is primarily concerned with the summary and formulation of a given research theory. It is a basic type of research that focuses on, for example, whether plant stunting or deformation influences how crop yield decreases or how soil fertility decreases influences how nutrients are limited in soil. This means that fundamental research is management towards finding information that has a wide sense of applications to the already existing organized body of scientific knowledge. It basically takes one of these forms – discovery (finding new explanations or ideas), invention (designing new methods) or reflection (analysing theories, models and techniques).
- ***Quantitative research:*** This type of research is based on quantity, amount, measurement, extent, size and magnitude. It is related to an object that can be expressed in terms of quantity and can be measured. Systematic experimental analysis of something that can be observed and counted through statistical analysis, mathematical calculation or computational techniques, especially in a numerical form, is generally used.

Examples include the measurement of percentage soil texture (sand, silt and clay), the measurement of gully erosion (in cm or m) in terms of width, depth, length or size, the measurement of soil nutrient budgets, the measurement of plant parameters (stem height, leaf size, root depth, etc.), and even the counting of the number and population size of forests and vegetation. Most of these studies can be digitally and computationally measured in more detail.

- ***Qualitative research:*** This type of research is concerned with qualitative and valuable phenomena. It is significantly related to quality, values and variety of something, e.g., the colours of the soils, quality of seeds, and values of rice. These research phenomena are characteristically descriptive and imaginative and, as such, very difficult to assess in terms of quantity. This means that qualitative research is primarily focused on visual assessment of the natural appearances of something in a more descriptive manner. It is not the same as numerical analysis where data can be measured or calculated. Examples include the classification of vegetation types based on physical and natural appearances and the definition of soil based on its natural colours and morphological properties.
- ***Conceptual research:*** This type of research is related to theoretical and intangible ideas, which can be built as a general concept towards achieving given objectives. Conceptual research is a theory that focuses on perception and philosophy, which can explain a particular concept being studied. It is generally used by logicians, philosophers and theorists, primarily to develop new concepts or to support and back existing theories. Examples include environmental security theory, the soil quality concept, the theory of diminishing returns, the theory of water quality, etc.
- ***Empirical research:*** Empirical research is a type of research that greatly relies on experience, practice, assessment and pragmatics. Research that helps researchers gain more knowledge by means of direct and indirect observation or experience. This means that empirical research skills are built and acquired through regular observations and, as such, can be regarded as an experimental type of research.
- ***Correlation research:*** This type of research defines the relationship among two or more variables without necessarily determining the cause and effect of this relationship. Examples include a correlation between dryland soils and fadama soils, a correlation between drought and rainfall scarcity, and a correlation between soil fertility and crop yields. This type of research helps researchers collect much information on a wide range of variables from different parts for a detailed explanation, although information regarding the causes is very limited.
- ***Ethnographic Research:*** This type of research involves the study of culture, values, religion and norms of people, society or nation. It comprises a systematic narration, collection, description, and detailed analysis of data for the development of theories of cultural behavior in society. This involves the sociological assessment of people's ethnic groups, agricultural values and culture, social welfare characteristics, and customs. In many cases, this type of research is conducted through questionnaires or verbal interviews, observations and descriptive data gathering.
- ***Experimental research:*** Experimental research is a type of research that focuses on the objectives, purposes and systematic of study. It is primarily established to predict and control phenomena. It also includes investigating, scrutinizing, and examining the probability and causality among variables. Example of an explanation of the dependent and independent variables of different soil samples. This type of research is important for determining the main causes and effects of the relationships between these different soil samples, although artificiality, feasibility, and unethical issues may exist.

- ***Exploratory research:*** This type of research is established for a given problem that has not been clearly defined. It basically helps to regulate the best research design, the best data collection method and the best subjects' selection for the research, and it is also quite informal and relies on secondary research. Example?
- ***Generalized research:*** This type of research exists in a situation where a researcher usually divides the identified population into smaller samples depending on the resource availability at the time of the research. This sample is understood to be the appropriate representative of the identified population, so the findings should also apply to the entire population.
- ***Structured research:*** Structured research is usually classified as quantitative research. This is because everything that forms the research process, such as objectives, design, sample, and questions, is predetermined. It is more appropriate to determine the extent of a problem, issue or phenomenon by quantifying the variation, e.g., how many soil samples have a microbial organism or plant biomass?
- ***Unstructured research:*** Unstructured research is usually classified as qualitative research because it allows flexibility in all aspects of the research process. This means that it is more appropriate to explore the nature of a problem, issue, or phenomenon without quantifying it.

Other research types: *environment-based opinions*

Similarly, research can be classified as *in situ* or *ex situ*, field or laboratory, social or scientific, or digital or analogue, depending on the nature, conditions and objectives of the research. Likewise, research can be classified based on a given subject area of study, e.g., soil research, crop research, animal research, forest research, fish research, water quality research, biological research, geological research, criminological research, environmental research, and clinical research. They can also be classified based on resources, e.g., natural resource research, vegetation research, petrochemical research, crude oil research, and gold research. These different types of research are established based on their individual nature and period; for example, field-setting research, laboratory research or classical research can be conducted. In this regard, the research is fully dependent upon the environment where it is decided to be conducted. For example, in soil science research that employs soil surveys (Usman & Usman, 2013; Usman, 2016), the type of research in this regard is fully dependent upon the nature and objectives of one of the following types of survey research: detailed (digital and detailed mapping), reconnaissance (maps based on observations), and detailed-reconnaissance (semi-detailed maps based on traditional procedures and scientific theories) (Usman et al., 2020). The type of research in this survey can be detailed research or descriptive research, which, in any option, has to employ the comprehensive stages and methodologies required (Usman et al., 2020).

However, because these illustrations are limited to various studies conducted in the field of agricultural science, many studies have shown them as an exemplary concept. For instance, for studies published in 2020, significant contributions have been made. Typical examples of these studies include conservation agriculture for regenerating soil health and climate change mitigation (Jat et al., 2023); advancing climate change mitigation in agriculture while meeting global sustainable development goals (Lal, 2020); assessing the impact of climate change on dryland agricultural systems (Ahmed et al., 2022); assessing soil quality for the rehabilitation of salt-affected agro-ecosystems (Basak et al., 2022); advancing soil and water management for dryland areas (Biazin et al., 2023); determining the future of soil, water, and air conservation (Delgado et al., 2020); estimating the global potential of water harvesting from successful case studies (Piemontese et al., 2020); applying big data processing technologies in agriculture (Ayyappan & Gnanasekaren, 2022); sustainable intensification in cropping systems through the inclusion of legumes (Lalotra et al., 2022); setting innovation free in agriculture (Sheldrake, 2021); identifying pesticides in soils and plants (Usman, 2020); and investigating cropping systems in agriculture and their impact on soil health (Yang et al., 2020). These volumes of studies have been achieved through the adaptation of methodologies and procedures/techniques involved in the various types of research highlighted above. A detailed understanding of these procedures or methodologies has helped researchers understand the techniques involved in conducting their various studies. These techniques require specific attention when conducting research (Kothari, 2019).

Research: ***its classification and significance***

The various types of research presented above can be classified further into categories depending on the viewpoint under which the research activity is initiated and conducted (UOU, 2010). This classification grouped them into three categories: (a) application of research study, (b) objectives in undertaking the research, and (c) inquiry mode employed for research. The application of research study comprises the pure, basic, fundamental, applied or decisional types of research. The objectives include descriptive, exploratory, and correlation, among others. The inquiry mode covered both saturated and unsaturated research. Similarly, research can be classified based on its methodology, which includes both quantitative and qualitative research. Additionally, research can be classified according to its nature, such as systematic activity, empirical evidence, logical processes, and control (Top4u, 2022). However, on the basis of the extent of the theory, research can also be classified as theoretical or empirical. Therefore, research has a wide range of significance in the sciences and policy development. According to some studies (e.g., Kapoor, 2016; Kothari, 2019), research plays a significant role in providing vital information for academics, economic development and policies or decision-making. Management in these three areas can be substantially improved in the following ways (Top4u, 2022):

- **Recognizing the potential opportunities and threats:** Research is a tool or an X-ray machine that can help management scan its environment and identify various existing opportunities and problems. This means that it is important for management to be successful in formulating strategies in accordance with these situations to overcome the prevailing problems and exploit the opportunities available to the completes.
- **Assessment of problems and opportunities:** Research allows managers to identify the existing problems and the factors responsible for the problems. It helps them to identify, explore, refine and quantify the opportunities existing in the environment and to set priorities in the case of multiple opportunities.
- **Selection of the best alternative action:** This research can assist managers in selecting the best among the alternative courses of action. This means that through research, various alternatives can be evaluated using specific evaluation criteria set by the researcher.
- Evaluating the course of action: Research allows managers to estimate the extent to which a given activity or project is executed according to the direction. This helps them to identify the potential factors that can affect the execution and control the strategies implemented for this execution.
- **Analysing competition:** This research allows managers to formulate strategies that can help them achieve their targets.

Research: ***step-by-step process***

The general body of research and its components, types and classifications require a step-by-step process to make it unique and scientific (Kapoor, 2016; Kothari, 2019). This step-by-step process is important because of its relevance to research objectives, research questions, methodology, and result interpretation. We described and modified these steps below based on agricultural perspectives, as reviewed in the literature (Upton, 1987; Hedrick et al., 1993; Kapoor, 2016; Kothari, 2019; Gilmor et al., 2023).

- **Selecting the research topic:** Selecting the research topic in agriculture must be related to its major machineries, which include agronomy, animal science, agricultural extension, forestry, fishery and soil science. Any topic to be selected needs to have these major agricultural machinery elements. For example, studies related to soil science should focus on the nature, properties and conditions of soils, such as assessments of soil erosion, soil profile diagnoses, or measurements of soil infiltration rates.
- **Defining the research problem:** Ensuring food security and animal productivity is crucial. Therefore, the agricultural research problem should be defined clearly and precisely because it can serve as a solution to whole-body problems. For example, research that focuses on soil erosion should define all the problems that have contributed to the occurrence of erosion and the methodology to be used for solving them.
- **Objectives of the research:** Identifying the objectives of the research is vital because it prevents the research from going outside the main context for which it was purposely established. When research objectives are outlined, it will be easy for a researcher to know the basic research questions involved and the direction for solving them. This will guide him in selecting appropriate methods and techniques for the research.
- **Literature review:** A review of the related and relevant literature on the topic selected is crucial. This will allow the researcher to examine previous studies that have been conducted in this area. The survey of the studies in the area of the topic selected will equip the researcher to develop excellent research by choosing the best methods to conduct his own assessment. Indeed, a literature review is the backbone of any research.
- **Design of hypothesis:** Identifying the potential variables of the study is the first step in formulating the hypothesis. Designing the theory for the research will help the researcher understand the real meaning of objectives and how research questions can be answered through more detailed analysis.
- **Research design:** The research design will help the researcher determine the necessary tasks to perform at each step of the research. It will guide him in outlining the various methods and techniques required as well as ensuring that these methods and techniques are appropriate for the research.
- **Sample design:** The sample design defines the number of items to be best included in the sample. It will help the researcher determine how the research design should be performed before the data are collected.
- **Data collection:** This step is the backbone of the research data. The results should be collected according to the objectives of the research. The data collected should be the answers to the research questions formulated. This information should be gathered for analysis and detailed discussion and interpretation. Data collection plays a vital role in merging theories with their practical applications in research.

- **Implementation of the research project:** This step ensures the correctness and reliability of the collected data. The use of questionnaires, which are scheduled for collecting factual information in tabular or lists form, is vital. This will allow the researcher to generate more vital information regarding the data collected through either question-and-answer sessions or verbal interviews. The data collected will be coded in this regard for detailed analysis.
- **Data analysis:** This step employed the use of statistical analysis of the data collected. It will guide the researcher to understand the true meaning of the data collected, how relevant it is to the general context of the topic studied, and the true answers to the objectives and questions of the research. Different formats are available for this analysis, and the data can finally be visualized with the help of tables, graphs, charts, etc.
- **Hypothesis testing:** The hypothesis can be tested using certain statistical calculations to check the accuracy of the data and results. In this regard, a hypothesis is said to be accurate if it shows the true differences and does not contain an error or fault.
- **Result interpretation and discussion:** General discussion can be made from the data analysed and hypothesized. The research should be able to explain all aspects of the results and relate them to the context of previous and present literature. He will be able to generate the real meaning of the study and explain what exactly observed.
- **Research report:** This step is the final step and involves the preparation of the overall report, which can be published or printed as a reference for decision-making, forthcoming research, academic records, and teaching purposes.

VARIOUS LABORATORY TECHNIQUES: *A WAY FORWARD*

Research, as a scientific tool to study many things (John, 2005) can be carried out using various methods and techniques, which are referred to as 'research methods' or research methodologies (Kothari, 1985). This means that research methods are tools and techniques for analysing and collecting data to solve many problems in academics, economics and decision-making (Top4u, 2022). The types of data collected using the various research techniques are primary and secondary. The primary data are original data that have been collected specifically for the purpose in mind, whereas the secondary data are collected by anyone other than the user (UOU, 2010). Thus, understanding various techniques involved in research would allow the researcher to ensure that findings and data information are valid and, inevitably, troubleshoot when results are not obtained (Gilmor et al., 2023). Laboratory techniques are the backbone of evaluating soil and plant nutrients, biological phenomena, and microbes (Gilmor et al., 2023). The laboratory techniques also include the use of chromatography (liquid chromatography, gas chromatography, or high-performance liquid chromatography) for separation purposes and a spectroscopic technique (UV–visible spectroscopy, NMR, or MS) for detection (Shafi & Zahoor, 2021). These techniques provide us with new opportunities to access natural products in a metabolic context and serve as potential untouched goldmines for future herbal-based medicine and pharmacologically active compounds (Shafi & Zahoor, 2021).

Many modern laboratory techniques have been developed and used for different research. There are significant developments in the fields of agriculture, health, and computer sciences. For example, in the field of animal science, Bellairs & Osmond (2014) reported the use of modern laboratory techniques with chick embryos, including 'milking' of hens to obtain cleavage stages by inducing early laying, incubation procedures, traditional and modern labelling techniques that are particularly useful in gastrulation studies, ex-plantation of the blastoderm, whole embryo culture methods, *in ovo* techniques, grafting of tissues, injection methods, the preparation of serial sections and the handling of early stages during the preparation of embryos for electron microscopy. These methods have provided advanced procedures in poultry and animal production for a wide range of economic development. In human health science, Kalaitzopoulos et al. (2016) noted that advanced laboratory techniques and progress in clinical diagnosis technologies have led to an unprecedented increase in the real-time production of data that are large in terms of volume (large amount), variety (different types/sources), velocity (massive output), variability (high inconsistencies), veracity (great range of qualities), and complexity (substantial interconnections). This has also led to automated genome sequencers becoming less expensive in such a way that even small labs can turn into generators of big data on their own since these data sets are generated at high velocities where data are captured, analysed, and shared (Kalaitzopoulos et al., 2016). These advancements in generating various data from the laboratory have also occurred in the field of soil science, where big data for physical, chemical and biological soil properties are captured and shared for soil and water conservation, irrigation, plant health and protection, and yield performance (FAO, 2020). This is quite true for most laboratory studies, such as biomedical analysis, plant analysis and biophysical analysis. To this end, it is important to demonstrate some of the advanced laboratory techniques applicable to agriculture and its major components, especially soil and crop science.

Soil testing techniques: *specialized examples*

This collection of soil testing techniques is part of a global farmer-to-farmer training initiative and student–student practical analyses, which aim to increase the knowledge of farmers across the world on soils through training (FAO, 2020). There are two-way rounds that are more or less related to rapid and laboratory analysis. According to the FAO (2020), analytical work in a soil testing laboratory mainly involves standard chemical methods that are suitably modified to permit the handling of a large number of soil samples with the required degree of accuracy and speed, many of which are carried out more conveniently with the help of common and more sophisticated instruments. On the other hand, rapid soil-testing kits, which are critical to soil health - a theoretical concept of on-farm soil testing - has been developed to simplify the analysis of soil physical, chemical and biological parameters in the field (FAO, 2020). This concept employed the use of the Soil Doctors Toolkit and Soil Testing Kit (STK) (FAO, 2020), Soil Colour Charts (Munsell, 1975), Field Book for Describing and Sampling Soils (USDA-NRCS, 2002), Keys to Soil Taxonomy(Soil Survey Staff, 2010), Visual Soil Assessment: a Field Guide (Shepherd et al., 2008), Guidelines for Soil Descriptions (FAO, 2006), Practical Pedology: Studying Soils in Field (McRae, 1988), and Soil Quality Test Kit Guide (USDA, 2001). These sets of soil testing kits and guidelines for soil descriptions in the field contain some equipment (e.g., measuring tape, pH kits, chemical kits, soil augers, shovels, poles, etc.) and resource information that is commonly used to take a deeper look at soils in the field (FAO, 2020).

Many methods have been considered for the assessment and analyses of soil physical, chemical and biological properties in the field (USDA, 2001; McKenzie et al., 2002; Rodrigues de Lima & Brussaard, 2010; Mylavarapu et al., 2020). These include the following as highlighted by FAO (2020):

- ***Physical property methods:*** These methods include the Feel method, Ribbon method, and Shaking test method for ‘Soil texture’; the Core method, Excavation method and Clod method for ‘Bulk density’; the gravimetric water content method, volumetric water content method, Feel and appearance method, and soil moisture determination by tensiometry for ‘Soil moisture’.

- ***Chemical property methods:*** These methods include the soil pH meter method, color card methods, soil pH test strips, and Vinegar and baking soda tests for soil pH; electrical conductivity, electrical conductivity using a saturated paste, electrical conductivity using the 1:1 ratio method, the presence of sulfates and chlorides, and field symptoms (visual symptoms of soil salinity) for soil salinity.
- ***Biological property methods:*** These methods include the earthworm density method, litter decomposition (tea bag method), active/labile carbon method, and soil respiration (soda lime) method.

However, laboratory techniques, which are largely based on diverse assessments of physical, biological, and chemical properties, employ the use of advanced instruments that, in many cases, use reagents and electrical light spectra for the detection of a particular nutrient or property (King et al., 2003; Robards & Ryan, 2022). The different soil laboratory instruments used were manufactured by Hoskin Scientific Ltd. (2013) and ICAR-DCR (2017). Typical examples of some of these instruments being applicable to most of the soil science laboratories in Africa are explained below.

- ***UV–Visible Spectrophotometer (Double beam):*** This instrument is used to measure P, Mo, and B in soil, plants, water, manure, fertilizers, and pesticides. It is also used for qualitative and quantitative DNA, RNA, and protein analyses. The instrument has third-dimensional spectrum utility for sample analysis and possesses various operational modes, such as standard, photometric, spectral, quantitative, kinetic, time scan, DNA and protein quantitation, in standalone and PC modes.
- ***Microwave digestion system:*** This instrument is used for the digestion of various materials in soil, plant, manure, sediment, food, and rock samples. The microwave power rating was 1900 Watts, and the cavity size was 70 litres.
- ***Refrigerated centrifuge:*** This instrument is used for isolating and separating suspensions and immiscible liquids. It is also used for DNA preparation and macromolecular separation. It can be used simultaneously for the removal of unwanted debris to make a clear solution for analytical use in spectrophotometers, HPLC, and GLC.
- ***Water distillation system:*** This instrument has two forms of applications: single and double. The two applications served the same purpose: the preparation of distilled water.
- ***Top loading precision balance:*** This instrument is used for accurately weighing soil samples and chemicals.
- ***pH meter:*** This instrument is used to measure soil pH and reagents.
- ***Digital conductivity meter:*** This instrument is used for measuring electrical conductivity and salt concentration in soil and solution.
- ***Water bath shaker:*** This was used for shaking and mixing the soil sample at the desired temperature.
- ***A magnetic stirrer with a hot plate*** was used to mix reagents with the help of a stirring bar, and heating was used to increase the solubility.
- ***Rectangular plate with a thermostat:*** This thermostat is used to heat chemicals, solution, and media.
- ***air oven:*** This instrument is used for drying plant samples, estimating soil moisture, and frying glassware and plastic waste.
- ***A vortex mixer:*** This was used to mix the samples quickly in the test tube.
- ***Labline Centrifuge:*** This instrument served the same purpose as a Hot plate rectangular with a thermostat, i.e., to heat chemicals, solution and media.

- ***DK 20 Digestor (plant sample digestion system):*** This instrument is used for the digestion of plant samples for elemental analysis and the digestion of soil samples for total nutrient analysis.
- ***The nitrogen analyser*** and refrigerated water-cooling circulation system was used to estimate the different forms of nitrogen in the soil and the nitrogen and protein contents in the plants.
- ***Horizontal Rotary Shaker:*** This instrument is used for shaking soil, plant samples and chemicals. It is closely related to the use of a water bath shaker.
- ***BOD Incubator:*** This indicator is used for the estimation of biological oxygen demand.
- ***Microwave oven:*** This oven is used for media preparation and reheating.
- ***Laminar air flow chamber:*** This chamber is used for providing contamination-free areas for microbiological studies.
- ***UV face shield:*** This shield is used for eye protection and safe operation under radiation.
- ***A colony counter (Digital)*** was used for counting the colonies.
- ***Microscope:*** This instrument is used for normal visualization of soil particles and soil organisms.
- ***Soil Gas Lance:*** This instrument is used for extracting soil gas from unsaturated soils. It has a semi-permeable hydrophobic membrane that is permeable only for gas and not for solution; thus, it has the functional power of not picking even moisture from the soil.

The detailed context of the general procedures and step-by-step analysis of physical, chemical and biological soil properties, using the above soil instruments in the laboratory, can be accessed from various soil laboratory manuals, such as Determination of total, organic, and available forms of phosphorus in soils by Bray & Kurtz (1945); Techniques for measuring soil physical properties by Archer & Marks (1977); Methods of soil analysis by Klute & Page (1982); Total carbon, organic carbon and organic carbon by Nelson and Sommers (1982); Soil plant analysis by Estefan & Rashid (2002); Soil Science Laboratory Manual by King et al. (2003); Determination of soil nutrients (NPK) using optical methods by Revati et al. (2021); Planar chromatography: Principles and Practice of Modern Chromatographic Methods by Robards et al. (2022); etc.

EXPERIMENTAL DESIGN AND HYPOTHESIS

Experimental/research design can be defined as the conceptual structure within which research is conducted, and its function is to provide for the collection of relevant information with the smallest possible input in terms of effort, time, and money (UOU, 2010). However, in the book Statistical Procedures for Agricultural Research by Gomez & Gomez (1984), the statistical hypothesis and experimental design are explained in a much harmonized scientific manner. According to these authors, theoretical considerations are vital in playing a major role in arriving at a hypothesis; for example, it can be theoretically shown that a rice crop removes more nitrogen from the soil than is naturally replenished during one growing season. Therefore, in this case, one may hypothesize that to maintain a high level of productivity on any rice farm, supplementary nitrogen must be added to every crop. However, once a hypothesis is framed for possible testing (e.g., Figure 2), the next step is to design a procedure for verification, which usually consists of four phases:

- The appropriate materials for testing were selected.
- Specifying the characters to measure,
- Selecting the procedure to measure those characters, and
- Specifying the procedure to determine whether the measurements made supported the hypothesis.

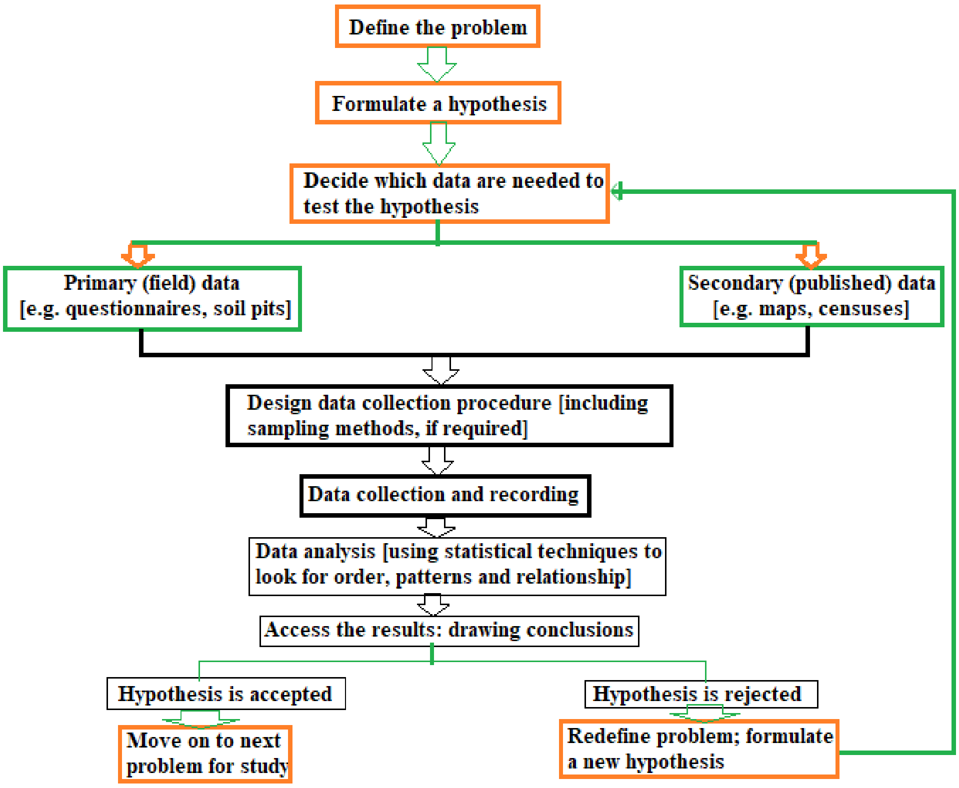

Figure 2. Hypothesis testing (Reconstructed by S. Usman after Waugh, 2000)

On the other hand, the procedures regarding how the measurements are to be made and how these measurements can be used to prove or disprove a hypothesis depend heavily on techniques developed by statisticians. According to Gomez & Gomez (1984), these two tasks constitute much of what is generally termed the design of an experiment, which has three essential components: (a) estimate of error, (b) control of error, and (c) proper interpretation of results. The scale and duration of the design stage depend upon whether appropriate technologies have already been developed and available on the shelf to be taken down and used when needed (Upton, 1987). This means that if this is not the case, then substantial scientific and technical research programs may be required to produce new technology (Upton, 1987). Therefore, the standard error of an experiment may be used either to estimate a confidence interval for the population mean or to test a hypothesis regarding the population mean (Freund, 1979). This error is defined as the difference among experimental plots treated alike and is the primary basis for deciding whether an observed difference is real or just due to chance (Gomez & Gomez, 1984). This clearly means that every experiment must be designed to measure the experimental error. In other words, every sampling method chosen must be free from bias and error. However, in agriculture, three commonly used techniques for controlling experimental error are highlighted: blocking, proper plot technique, and data analysis (Gomez & Gomez, 1984).

According to these authors, error control can be achieved through blocking by putting experimental units that are as similar as possible together in the same group (known as blocks) and by assigning all treatments into each block separately and independently. This blocking design ensures that the variation among blocks is measured and removed from the experimental error. Likewise, a proper plot technique is essential in this regard so that all factors other than those considered treatments can be maintained uniformly for all experimental units (Gomez & Gomez, 1984).

To this end, proper interpretation of the results is important because it is regarded as an important feature of the design of experiments because of its ability to uniformly maintain all environmental factors, which are not a part of the treatments evaluated. This means that maintaining this uniformity is vital to the measurement and reduction of experimental error, which are essential in hypothesis testing. This feature critically limits the applicability of the experimental results and is always considered in the interpretation of results (Gomez & Gomez, 1984). This shows that an experimental design is important because it guides the researcher to identify the correct methods of data collection and analysis, conditions in which the activity of research shall be carried out and approximation of the funds to be utilized for it, maintaining its connectivity to the purpose of research (UOU, 2010). Hence, the design of a sample is identified as a fixed plan or system to enable a researcher to obtain data of smaller sizes from parts of a larger population known as samples and includes the modules, techniques or procedures to be used in identifying the items for the sample (UOU, 2010). In other words, a sample design is used to define the number of items to be included in the sample. Therefore, a good experimental or sample design is expected to be proportional (truly representative of the sample population), free from error and bias, budgeted and generalized.

Experimental design: *one-factor, two-factor and three-factor classifications*

There are scientific advancements that have been detailed in the book Statistical Procedures for Agricultural Research by Gomez & Gomez (1984). This exciting development in the field of agricultural statistics has provided an opportunity for understanding three different classes of experiments, as highlighted below:

a. *One-Factor Experiment:* This class of experiment involves a single factor. According to Gomez & Gomez (1984), these experiments are designed so that only a single factor varies while all others are kept constant. This accounts for the treatments consisting solely of the different levels of the single variable factor, whereas all other factors are applied uniformly to all plots at a single prescribed level. For example, Gomez & Gomez (1984) indicated that most crop variety trials are single-factor experiments in which the single variable factor is variety and the factor levels or treatments are different varieties. Thus, in this context, only the variety planted differed from one experimental plot to another, while all management factors (fertilizer, insect control, and water management) were applied uniformly to all plots.
b. *Two-Factor Experiments:* This class of experiment focuses on a factorial experimental design where two or more variable factors are handled simultaneously. For example, Gomez & Gomez (1984) showed that the response of biological organisms, which are simultaneously exposed to many growth factors during their lifetime, to any single factor may vary with the level of the other factors, and single-factor experiments are often criticized for their narrowness. Thus, when the response to an a factor of interest is expected to differ under different levels of the other factors, a researcher is advised to avoid single-factor experiments and instead consider the use of a factorial experimental designed to handle two or more factors (Gomez & Gomez, 1984).

c. *Three-or-More-Factor Experiments:* This class means that a two-factor experiment can be expanded to include a third factor, and a three-factor experiment can include a fourth factor, depending on the nature and objectives of the research. In this situation, Gomez & Gomez (1984) indicated that two important consequences are related to a rapid increase in the number of treatments to be tested and an increase in the number and type of interaction effects; for example, a three-factor experiment has 4 interaction effects that can be examined, while a four-factor experiment has 10 interaction effects.

Sampling methods: *theoretical examples*

Sampling is a process used in statistical analysis in which a predetermined number of observations are taken from a larger population, and the methodology used to sample from a larger population depends on the type of analysis being performed (UOU, 2010). There are various sampling methods used for FSR. These sampling methods include replication, randomization, systematic, stratification, clustering, multistage sampling, and simple random sampling. Let us look at the concept of some of the most common sampling designs in agriculture. However, the detailed step-by-step procedures and complete designs can be found in the literature (refer to Freund, 1979; Gomez & Gomez, 1984; Upton, 1987). The conceptual idea and description presented below are based on the theories observed in the book of Statistical Procedures for Agricultural Research by Gomez & Gomez (1984).

- ***Completely randomized design (CRD):*** This sampling design is one that is assigned completely at random so that each experimental unit has the same chance of receiving any one treatment and can take care of any difference among experimental units by receiving the same treatment, which can be considered an experimental error (Gomez & Gomez, 1984). This type of sampling is a single-factor design and is more appropriate for experiments with homogeneous experimental units, such as laboratory experiments for soil chemical analysis. The environmental effects in this laboratory are relatively easy to control and manage. Similarly, in field experiments where there is generally large variation among experimental plots, for environmental factors such as soil, CRD is rarely used (Gomez & Gomez, 1984).
- The analysis of variance involved two sources of variation among the '*n*' observations obtained from a CRD trial – the treatment variation and an experimental error; however, the relative size of the two is used to indicate whether the observed difference among treatments is real or is due to chance. In this regard, the treatment difference is said to be real if the treatment variation is sufficiently larger than the experimental error (Gomez & Gomez, 1984). This simplicity in the computation of analysis of variance is a major advantage, and this advantage is even greater when the number of replications is not uniform for all treatments.
- ***Randomized Complete Block (RCB):*** This design is among the most widely used experimental designs in agricultural research. The design is especially suited for field experiments where the number of treatments is not large and the experimental area has a predictable productivity gradient. The primary distinguishing feature of the RCB design is the presence of blocks of equal size, each of which contains all the treatments; however, the purpose of this blocking is to reduce experimental error by eliminating the contribution of known sources of variation among experimental units (Gomez & Gomez, 1984).The randomization process is designed both separately and independently for each of the blocks.

- The analysis of variance involved three sources of variability in an RCB design: treatment, replication (or block), and experimental error.

▪ ***Group balanced block design (GBBD):*** The primary feature of the group balanced block design is the grouping of treatments into homogeneous blocks based on selected characteristics of the treatments. In a group-balanced block design, treatments belonging to the same group are always tested in the same block, but those belonging to different groups are never tested in the same block. This shows that the precision with which the treatments are compared is not the same for all comparisons, and the treatments belonging to the same group are compared with a higher degree of precision than those belonging to different groups (Gomez &Gomez, 1984).

▪ ***Latin Square Design (LSD):*** The major feature of the Latin square (LS) design is its capacity to simultaneously handle two known sources of variation among experimental units, and it can treat the sources as two independent blocking criteria instead of only one, as in the RCB design (Gomez & Gomez, 1984). Two-directional blocking, known as 'row-blocking' and 'column-blocking', is accomplished by ensuring that every treatment occurs only once in each row block and once in each column block. According to Gomez & Gomez (1984), this procedure makes it possible to estimate variation within row blocks and among column blocks and to remove them from experimental error. This means that the lattice design achieves homogeneity within blocks by grouping experimental plots based on known patterns of heterogeneity in the experimental area, and the group balanced block design achieves the same objective by grouping treatments based on known characteristics of the treatments (Gomez & Gomez, 1984).
  - There are four sources of variation, two more than that for the CRD and one more than that for the RCB design. These sources of variation are row, column, treatment, and experimental error.

▪ ***Split-Plot Design (SPD):*** The SPD is specifically suited for a two-factor experiment that has more treatments than can be accommodated by a CBD and one of the factors is assigned to the main plot, which is called the main-plot factor. According to Gomez & Gomez (1984), the main plot is divided into subplots to which the second factor, called the subplot factor, is assigned; thus, each main plot becomes a block for the subplot treatments. This means that with SPD, the precision of the measurement of the effects of the main-plot factor is sacrificed to improve that of the subplot factor, and the measurement of the main effect of the subplot factor and its interaction with the main-plot factor is more precise than that obtained with RCB.
  - The analysis of variance was divided into main-plot analysis and subplot analysis.

Statistical analysis

The results or data obtained from the research can be subjected to various analyses in FSR, including descriptive analysis, farm business analysis, financial analysis, cash flow analysis, and statistical analysis, including regression analysis. The application of statistics in agriculture has dominated most commonly used analyses in agriculture (Borrelli et al., 2021). Various statistical techniques are used in agricultural studies to ensure efficient planning of experiments and for interpreting experimental data (Bayo, 2014). Statistical techniques are also used for economic analyses and future predictions of different businesses of great value for human development (Lind et al., 2012).

These statistical analyses are considered in various agricultural sciences to respond quickly and efficiently to an existing problem for future solutions (Collinson, 1982), and this has been the result of the integration of various statistical tools and models into agricultural science. The FAO (2023) noted that the basic statistical tools commonly used for agricultural analyses with various statistical software include the sum, mean, standard deviation, coefficient of variance, confidence limit of measurement, and propagation of errors, while the statistical tests include two-sided vs. one-sided tests, F tests for precision, t tests for bias, linear correlation and regression, and analysis of variance (ANOVA). However, the common statistical software packages are Excel spreadsheet, SPSS (Statistical Package for Social Science) (Quintero et al., 2012), SAS (Statistical Analysis Software) (SAS Institute, 2023), GENSTAS (Warwick University, 2023), Stata (Eric et al., 2016), Minitab (Barbara et al., 1972), R, Epi-info (CDC, 2023), Epi-data (EpiData Association, 2023), NVivo (Lumivero, 2023) and ATLAS.ti (ATLAS-ti Scientific Software Development GmbH, 2023). These specialized programs are designed to perform complex statistical analyses, assist in the organization and interpretation of the results, and calculate and present the overall results for present and future use (Lind et al., 2012). With computer technology and its application in agriculture (FAO, 2011; Abbasi et al., 2014; Choudhary et al., 2022), these sets of software can be used to perform many statistical analyses and solve voluminous problems in agriculture (Bayo, 2014). In many instances, this statistical software requires minimal practice to operate and generate significant results for detailed interpretations.

CONCLUSION

Research and its methodologies are major components of science. They provide the complete structure and guidelines on how to start and complete agricultural research both in the field and in the laboratory. Research methodology is a science and technology that must be studied and examined before the initiation of any study under any of the agricultural components (animal science, agricultural extension, agronomy, soil science, among others). It is a major driving machine that can be used to achieve any objective and answer important research questions in relation to agricultural research objectives. It plays a key role in deciding how science and economic development are pictured in global academic and policy decision-making. This piece of knowledge compilation emphasizes the need for regular reading and examination of the overall concept of research, its methodologies, experimental designs and statistical hypotheses and analyses. There are many advances in the way research and research analysis should be performed in practical fields of study, such as agriculture, and this must be learned regularly in both universities and colleges. Similarly, theories and principles must be understood at all levels of research and studies in the fields of agriculture, sciences and social sciences.

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