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Scientific Research Methods

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Abstract: ***The function of the research method is to organize research procedures with the aim of minimizing error, saving effort, and supplying efficient collection of evidence relevant to the research objectives. The literature presents a wide range of research methods, with different procedures and names that vary according to the area of science. Here, the most common research methods in biology and particularly in agriculture are considered in a unified and rational way. Due to their characteristics, each of these methods is more suitable for one of the three objectives of scientific research: exploratory, descriptive and explanatory.***

Keywords: Exploratory research, descriptive research, explanatory research, case study, prototype study, mathematical modeling, sample survey, observational study, experiment

1. Introduction

The objective of scientific research is to verify a scientific hypothesis about a scientific problem. According to the purpose of consideration of the problem, the research objective can be exploratory, descriptive or explanatory. In practice, these three objectives, or functions, are not mutually exclusive, and scientific research can often combine more than one of these objectives.

In general, the objective of exploratory research is to identify problems of the units of a target population, suggest hypotheses and discover and investigate the feasibility of themes, areas and techniques for more intensive research; descriptive research aims to identify and describe the relevant characteristics of those units, and important relationships between these characteristics; explanatory research aims to derive inferences about cause and effect relationships between characteristics of the units of the target population in order to provide information for the control or prediction of a subset of characteristics based on alteration or knowledge of another subset of characteristics.

Whatever its objective, scientific research must be performed by one of several alternative research methods. The function of the research method is the organization of research procedures with the purposes of minimizing error, saving efforts and providing efficient collection of evidence relevant to the research objectives.

The literature presents a wide range of research methods, with differences in procedures and designations that vary with the area of science. This article considers the most common research methods in biology and particularly in agricultural research. Each of these methods, by its characteristics, is more appropriate for one of the three objectives. However, in general, they are usable for more than one research objective.

This article provides a brief review of scientific research methods for researchers in the various fields of science. The topics that seem most important are considered: the basic methods that implement the three objectives of scientific research: exploratory, descriptive and explanatory, and their relationships and strategic use in scientific research. This review is a sequel to Silva [1, 2] and is based primarily on contributions from Bernard [3], Bertalanffy [4], Bunge [5], Bronckingtn & Scarci [6], Carey [7], Castro & Cobbe [8], Christensen [9], Cochan [10, 11], Cox [12], Federer [13], Fisher [14], Green & Tull [15], Heath [16], Kempthorne [17, 18], Kish [19, 20], Lastrucci [21], Mitchell & Jolley [22], Petrie [23], Shadish, Cook & Campbell [24], Silva [25, 26, 27, 28], Smith & Sugden [29], Soares & Colosimo [30], Urquhart [31], Wilson [32]..

In the following sections, research methods are presented and illustrated with respect to the purposes for which they are most specifically proper. Thus, the next two sections present the methods of exploratory and descriptive research, which is usually called survey. The following section considers the methods of explanatory research, with consideration of two specific topics of explanatory research: relationships of characteristics and control of the sample. The next section addresses explanatory research methods and highlights the distinctions between these methods that have relevant implications for inferences related to causal relationships of characteristics. In the last section, the use of exploratory, descriptive and explanatory research methods is discussed, to characterize that they should be used strategically in the initial synthesis, analysis and final synthesis phases of the application of the scientific method for the generation of knowledge.

2. Exploratory Research Methods

Exploratory research methods have greater flexibility and versatility and are less structured than descriptive and explanatory methods. However, they do not supply the basis for generalization provided by some descriptive research methods, nor the basis for inferences related to causal relationships that characterizes the methods of explanatory research.

Exploratory research methods are proper for use in the initial phase of a cycle of the scientific method, for the search for information that allows identification of scientific problems and fertile hypothesis, and in the final phase, for the incorporation of the knowledge generated by analytical research into the existent body of knowledge. These methods are particularly useful to identify characteristics, areas and important themes for research on systems of a target population about which there is still not enough knowledge to formulate scientific problems and, consequently, also scientific hypotheses.

The most common exploratory research methods are case study, prototype study and mathematical modeling.

Case study

*The **case study** comprises the choice of a subset of a few units (**cases**) of the target population with the characteristics relevant to the purpose of the research, and the description of a large subset of characteristics of these units, according to a pre- established plan.*

The case study method is appropriate for the intensive description of a few units, based on direct observations and interviews. Cases can be typical units that characterize the diversity of the target population, or units of some particular interest. Information regarding all characteristics relevant to the identification and detailed description of these units is recorded.

This research method originated in social sciences, but is also used in other areas of research, such as public health, industry and agriculture.

Case study is a proper research method to provide ideas, identify problems and suggest hypotheses that can be verified by explanatory research. For this reason, it is very useful in the initial synthesis phase of a cycle of the application of the scientific method in research. Case study is also very useful for describing rare events and for provision of counterexample of some universally accepted principle.

Case study can follow descriptive research. In some studies, a sampling survey is initially conducted to identify typical clusters of the units of the target population. After this typification phase, a case study follows with one or a few units of each of these clusters. For example, in a research with the purpose of deepening the knowledge of the production systems in use in a region, a survey is carried out to identify the groups of typical systems in use; then, a system is chosen from each of these groups and is followed by a time interval, when data are recorded for a large number of characteristics of these systems.

Prototype study

- *The **study of prototypes** consists of assembling one or a few units (**prototypes**) with a set of chosen characteristics and carrying out the observation and measurement of the relevant characteristics of these units, according to a pre-established plan.*

The study of prototypes emerged in industrial research. The purpose of a prototype study is primarily problem detection. In the industry, prototypes are physical models of machinery or equipment that result from the aggregate of components developed and produced independently from various specialized suppliers. The study of prototypes aims mainly at evaluating the performance of these models, before large-scale manufacturing and commercialization.

Unlike the case study, in which the units exist before the research is carried out, in the study of prototypes the units are assembled especially for the research.

The study of prototypes is an especially useful exploratory research method to provide the synthesis of explanatory analytical research results through their integration into real systems, and to provide the identification of problems and hypotheses that can be verified by explanatory research. For example, a unit or system of production of pigs is assembled, incorporating the technologies generated by the research, in order to observe the results of the interactions of these technologies when integrated into the global system, and the performance of the new system. In these circumstances, this unit is a laboratory for experience and observation for the identification of problems and the suggestion of hypotheses that can be verified by explanatory research.

2.3 Mathematical modeling

The method of mathematical modeling also originated in industrial research, from the advent of electronic computing. It is distinguished from other research methods by being a conceptual or formal method, that is, the units or systems are not real or empirical, but abstract or conceptual:

- ***Mathematical modeling** consists of representing a set of real units (systems) by a conceptual model, that is, a **mathematical model**, or **simulation model,** which expresses the relationships between the relevant characteristics of the units. The model is then submitted to validation through numerical experimentation, with the aid of an electronic computer, and comparison of the results of this experiment with results obtained by other research methods.*

The mathematical model is assembled based on information provided by other research methods - survey, case study, experiment, etc., and even by indirect sources, including opinions.

The mathematical modeling method involves the identification of relationships between the relevant characteristics of the units of interest, the mathematical representation of these relationships, the construction of a global model to represent (simulate) the functioning of these units and their changes in time, and the use of this model to derive new knowledge about dynamic interactions between characteristics of these units.

For example, a sheep research unit can assemble a model of lamb production systems, or part of these systems, with the characteristics and relationships of essential characteristics. A first model can be built based on the user's regular practices, research results and opinions of producers, extensionists and researchers. This model can be progressively improved with the incorporation of new characteristics and relationship of characteristics, and reformulations of characteristic relationships, based on new technologies that are generated by the research. Its adequacy can be checked periodically, by comparing the results it provides with results of real systems of the target population (production units of the region).

Because the method of mathematical modeling focuses on the system globally, it is particularly useful for verification of the behavior of new technologies generated by research when integrated into global systems, identification of relevant interactions between characteristics of systems, and critical characteristics that require research. It can be also especially useful for other purposes related to scientific research, such as identification of research problems, suggestion of hypotheses, indication of research priorities and derivation of extrapolation of explanatory research results.

3. Descriptive Research Methods

In contrast to the flexibility of exploratory research, descriptive research requires clear definitions of the target population and research objectives, the specification of the questions it aims to answer, and careful planning regarding the sources of information to be used and the procedures for information collection:

*- **Descriptive research methods**, also called **surveys**, are suitable for research with the purpose of identifying, describing and representing the relevant characteristics of the units of a target population and their correlations.*

A survey can be conducted on all units of the target population or on a fraction of that population, that is, on a sample of the target population:

*- If the research involves the observation of all units of the target population, the research method is called **census**. If it is conducted on a sample of the target population, it is called **sample survey**.*

The census is only applicable in situations where the target population is finite, and its units are identifiable and available for information collection. Even in these circumstances, for economic, ethical or other reasons, sample survey may be more convenient and appropriate. For this reason, it is much more frequently used.

In a descriptive research, observations and measurements are made of characteristics of the units that manifest themselves without interference from the researcher. The researcher is limited to the recording of information according to a pre-established plan, very often through a questionnaire.

At elementary level, descriptive research focuses only on the measurement of characteristics and determination of their important properties, such as means and variances, or frequency distributions. At a more advanced level, descriptive research can aim also at identifying and describing association relationships between characteristics. For this reason, descriptive research methods are sometimes called "correlational methods". However, descriptive research is not suitable for the purpose of deriving inferences about causal relationships, that is, cause-and-effect relationships between characteristics.

The sampling process determines the **sampling design**, that is, the structural relationship between the sample and the target population and he chances of selecting units from the target population. There is a wide variety of sampling design. The most important distinction between these designs refers to the sample selection process, which can be objective and probabilistic, or subjective and non-probabilistic.

*- If the sampling process is objective and establishes a known probability that each unit of the target population is included in the sample, it is **called probabilistic sampling** or **random sampling**; otherwise, it is called **non-probabilistic sampling or non- random sampling**.*

A target population can be a real or conceptual population. Real populations are finite, that is, they have a certain number of units that, in many situations, can be identified and listed. Sampling processes for these populations can be objective and random, or subjective and non-random. Conceptual populations are of unknown size; they are often very large and, in these circumstances, for convenience, they are usually considered infinite in statistical inference procedures. For this reason, sampling processes for conceptual populations are necessarily subjective and not random. The most used sampling designs are considered below.

Probabilistic sampling

Probabilistic sampling has the following properties:

a) Each unit of the target population has a known probability of being selected for the sample,
b) The sample is selected by some method consistent with these probabilities,
c) Objective inferences can be derived for the target population by statistical procedures that consider these selection probabilities.

Probabilistic sampling design is also convenient because: a) they allow the determination of the sampling error, i.e., the degree to which the sampled population differs from the target population; b) this information allows the objective assessment of the validity of the sample. Non-probabilistic sampling design does not allow this evaluation.

The most common probabilistic sampling designs are: simple random sampling, stratified random sampling, random cluster sampling, cluster-stratified random sampling, random sampling in stages, systematic random sampling and multiple random sampling.

Simple random sampling

The simple random sampling process is the purest form of random sampling: the sample units are randomly chosen from the target population without any restriction:

*- A **simple random sampling design** consists of selecting the units of the target population in an unrestricted manner and such that all units have an equal probability of constituting the sample. In other words, a **simple random sampling***

design of size n *consists of selecting the sample with the property that all subsets of n units of the target population have the same probability of selection.*

The following surveys illustrate the use of simple random sampling: a) survey of the incidence of diseases in animals of a herd of beef cattle of a farm in which the sample consists of a group of animals randomly selected from the register of animals of this herd; b) survey of the opinion of the members of a cooperative of wheat producers to identify the most relevant problems for research whose sample consists of farmers randomly chosen from the register of members of this cooperative.

Simple random sampling is particularly proper for relatively homogeneous and not very large target population. As it requires the identification and listing of all units of the target population, it can become laborious or impractical for large populations. It is also inconvenient when the target population comprises subpopulations or groups of units among which characteristics relevant to the purposes of the research vary markedly. In these circumstances, the random choice of the sample without restriction may result in failure to represent variation between these groups.

Stratified random sampling

A proper sampling process to constitute a representative sample of a target population comprising groups of considerably heterogeneous units may be the random and independent choice of a subset of units of each of these groups:

A ***stratified random sampling design*** *of size n consists of classifying the units of the target population into k groups (****strata****) and then selecting a simple random sample of* n_i *size of the i-th stratum, so that* $n_1+n_2+...+n_k = n$.

The numbers of units selected from the strata of the target population can be equal or different:

- *If the stratified random sampling process selects the same number of units from each of the strata of the target population, the sampling process is called* ***equal allocation****. If the numbers of units selected from the strata are proportional to the sizes of the strata, then it is called* ***proportional allocation****.*

In a stratified random sampling design, the sampling error comes from the variation between units within strata; it is not affected by the heterogeneity of the strata. Thus, when the variation of characteristics relevant to the research aims is considerably higher between the strata than between the units within the strata, stratified random sampling leads to smaller sampling error and more accurate statistical inferences than simple random sampling. These advantages are more salient when the sizes of the strata are sharply different.

Stratified random sampling may also be convenient when information regarding individual strata is desirable and when collecting information separately for each stratum is easier for physical or administrative reasons.

The following examples illustrate surveys with stratified random sampling: a) survey of the incidence of diseases in animals of a herd of beef cattle of a farm whose sample consists of a group of animals randomly selected from the register of animals of each of the three breeds of this herd; b) survey to characterize the quality of lamps received by a network of appliance stores from various manufacturers in which are drawn to test some lamps from each of the manufacturers; c) survey of the opinion of the members of a cooperative of wheat producers to identify the most relevant problems for research whose sample consists of randomly chosen farmers from the register of members of this cooperative of each of three property sizes.

Stratified random sampling, as well as simple random sampling, requires the identification and listing of all units of the target population. When the size of the target population is too large, the preparation of this list can be too laborious or impractical. Other drawbacks of the use of these sampling processes in these circumstances are the high costs and administrative difficulties arising from the collection of information from dispersed units.

Random cluster sampling

When the size of the target population is too large, random sampling can become easier and more convenient for preparation, cost, and administration when units constitute relatively homogeneous natural groups. In these circumstances, a proper sampling process to constitute a valid and representative sample can comprise the random selection of a subset of these groups, instead of a subset of individual units:

- *A* ***random cluster sampling design*** *consists of classifying the units of the target population into groups (****clusters****) and then extracting a simple random sample of the clusters.*

The sample can consist of all units of the selected clusters or a simple random sample of each of these clusters. In the latter case, equal allocation or proportional allocation to cluster sizes can be adopted. Proportional allocation is most often used.

In many situations, clusters comprise geographically close units and are areas corresponding to divisions of a region that constitutes the target population. In these circumstances, the design is usually called **random sampling by area**.

Examples of characteristics that may be appropriate for cluster formation are: a) farm in a survey of the incidence of diseases in animals in a region in which the unit is an animal; b) county in a survey of technologies adopted by farmers in a region in which agricultural property is the unit; c) family in a survey of the socioeconomic situation of the inhabitants of a neighborhood of a city in which unity is the individual. A random cluster sampling illustration is provided by a survey of consumption in a city in which the sample unit is the family defined as the set of people who inhabit the same residence, the blocks are identified on a city map and a certain number of blocks is chosen at random for collecting observations. Next, a subset of the residences of each of the chosen blocks is selected by simple random sampling with proportional allocation (to the number of residences of these blocks).

This random sampling process requires only the identification of clusters and the listing of the units of the clusters selected for the sample. For this reason, it is convenient for considerably large target populations, especially when a complete list of units is not available and obtaining it would entail a lot of work and high cost.

When the variation of relevant characteristics is lower among clusters than between units within clusters, random cluster sampling produces less sampling error and more accurate statistical inferences than simple random sampling. Thus, in the planning of a random cluster sampling survey, greater homogeneity between clusters should be sought than between units within clusters. This is the opposite of what should be sought with the stratified random sampling process, where greater homogeneity within the strata than between the strata is convenient.

Stratified and cluster random sampling

In some situations, a stratified and clustered random sampling design may be convenient:

- *In a **stratified, cluster random sampling design** the target population is divided into groups (**strata**); each of these groups is subdivided into subgroups (**clusters**); from each of the strata, a simple random sample of clusters is extracted; then, from each cluster (from each stratum) a subset of units is randomly selected by some appropriate criterion.*

The two surveys that follow exemplify stratified and cluster random sampling design: a) Survey of consumption in a city in which the sample unit is the family, i.e., all people living in the same residence, the city is divided into zones (strata) and the blocks (clusters) of each of these zones are identified; then, a simple random sample of the blocks of each of the zones is extracted, and a subset of families from each selected block of each city zone is randomly chosen. b) Survey of opinions of wheat growers a wheat region in which this region is divided into counties (strata) and each county into areas (clusters); then, a simple random sample of areas within each county is selected with the number of areas selected proportional to the number of wheat growers areas in the county, and from each area a sample of wheat growers is randomly chosen.

Random sampling in stages

Stratified and cluster random sampling design is a two-stage sampling design; the first stage consists of simple random sampling of clusters within each stratum; the second stage, in the random sampling of the units of each cluster selected in the first stage. This idea of stage sampling can be conveniently extended to very large and complex population situations.

For example, a national survey on employment and unemployment, with survey in homes. It would not be practical to obtain and maintain a list of the country's residences. In addition, data collection through interviews in very dispersed households would have an exorbitant cost. For these circumstances, it is interesting to design a sampling in stages, such as the design in the three stages that follow: 1 - extraction of a random sample of the counties of each State of the country; 2 - selection of a random sample of the blocks of each of the chosen counties; and 3 - selection of a random sample of the residences of each of the blocks.

Systematic random sampling

Systematic random sampling is a probabilistic sampling process used with some frequency when it is possible to list or sort all units of the target population.

- *A **systematic random sampling design** of a sample of size n from a population of size N consists of randomly choosing the c- th unit of the subset of the first k = [N/n] units, and then taking each of the k-th units from it, so that the sample results from the units of the taget population of orders c, c+k, c+2k,... ([r] denotes the largest integer that does not exceed the rational number r).*

In this design the random choice of the first unit of the sample determines the whole sample. Suppose, for example, the extraction of a sample of 10% from the list of the 620 associates of a cooperative of milk producers. To do this, a number is randomly selected from the set of the first 10 integers, 6 for example, and then the producers identified in the list with the numbers 6, 16, 26 and so on, up to 616 are taken.

Systematic random sampling considerably reduces the number of subsets of units of the target population that can be chosen to constitute the sample but ensuring that all units of the population have a chance to constitute the sample.

This design has three advantages over the simple random sampling design: it considerably reduces the number of subsets of units of the target population that can be chosen to constitute the sample, ensure that all units in the population have a chance of constituting the sample. it is easier to plan, since only a random number is required, and distributes the sample more evenly over the target population. For this last reason, the systematic random sampling design sometimes leads to smaller sampling error and more accurate inferences than the simple random sampling design. However, it has disadvantages. An important disadvantage is that if there is any hidden ordering of the units of the target population according to the levels of some relevant characteristic, a severely biased sample may result. Thus, for example, a) a systematic sample of the houses of a city may have too large, or too small, numbers of corner houses; b) a systematic sampling of the plants in an orchard may have the plants selected from the same positions along each of the rows of the orchard.

Multiple random sampling

In some circumstances it may be convenient to select the units for the sample in stages:

- *In a **multiple sampling design,** the sample consists of units that are selected from the target population in successive stages. Depending on the results observed at each step, subsequent steps may be waived.*

This sampling process is often employed in sampling inspection for product testing or quality control. An example is provided by the following double sampling process for decision regarding acceptance or rejection of a batch of an industrial product: A random sample of the units of the lot is chosen; if the number of defective units in this sample is at most 5%, the lot is accepted; if it is at least 10%, the lot is rejected. If the number of defective units is between 5 and 10%, a second sample is required. So, if the number of defective units in the combined sample of these two samples is at most 10%, the lot is accepted; if the number of defective units is greater than 10%, the lot is rejected.

Multiple random sampling starts with relatively small sample and proceeds with the successive increment of the sample size in stages until the decision criterion is achieved. Thus, it is a convenient sampling process because it allows the reduction of the sample size and the reduction of cost and time.

An extreme case of multiple sampling is **sequential sampling**, in which the sample is increased unit per unit, until a conclusion is reached about accepting or rejecting a given hypothesis referring to the target population. Sequential sampling allows to minimize the average sample size in the long term.

Non-probabilistic sampling

In some circumstances it may be impractical or inconvenient to consider all units of a real population in the sample selection process. Thus, for example, a) in a survey of a state's voter preference over candidates to governor in the next election, it is impractical to sample a subset of individuals selected from the list of eligible voters; b) in a survey of the opinion of the citizens of a county on a particular topic, it may be impractical or inconvenient to consider all the inhabitants of that county in the sample selection process. Similar circumstances occur when the units of a real population cannot be all identified or are not all accessible, such as in a survey of the fish population of a lake, in a survey for botanical characterization of plant species native in a region, and in a survey of animals from a biological reserve. In such circumstances, the use of a probabilistic sampling design becomes impractical or unfeasible. The use of probabilistic sampling design is also unfeasible when the target population is a conceptual population, whose units are not all available at the time of research execution. In this case, the target population can be specified only conceptually, that is, by describing the properties of the units that constitute it.

In all these situations, the choice of sample should be based on human criteria and judgment. In these circumstances, the probability of each unit of the target population being chosen to constitute the sample is not known. In fact, in many situations a considerable fraction of these units has no chance of being selected for the sample.

As these sampling processes have no probabilistic basis, they do not allow the determination of the sampling error, and they do not allow the derivation of inferences to the target population by statistical procedures. Such inferences should be based on subjective judgment. Consequently, they are generally subject to bias, which cannot be objectively assessed.

The most common non-probabilistic sampling designs are: trial sampling, convenience sampling, quota sampling, systematic non-random sampling, sampling at random and mechanical sampling.

Judgement sampling

*- In a **judgement sampling design**, the sample is constituted based on the judgment of the researcher who seeks to select a subset of units that is representative of the target population.*

Very often, the sample is chosen by a researcher who, because he is considered to have a deep knowledge of the relevant characteristics of the target population units, is judged qualified to select a sample that represents these characteristics and the variability present in the population.

The following research illustrate a judgement sampling design: a) Survey of the opinions of the workers of an industry to increase productivity in which only a part of the workers should be interviewed; the choice of these workers is made by the production manager because he is considered the most qualified to obtain an appropriate representation of all workers. b) Survey of characteristics of bean production systems in a region in which a subset of counties whose producers should be included in the sample should be chosen; the choice of counties is made by a group of researchers.

Trial sampling is a very common non-probabilistic sampling process. In fact, it is the most usual process in conceptual population situations and the most feasible in many situations of high-sized real population, particularly when there are resource and time constraints.

Convenience sampling

*- In a **convenience sampling design**, the sample consists of units selected from the target population by some convenience criterion, very often related to the accessibility of the units.*

Convenience sampling is often used to obtain approximate information about the target population in a short time and with low cost. Its is exemplified by the following surveys: a) survey of information about families when the interviewer chooses families close to their residence or workplace; b) survey of opinions of the residents of a district in which the interviewer decides to interview the 200 people who are present in a certain event next weekend; c) survey of characteristics related to the quality of cement from an industry in which the sample consists of bags chosen from the top of one or more trucks with a load of cement from that origin.

Quota sampling

This non-probabilistic sampling process is like the stratified random sampling design. It differs from this design in that the units are selected from each of the strata by a non-random process. The researcher first identifies the strata and proportions in which they are present in the target population and then uses non-random sampling to select the required number of units of each of the strata:

- *A **quota sampling design** consists of : 1) division of the target population into subpopulations or strata representing the various categories in which their units are classified according to some relevant characteristic; 2) determination the sample fraction size (**quota**) corresponding to each of these strata; and 3) delegation to the executor of the survey in each stratum the selection of the units until completing the quota as indicated to him.*

The choice of units of each stratum is usually carried out by judgement or convenience sampling. Frequently, unaffordable or difficult-to-access units are overlooked.

Illustrations of sampling survey by quota: a) survey of information from rural producers of a region through interviews in which the region is divided into sections and each section is assigned to an interviewer, and the interviewer is responsible for choosing a certain number of producers from his section for the interviews; b) survey of the socioeconomic conditions of the families of a district in which the district is divided into segments of streets and the interviewers are assigned the choices of the residences of the corresponding segments so that the predetermined numbers of residences are completed.

Systematic non-random sampling

This sampling process is usable in situations where the units of the target population will become available one by one over time:

- *A **systematic non-random sampling design**, also called **interval sampling design**, consists of taking one unit at the end of each repetition of a given time interval, as the units of the target population become available, or taking each unit that arises immediately after a subset of a certain number of units.*

This sampling process requires that the starting point, that is, the initial instant or the first unit be selected by some objective criterion. It is sometimes used in the industry to monitor the operation of equipment and production processes and for product quality control, and in surveys involving interviews of people. Examples of this sampling method are: a) survey to verify that the set of equipment or the production process of an industry is working according to specifications in which a production line item is selected for testing every time interval (e.g. every 60 minutes), from a pre-established time; b) survey of the opinion of the customers of a store in which is selected every tenth person who enters the store, from the opening of the store; c) survey to collect suggestions from the residents of a street regarding a remodeling project, in which the sample consists of the occupants of each tenth house of this street, from a given corner.

Haphazardly sampling

Haphazardly sampling is a process of non-random sample usable when the units of the target population are arranged in some container, compartment or facility, and are not identified or is difficult to access selected units:

- *In a **haphazardly sampling design,** the sample consists of units selected from various points of the target population chosen by some procedure that simulates chance.*

This non-random sampling seeks to constitute the sample by units chosen by process, supposedly corresponding to the random choice, without, however, a probabilistic basis. This can be proceeded in several ways. For example, if the units are arranged in some container, taking the units at hand, in various positions; if the units are in some large compartment or installation, traveling through the compartment or installation and taking the units within reach, at various points.

The following example illustrates situations of use of haphazard sampling: a) survey of the characteristics of the screws contained in a box made by means of a sample of some screws caught in each of ten points of the box; b) survey of characteristics of chicks arranged in several cages each with 100 chicks in which from each of these cages the researcher picks five chicks within reach of his hand; c) survey to characterize the quality of meat stored in a cold room whose sample consists of parts of meat collected in various positions along a walk through the warehouse.

The haphazard sampling can be a reliable sampling process if the target population is homogeneous or there is no tendency of systematic grouping of the units, and there is no possibility of the researcher being influenced by some characteristic of the units.

Mechanical sampling

This non-random sampling process is usable when the target population comprises a solid, liquid, or gaseous volume:

- *A **mechanical sampling design** consists of constituting the sample of a target population comprising a solid, liquid or gaseous volume by parts taken at various points of this volume chosen in a supposedly random manner.*

Mechanical sampling is usually conducted with the use of special instruments such as claw, shell and probe. This sampling process is similar to haphazard sampling and should be used with the same care as indicated for that sampling process.

4. Explanatory Research Methods

Characteristic relationships

Descriptive research can provide the identification of association relationships between characteristics. Although descriptive information is often useful for predicting relevant characteristics, it is usually desirable to identify the origin of variation in these characteristics, that is, whether the variation of predicted characteristics results from the variation of other characteristics, and the identification of these characteristics. It is also desirable to know the relationships of the characteristics that are the object of prediction (effects) with the characteristics that produce their variation (causes). This knowledge is important because knowledge of causes increases the ability to predict and control effects. This is the purpose of explanatory research.

Explanatory scientific research aims to derive inferences about causal relationships between two subsets of characteristics of the units of a target population where, supposedly, one of these subsets is the cause and the other is the effect. These two subsets of characteristics constitute the class of explanatory characteristics and the class of response characteristics, respectively:

- ***Response characteristics*** *express the performance or behavior of the units, and* ***explanatory characteristics*** *are supposed to affect that performance or behavior.*

Explanatory research aims to provide information for the control or prediction of response characteristics based on the alteration or knowledge of explanatory characteristics. The difficulty of this process is the presence of natural variability of the third class of characteristics of the units of the target population that also affect the response characteristics, which are called **extraneous characteristics**.

The response and explanatory characteristics constitute the objectives of the research and are designated based on substantive scientific theories and empirical knowledge. The identification of these characteristics requires knowledge and vision of the research area. The class of the extraneous characteristics is defined by exclusion, that is, the characteristics of the units excluded the class of response characteristics and the class of explanatory characteristics. The distinction and classification of the characteristics of the units of the target population in these three classes is a crucial step in planning explanatory research.

In general, only a subset of the response characteristics is of interest in particular research. The characteristics of this subset and the explanatory characteristics must be identified and defined explicitly. The extraneous characteristics constitute an extremely numerous set and usually it is necessary to individualize only the most relevant ones.

The units of the sample also include the three subsets of the characteristics of the units of the target population, that is, the responses, explanatory and extraneous characteristics. Conceptually, these characteristics of the sample are the same as those considered in the target population. Ideally, the levels of the extraneous characteristics of the sample are a representative sample of the corresponding levels in the target population. The levels of the explanatory characteristics of the sample are the levels of the target population themselves or subsets of these appropriately chosen levels.

These concepts are illustrated by the examples that follow:

a) Research on the control of the incidence of giberela in wheat crops in a tricultural region.

The set of response characteristics comprises the characteristics that express the performance of the crops, that is, the characteristics of the grain and the plant. However, in this research, only the response characteristics relevant to its aim are of interest, that is, control of the incidence of giberela, a fungus that causes damage to wheat production in this region. These characteristics are weight of grain production and degree of infection of giberela.

To achieve the objective of this research, it is decided to consider the effect of fungicides, and three fungicides are chosen: Mancozeb, Ciproconazole and Propiconazole, and absence of fungicide to verify the need for fungicide application. As the effect of fungicide may depend on the cultivar, it resolved to consider three cultivars: BR 18, BR 23 and BRS 177, respectively of early, medium and long cycles. Thus, two explanatory characteristics are defined: fungicide and cultivar; the first with four levels: fungicides Mancozeb, Ciproconazole and Propiconazole and absence of fungicide, and the second with three levels: cultivars BR 18, BR 23 and BRS 177. As the effects of fungicides may depend on environmental conditions, which vary in space and time, it is decides to conduct the research in four sites in the triticultural region in the next three years; thus, location and year are also considered as explanatory characteristics.

The levels in the sample of the characteristics fungicide and cultivar are the same as in the target population. However, the levels of the local and year explanatory characteristics in the sample are, respectively, the locations and years of conducting the research; therefore, subsets of the respective levels defined for the target population, appropriately chosen to represent the corresponding populations of levels.

In each location, each year, the research is conducted on a plot of land divided into 48 plots. The 48 combinations of the four levels of fungicide and the three cultivars are assigned to these plots so that each combination results in four plots. Then, the extraneous characteristics are: the characteristics of the seed (genetic, except those related to the explanatory characteristic cultivar, and phenotypic: size, vigor, purity, sanity, etc.), environment (soil, climate, incidences of pests, diseases, weeds and predators, etc., except the characteristics inherent to location and year, defined as explanatory characteristics), cultivation techniques (soil preparation, planting, application of pesticides, except for fungicide for control of the giberela, which are explanatory characteristics, etc.), and measurement processes.

b) Research on the control of intestinal worms in lamb production units.

The important responses characteristic for the objectives of the research are body weight and number of parasites in the animal's viscera at slaughter (154 days of age), and body weight and number of eggs in specific moments of the research period (70-154 days).

The researcher decides to consider the anthelmintic Ranizole and establishes the objective of determining the optimal dose of this anthelmintic in the range of 0 to 40 mg/kg live weight for male and female animals. So, for the response characteristics measured at slaughter, there are two explanatory characteristics: anthelmintic and sex. For the response characteristics measured at several moments of the research period, there is an additional explanatory characteristic: age of the animal. The levels of the explanatory characteristic anthelminthic in the target population are the doses in the range [0; 40 mg/kg of live weight]; the levels of sex are the two sexes – male and female and the levels of age are the ages in the interval [70; 154 days].

The levels of anthelmintic in the sample are the two extremes and the middle levels of the interval of doses in the target population, i.e. 0, 20 and 40 mg/kg mg/kg. The levels of sex in the sample are the same levels in the target population themselves, i.e., male and female, and the levels of age are 70, 84, 98, 112, 126, 140 and 154 days.

The research is carried out in a facility with 18 pairs of pens, each pen with capacity for one animal, and each pair of pens with a common feeder and drinker, and 36 Ideal breed animals, 18 males and 18 females, with an approximate age of 70 days, with research period ending with the slaughter of animals at five months of age. Then, the extraneous characteristics of the sample are the characteristics related to the animal (genetic, age, age, weight, sanity etc., except sex, which is explanatory characteristic), the environment (installation, pasture, climate, incidences of diseases, parasites and predator), management (lamb preparation, application of antibiotics, vaccines and parasiticides, except for the application of anthelmintic, which is explanatory characteristic) and measurement processes.

c) Research on the effect of the incidence of winding virus on the quantity and quality of grape production of vines of the Italy cultivar, in a wine-growing region.

The important responses characteristics are bunch weight, number of bunches, average bunch weight, and sugar and acidity grape content.

The objective of this research defines the incidence of winding virus as an explanatory characteristic. It is decided to consider three degrees of infection: no infection, medium infection and strong infection; so, these are the three levels of this explanatory characteristic in the target population. Location and year are also considered as explanatory characteristics since the quantity and quality of grape production may depend on environmental conditions.

The research is conducted in a vine orchard with eight plants chosen with each of the three degrees of infection. Thus, the levels of winding virus infection in the sample are the same as in the target population. The locations and years of the sample are chosen so that the proper representation of the environmental variation of the target population is achieved. The extraneous characteristics of the sample are the characteristics of the plant (genetics, vigor, sanity, except the incidence of winding virus, which is an explanatory characteristic), the environment (soil, climate, incidences of pests, diseases, predators, etc., except the properties inherent to location and year, which are explanatory characteristics), cultivation techniques (fertilization, application of insecticides, herbicides, fungicides, etc.), and measurement processes.

The objective of the research defines five explanatory characteristics: cultivar, fertilization, insecticide, herbicide and fungicide. The first of these characteristics has an unspecified number of levels; the researcher decides to consider two levels for each of the other characteristics – adopts and does not adopt. Location and year are also considered as explanatory characteristics since the productivity of the bean depends on the environment.

The levels of explanatory characteristics fertilization, insecticide, herbicide and fungicide in the sample are the same as the objective population, that is, it adopts and does not adopt; the levels in the sample of explanatory characteristics cultivar, year and place are subsets of the levels of the objective population, that is, the cultivars, the sites and years, respectively, that are present in the units chosen to constitute the sample.

The extraneous characteristics of the sample are the characteristics related to: seed (except cultivar, which is explanatory characteristic), environment (except the properties inherent to site and year), cultivation techniques (except fertilization, insecticide, herbicide and fungicide, which are explanatory characteristics) and measurement processes.

Sample Control

The variation manifested by the response characteristics in the units of the sample is due both to the effects of the explanatory characteristics and to the effects of the extraneous characteristics. Consequently, there is a confounding of the effects of explanatory characteristics with effects of extraneous characteristics:

The effects of the explanatory and extraneous characteristics on a response characteristic are ***confounded*** *when they cannot be distinguished from each other.*

Confounding hinders and may make it impossible to derive unbiased inferences related to causal relationships between response characteristics and explanatory characteristics:

*The effect of extraneous characteristics on a response characteristic is called re**search error**.*

The term "research error" comes from the fact that inferences about casual effects of explanatory characteristics on response characteristics are subject to error arising from the effects of extraneous characteristics.

The basis of scientific research for inference of causal relationship between a response characteristic and an explanatory characteristic is the following **principle of causality**: if the level of an explanatory characteristic is altered and the extraneous characteristics remain constant, any variation manifested by the response characteristic is due to the change in this explanatory characteristic.

This ideal is approximately achieved in certain laboratory experiments in physics and chemistry, where essentially identical units can be built, so that the research error is reduced to irrelevant proportion. However, in research in natural sciences, particularly in biology, units can be considerably heterogeneous, mainly due to variation in environmental characteristics. In these circumstances, the control of this heterogeneity is generally necessary. On the other hand, the the exaggerated reduction of research error may imply conducting the research under very special conditions, not representative of populations of natural units, usually with considerable variability.

The solution of this essential problem of the explanatory research is the control of the sample to avoid or decrease the confounding of effects of explanatory and extraneous characteristics, to the point where it is possible and appropriate, and to make the remaining confounding unbiased.

The following procedures can be considered for sample control with a view to reducing the research error and its bias: control of the manifestation of explanatory characteristics, control of research techniques, local control or pairing, statistical control, and randomization.

Control of the manifestation of explanatory characteristics
This control is exercised by choosing the levels of one or more explanatory characteristics for the sample and assigning those levels to the sample units according to a plan.

Due to the relevance of the implications for the validity of inferences, two classes of explanatory characteristics must be distinguished according to the control that is exercised over its manifestation in the sample: extrinsic characteristic (treatment characteristic) and intrinsic characteristic:

An explanatory characteristic whose levels chosen for the sample are randomly assigned to the units of the sample and whose effects are not biasedly confounded with effects of extraneous characteristics is an ***extrinsic characteristic*** *or* ***treatment characteristic****. An explanatory characteristic that is inherent to the units of the sample or whose effects are biasedly confounded with the effects of extraneous characteristic is an* ***intrinsic characteristic****.*

The levels of a treatment characteristic are called **treatments**; more generally, the levels of an explanatory characteristic (extrinsic or intrinsic) are called **conditions**.

The distinction between extrinsic characteristic and intrinsic characteristic is illustrated by examples in section 4:

a) In the research on control of the incidence of giberela in wheat crops, the levels of fungicide and the levels of cultivar are randomly assigned to the units of the sample. If control of extraneous characteristics ensures no biased confounding of their effects with effects of fungicide and cultivar, these two explanatory characteristics are treatment characteristics. However, the sites and years are inherent to the units of the sample; therefore, location and year are intrinsic characteristics. The levels of fungicide, cultivar in the sample are treatments; the levels of fungicide, cultivar, sites and years in the sample are conditions.
b) In the research on control of intestinal worm in sheep, doses 0, 20 and 40 mg/kg of the anthelmintic are randomly assigned to the pairs of boxes and the sexes male and female are assigned at random to the two boxes of each of those pairs. Thus, if the control of extraneous characteristics guarantees absence of biased confounding of effects of these extraneous characteristics with anthelmintic effects, anthelmintic is a treatment characteristic and they doses are treatments. However, sex is an inherent characteristic of the animal; therefore, the effect of sex is confounded with extraneous characteristics of the animal. If the difference of the extraneous characteristics between the two sexes is irrelevant, sex can be considered a treatment characteristic. This is the case if the animals of the two sexes come from the same herd and proper control of extraneous characteristics is exerted. Otherwise, sex should be considered an intrinsic characteristic.
c) In the research on the effect of the incidence of winding virus on the quantity and quality of grape production of vines, the degree of infection of the winding virus is inherent to the plant and is manifested outside the control of the researcher; therefore, winding virus infection is an intrinsic explanatory characteristic. Age is also an intrinsic explanatory characteristic, because its effect is confounded with effects of the extraneous characteristics (of the environment and cultivation techniques) that vary between moments of mensuration. Thus, this research does not comprise treatment characteristic.

Control of research techniques
- *The* ***control of research techniques*** *comprises the execution of intervention actions in the sample to make the manifestation of extraneous characteristics constant or irrelevant.*

The control of research techniques is exercised from the initial choice of the sample to the measurement process. In the initial constitution of the sample, it consists of the selection or construction of homogeneous units regarding extraneous characteristics. During the conduct of the research, it is carried out by the controlled execution of research techniques with the purpose of making manifestations of extraneous characteristics constant or uniform. Control of research techniques is also used in measurement processes to avoid the introduction of extraneous characteristics that may imply bias due to the use of poorly calibrated instruments, which overestimate or underestimate values of the measured characteristics, and measurement errors from other sources. The measurement of some response characteristics is performed by judges. This is the case, for example, of measurements by laboratory analysis and organoleptic evaluations by tasters. These assessments may require subjective judgment and require experienced judges with specialized training.

The use of research technique control is illustrated by examples in Section 4**4.1**.

a) In each of the four locations and three years of running the experiment on control of the incidence of wheat giberela with fungicides, the control of experimental techniques should include use of homogeneous seeds regarding germination, vigor, purity, health, etc., and adoption of cultivation techniques (soil preparation, planting, control of diseases, pests, invaders and predators, harvesting) and uniform measurement procedures.
b) In each of the three sites, the research on the control of intestinal sheep worms with anthelmintics, should be conducted with homogeneous animals regarding genetic characteristics, sanity, age, weight; with

uniform management techniques (food and water supply, applications of antibiotic, vaccines and parasiticides) slaughter and measurement processes.

c) The research on the incidence of vine winding virus should use plants chosen from each of the defined three degrees of incidence of the virus that are uniform in terms of vigor and sanity, except for the incidence of the winding virus, and adopt uniform cultivation techniques and measurement procedures.

The extraneous characteristics submitted to the control of research techniques are manifested in the sample constantly or, more often, in the level of uniformity achieved by the control exercised. Thus, the confounding of the effects of the controlled fractions of these characteristics that are confounded with effects of explanatory characteristics is eliminated or reduced.
The use of this sample control technique should be used with care in technological research, where it is required that the sample appropriately represents the target population. It should be used without prejudice to the representativeness of the sample, or rather, to the extent that such injury can begin.

Local control or pairing
- *Local control or **pairing** (**matching**) for a relevant extraneous characteristic consists of classifying the sample units into groups of units more homogeneous in relation to that characteristic than the complete set of sample units, so that the variation of the response between the groups could be eliminated from sample error and from differences in responses between levels of explanatory characteristics or matching for a relevant extraneous characteristic consists of classifying the sample units into groups of units more homogeneous in relation to that characteristic than the complete set of sample units, so that the variation of the response between the groups could be eliminated from sample error and from differences in responses between levels of explanatory characteristics.*

Illustrations of the use of local control or pairing are provided by researchers described in examples in Section 4: a) For the control of soil characteristics (fertility, texture, structure, moisture), which are usually more similar in nearby than distant plots, in each of the four sites and the three years, the 48 plots are classification into four blocks of six nearby plots. Then, a complete collection of the 12 combinations of the four fungicide levels and the three cultivars is assigned to the 12 plots of each block. Thus, the variation between blocks can be eliminated from the differences between fungicides and the differences between cultivars, and from the research error. b) The 18 pairs of pens are classified into six groups of three homogeneous pairs for the characteristics of the environment, and the 36 lambs into six groups of three male and three females, according to six dates on which they become available at the specified age of 12 weeks. The six groups of pairs of pens are associated with the six groups of animals to constitute six homogeneous blocks of pairs of pens and animals. Then, the three doses of the anthelmintic are attributed to the three pairs of pens of each of the six blocks and, on each of the dates on which they become available, three pairs of male and female animals are assigned to the three pais of a block. Thus, the differences between blocks, due to pairs of pens and times of entry of the animals, are eliminated from the differences between anthelmintics and the research error. c) If the plants of each of the three degrees of incidence of the virus are heterogeneous, they should be ordered as to the level of vigor and then classified for pairing according to the vigor level, each of the groups consisting of plants with the three degrees of winding virus. Thus, the variation due to the vigor level can be eliminated from the differences between degrees of infection and the research error.

Statistical control
*The **statistical control of** a relevant extraneous characteristic comprises the data recording of this characteristic and its use to adjust the observed values of response characteristic, with a view to eliminating the variation attributable to the controlled extraneous characteristic.*

With an appropriate statistical analysis procedure, **called covariate analysis**, the variation due to the controlled extraneous characteristic (expressed by a variable called **covariate** or **concomitant variable**) is eliminated from the research error and the differences in response between the levels of explanatory characteristics.

For illustration of statistical control, the example b) in Section 4 is considered again**4.1**. In the research on intestinal worm control of sheep with anthelmintic, if the initial weight variation of the animals is relevant, it may be appropriate to exercise statistical control to adjust the observed values of response variables in order to eliminate the differences attributable to this extraneous variable. The adoption of statistical control does not seem relevant in example c).

Statistical control has two assumptions: existence of a linear or otherwise simple relationship between the response variable and the covariate, and the absence of effect of the explanatory characteristics on the covariate.

Local control or pairing and statistical control do not interfere with the constitution of the sample. The manifestation of controlled extraneous characteristics is unchanged. However, the variation of the response attributable to controlled characteristics is eliminated from differences between the levels of explanatory characteristics and the research error. Thus, these two procedures can allow the control of relevant extraneous characteristics, eliminating the confounding of their effects with effects of explanatory characteristics, without preventing their manifestation in the sample.

Randomization
Randomization is a procedure for controlling extraneous characteristics whose manifestation is not subject to the control of research techniques, local control and statistical control. It can be adopted in the association of levels of treatment characteristics with sample units and in the execution of research techniques, to prevent treatments from being benefited or harmed by bias.

***Randomization** is the process of controlling the* *manifestation of extraneous characteristics in the sample units, to avoid that the confounding of their effects with the effects of the treatment characteristicsis biased.*

The randomization is accomplished through the randomization of the treatments and the randomization of the order of the execution of research techniques:

*The **randomization of the treatments** consists in the assignment of the treatments to the units of the sample by objective draw procedure that assigns all units the same chance of receiving any of the treatments.*

*The **randomization of research techniques** consists of the establishment of a random order of execution of research techniques, determined by some objective draw procedure that assigns to all units of the sample equal chance of being favored or disadvantaged.*

In experiments in which local control is performed, randomization must be carried out block by block, separately and independently.

Consider, again, the research described in the examples in section 4**4.1**. a) In the research on control of the incidence of giberela in wheat crops, the 12 combinations of the levels of the explanatory characteristic fungicide and cultivars are randomly assigned to the 12 plots of each block, separately and independently foreach block.

pairs of pens and sex to the pens inside pairs of pairs of pens, by random processes, independently for each block.

b) In the research on control of intestinal worm in sheep, the randomization is carried out by the assigned of the anthelmintics to the pair of pens, separately and independently for each block, and of sex to the pens within pairs of pens, separately and independently for each pair. c) Randomization of treatments is not feasible in this research, since it does not include explanatory characteristics of treatment.

If there are differences in extraneous characteristics that could favor or disfavor responses to treatments, chance ensures that all treatments have an equal chance of being favored or disadvantaged. Thus, the confounding of the effects of extraneous characteristics covered by randomization with treatment effects becomes unbiased.

Randomization has no effect on the constitution of the sample and does not avoid the confounding of effects of extraneous characteristics with explanatory characteristics effects. However, it makes this confounding unbiased.

Classification of extraneous characteristics implied by sample control

Sample control procedures are essential for the derivation of sample inferences to the target population. Local control or pairing and statistical control contribute to greater sensitivity to detect effects due to explanatory characteristics; randomization allows the detection of such bias-free effects.

The following classification of the extraneous characteristics of the sample may be useful for a better understanding of the implications of the experimental control procedures adopted for the derived inferences for the target population:

- Controlled extraneous characteristics,
- Randomized extraneous characteristics and
- Potentially disturbing extraneous characteristics.

*The **controlled extraneous characteristics** are the extraneous characteristics of the sample whose control is exercised through local control (or pairing) and statistical control; **randomized extraneous characteristics** are the extraneous characteristics covered by randomization; **potentially disturbing extraneous characteristics** are the other extraneous characteristics, i.e., the uncontrolled and non-randomized extraneous characteristics.*

The causal effects of potentially disturbing characteristics on response characteristics are confounded with explanatory characteristic effects. Characteristics of this class that manifest themselves in an irrelevant way behave as if they were randomized, that is, their effects do not result in biased confounding with effects of explanatory characteristics. Control of research techniques is the resource that may be proper for this purpose. The effects of potentially disturbing characteristics that manifest themselves in a relevant way are tendentially confounded with the effects of explanatory characteristics:

- *The relevant potentially disturbing extraneous characteristics whose effects are biasedly confounded with the effects of explanatory characteristics constitute the class **of disturbing extraneous characteristics**.*

The randomized characteristics and potentially disturbing characteristics constitute the **research error**. For this reason, in the assumption of absence of disturbing extraneous characteristics, the search error is usually called **random error** or **casual error**.

Local control and statistical control are intended to reduce the effect of bias caused by disturbing extraneous characteristics and to reduce random errors resulting from random extraneous characteristics. However, it is not practical to control more than a few of the extraneous characteristics. Most of them should be left uncontrolled. Such characteristics should be placed in the class of random characteristics, through randomization, or irrelevant behavior characteristics, by appropriate research techniques.

Explanatory Research Methods

The most common explanatory research methods are the experiment and the observational study.

Experiment

- *The **experiment**, also called **controlled experiment**, is the explanatory research method in which there is intervention in the sample, with the imposition of one or more treatment characteristics, and control of extraneous characteristics with experimental techniques to avoid biased confounding of effects of treatment characteristics with extraneous characteristics.*

The sample is usually composed of units built especially for the research or, in rare situations.

The experiment comprises at least one treatment characteristic, whose levels, that is, treatments, are assigned to the sample units by a random process. Typically, treatments are stimuli assigned to the units under the researcher's control in order to assess the corresponding effects on response characteristics.

The experiment is the appropriate method for the research described in examples a) and b) in section 4, on control of giberela incidence in wheat crops and control of intestinal worms in lambs. It may also be appropriate for research with objectives synthetically defined by the following titles: "efficacy of herbicides in the control of weeds in soybean crops", "effect of mineral supplementation on weight gain of laying birds" and "comparison of cultivars in a wheat breeding program".

The experiment is the research method that adopts the strongest sample control. The control of research techniques, **called control of experimental techniques**, is intensively used. The grouping or classification of units for the purpose of controlling extraneous characteristics, which in the experiment is called **local control**, and statistical control, are also very often adopted. Moreover, the experiment is the only research method that adopts randomization in the assignment of the levels of explanatory characteristics to the sample units.

Due to these properties, the experiment is the research method that supplies greater reliability for inferences about causal relationships of characteristics. For this reason, it is considered the method of explanatory research par excellence.

5. Observational Study

- *The **observational study** is the explanatory research method in which the sample choice is limited to accessible target population units; the explanatory characteristics are inherent to the sample units, so that they manifest themselves without interference from the researcher; explanatory and response characteristic data are recorded in the present or in the future, or are taken from records constructed in the past.*

Therefore, in the observational study there is no treatment characteristic; explanatory characteristics are all intrinsic characteristics. On the other hand, the choice of the sample is limited; the sample consists of units selected from the target population that are accessible. Data is collected from the units of this sample or are taken from records constructed in the past.

The explanatory observational studies comprise three main classes:

- Prospective observational study,
- Retrospective observational study and
- Uncontrolled observational study.

Prospective observational study

*In a **prospective observational study,** a group of units with the appropriate characteristics for the purposes of the research is chosen; data of explanatory characteristics of these units are recorded; and then these units are followed by a time interval, during which information about the response characteristics is recorded., sometimes corresponding to the occurrence of an event of interest, such as death.*

Thus, the explanatory characteristics are characteristic of the units present at the beginning of the research and the response characteristics are characteristics manifested in the future.

The prospective observational study method is illustrated by the research on the effect of the incidence of winding virus on the grape production of vines of the cultivar Italia, in a wine-growing region (example c in section 4).

In epidemiology, the prospective observational study method called **cohort study** is used for inferences regarding the relationship between disease incidence and risk factors. Two comparable groups of individuals are selected, one of whom was exposed to a risk factor, to verify whether the two groups develop the disease in different proportions. For example, **i**n a study on the relationship between smoking and lung cancer incidence, conducted in England between 1951 and 1961, data were collected from more than 2/3 of 60,000 physicians who were sent a questionnaire regarding smoking. After 10 years, 135 deaths associated with lung cancer were recorded, of which only three were nonsmokers. The research concluded that the risk of death from lung cancer of smokers is almost 32 times higher than the risk of death of nonsmokers.

Retrospective observational study

*In a **retrospective observational study**, a group of units with the appropriate characteristics for the purposes of the research is chosen; data on response characteristics are recorded from these units; and then historical information from these units is examined for the identification of relevant explanatory characteristics.*

In these circumstances, the response characteristics are characteristic of the units present at the beginning of the research and the explanatory characteristics, characteristics of the past.

In epidemiology, the retrospective observational study method called **case-control study** is used to research the relationship between risk factors and incidence of a disease. Two comparable groups of individuals are chosen, one of these groups (which is called case) consisting of individuals who manifest the disease under consideration and the other (called **control**) by individuals who do not manifest it, to verify whether the two groups differ in relation to exposure to risk factors under consideration.

One example follows: In a study on risk factors in breast cancer conducted at the Clinical Hospital of the Federal University of Minas Gerais, between 1978 and 1987, a group of breast cancer patients aged between 25 and 75 years (cases) and a group of patients without indication of breast pathologies, but similar in terms of age distributions and date of hospitalization in the hospital (control) was considered. The research concluded that the presence of a family history of cancer increases the risk of this pathology by 8.84 times.

These observational study methods use more restricted sample control than the experiment. They do not adopt randomization and do not adopt the control of research techniques or adopt it considerably less sharply than the experiment. Therefore, they need to resort more markedly to the use of the control of extraneous characteristics through pairing and statistical control.

In these circumstances, prospective observational study and retrospective observational study are less reliable explanatory research methods than the experiment. However, they are research methods that the researcher must resort to when the intervention required by the experiment is impractical or inconvenient, often for ethical reasons. This last situation occurs in much research in human health and in sociology.

These methods of observational study are sometimes called **quasi-experiments and pseudo experiments**, because they have similar purposes as the experiment, but the lack of control over the manifestation of explanatory characteristics and the control over extraneous characteristics is markedly limited.

Uncontrolled observational study

- *The uncontrolled observational study uses existing data from previously collected records for some purpose other than current research. The researcher has no control over the choice of the sample or data collection.*

This research method receives names in some areas of research, such **as pure observational study** and **archive research** in social sciences.

Unlike prospective observational study and retrospective observational study, in the uncontrolled observational study there is no data collection; data already collected and available are used. In fact, a huge amount of data with varied and rich information is available in archives of research institutions, public offices, organizations specialized in data collection, hospitals, clinics, etc. For example, national and regional agricultural research units have available data generated by regional experiments of plant breeding, usually planned for the recommendation of cultivars based on the comparison of averages. This data can be exploited to generate relevant information for various purposes, by research that requires few financial resources, such as:

a) Studies of adaptability and stability of genotypes to the environment;
b) Regionalization of plant breeding programs;
c) Regionalization of the recommendation of cultivars;
d) Location of regional experiments and determination of the appropriate amounts of sites and years of execution of experiments.

The uncontrolled observational study is the explanatory research method that usually requires fewer financial resources. This is its main advantage, and, for this reason, it is universally used. However, it has quite restrictive disadvantages. The main ones are: a) absence of research planning, particularly with regard to the choice of sample, the design of the research and the data collection process; b) lack of control over data generation and, for this reason, little or no information on data quality; c) precarious representativeness, resulting from the absence of control of the researcher over the choice of the sample, unless, perhaph, exclusion of units according to information that may be available; d) very often, data available in files were collected and expressed in inappropriate variables for a particular research; e) often there is no information that can clarify doubts, especially regarding the quality of the data.

Because of these restrictions, this research method is not recommended for the derivation of inferences about causal relationships of characteristics. Results of explanatory research that employs it should be used with great caution and be more properly considered as hypotheses to be verified by reliable explanatory research.

Choosing the explanatory search method

From an appreciation of the properties of explanatory research methods, it can be inferred that they present important common and uncommon properties. The common property is the non-random process of choice of the sample; in the experiment, units are usually constructed during its execution; in observational studies, the units are chosen among the available units of the target population with characteristics appropriate to the objectives of the research. The non-common property concerns the level of interference and control exercised by the researcher: in the experiment, the researcher has control over the choice of the levels of the one or more explanatory characteristics for the sample and their manifestation in the sample units, which can be determined by random process. This difference between experiment and observational studies is relevant for its implication for the two desirable properties of an explanatory research: a) reliability of inferences related to causal relationships and b) validity of the inferences for the target population. The reliability of inferences related to causal relationships between response characteristics and explanatory characteristics distinguishes the experiment from observational studies. As for this property, the experiment has three important advantages:

a) Control over the choice and variation of explanatory characteristics clarifies the direction and nature of the causal relationship between response and explanatory characteristics,
b) Randomization of extraneous characteristics prevents bias that can result from the manifestation of potentially disturbing extraneous characteristics,
c) The flexibility of experimental designs allows efficient and powerful statistical manipulation, while the analytical treatment of observational studies presents statistical difficulties.

In fact, in the experiment, specific levels of explanatory characteristics are chosen and applied to the units by objective process of randomization under the control of the researcher. In the ideal experiment, all extraneous characteristics are controlled (by experimental techniques, local control or statistical control) or randomized. Thus, with no potentially disturbing characteristics, the bias that may come from these characteristics is eliminated. In these circumstances, it can be logically inferred that a considerable response variation in units with different treatments is a consequence of differences in the effects of these treatments.

However, in the experiment, as well as in the observational study, the non-random choice of the sample may imply low representativeness and, therefore, bias of these inferences to the target population. Consequently, in research with these methods, in general, there is a disparity between the target population and the sampled population that should be considered subjectively in inferences. In fact, conceptually, sample inferences are valid for the sampled population; will be valid for the target population to the extent that the disparity between these two populations, i.e., the sampling error is irrelevant. This judgment is necessarily subjective.

The advantages of the experiment as an explanatory research method are well known. However, in many situations, the experiment is not feasible and, even when feasible, presents difficulties that must be circumvented or tolerated. The first of these is that the choice and operation of controlling explanatory characteristics and extraneous characteristics can be difficult. Therefore, delineating an "ideal" experiment can be difficult or impossible. Thus, the advantages of the experiment related to sample control are often only relative, not absolute. Second, it is often difficult to design experiments with representative samples of important populations. In fact, the problem of sample representativeness has been ignored in experimental research. Thirdly, the elaboration of the sample with the desired realism of the conditions present in the target population is generally not feasible and is often not considered in experimental research.

In general, in any scientific research only part of the conditions for reliable and valid inferences can be controlled objectively and firmly. Another part remains uncontrolled; their implications should be evaluated by subjective judgment. The researcher should use the available resources to maximize the objective component and, consequently, minimize the subjective, and strive to exercise skilled and judicious judgment. It should make the strategic choice of the research method, considering the purposes of the research, the means for its execution and its costs, and considering the following three desirable criteria of scientific research: representativeness, realism and reliability.

The emphasis on realism or reliability tends to result, respectively, in observational study or experiment. As previously pointed out, the experiment is powerful in the control of explanatory characteristics and extraneous characteristics, but it is usually weak regarding the representation of the target population and often also about realism. Observational studies are usually weak in control and in representativeness; its advantage is the realism of the manifestation of the characteristics of the target population in the sample.

Usually, these three criteria cannot be adequately met in scientific research, and often not even two of them, due to unfeasibility or lack of resources. Very commonly, the researcher emphasizes a criterion for reasons of cost and convenience, or because it may seem, convincingly or hopefully, the most justifiable. On the other hand, none of the three criteria is higher than the others for all situations and, sometimes, the three can be satisfied in complementary research of a research program. Thus, for each situation, the researcher must decide for a compromise between the desirable and the feasible and choose the research strategy that best fits the available resources.

In addition, each of these explanatory research methods can be refined with efforts to overcome their main weaknesses. Withdrawals can be improved by using auxiliary information to control potentially disruptive characteristics. On the other hand, sometimes experiments and observational studies can be improved regarding representativeness by some compromise between the desired amplitude for the target population and the amplitude that can be reached for the sampled population.

6. Use of Scientific Research Methods

A summary of the essential characteristics of the research methods described in the previous 0sections may be be useful for a better understanding of their applicability in scientific research.

Exploratory research methods (case study, prototype study and mathematical modeling) are systemic research methods, that is, research methods that focus on units globally. The fundamental distinction between case study and prototype study is that the first focuses on the existing units without the intervention of the researcher, while in the latter the units are assembled or constructed based on the synthesis of information about the units present in the target population, information generated by scientific research and opinions. Mathematical modeling performs the conceptual representation of existing units and new units that insert recent results generated by scientific research and opinions.

Descriptive research methods (census and sample survey) and explanatory research methods (experiment and observational study) are analytical research methods, which focus on subsets of characteristics of the target population.

In the initial synthesis phase of a cycle of the scientific method, the researcher proceeds to the overall assessment and inspection of the units of the target population to detect the relevant characteristics, particularly the most influential ones on the functioning and performance of the units, and the relationship of these characteristics, with the purpose of identifying important problems and obtaining suggestions for fertile hypotheses. This is an exploratory research phase. Case study and mathematical modeling are useful in this phase of synthesis.

In the analysis phase, the descriptive survey is useful to provide a description of the relevant characteristics and their relationships, and to identify research problems and hypotheses. Descriptive research and exploratory research are particularly relevant for the establishment of the most effective explanatory research paths. Then, explanatory research methods are now applicable, i.e., the experiment and observational study. The new knowledge generated by these research is characteristically sparse, since it is derived by a set of researches that cover several parts of the units.

In the final synthesis phase, this new knowledge should be inserted into the existing body of knowledge, through new research that focuses on systems globally. The study of prototypes and mathematical modeling are the research methods proper for this purpose.

Briefly, this research approach requires the execution of exploratory, descriptive and explanatory research, which requires the appropriate and strategic use of the various research methods described in sections 1, 20, and 3.

The experiment and the sampling survey are traditional research methods in agricultural research. The observational study has been little used. However, this research method can be used to great advantage; especially the uncontrolled observational study that may be useful for the use of the large mass of data generated by research already performed, with relatively low costs.

Case studies and prototype studies have occasionally been used in agricultural research. In agriculture, a case can be, for example, an agricultural property, a farm, a crop, an orchard, or a farm facility for which the producer provides reliable information and gives ease of access and in-depth study. A prototype can be one of the same types of units installed by the research institution, on its own physical basis or in producer property, to realistically simulate a viable production system, incorporating results indicated by research.

Case study and prototype study are exploratory research methods of great potential for use, which can be implemented to the benefit, respectively, for the better knowledge of the systems in use by producers and to test the integration of technologies generated by research in real systems. They are also instruments of high value for the integration of research activity with the extension and approximation with producers. Mathematical modeling can also fulfill these functions, with the advantage over those two empirical methods of providing more flexibility to simulate real production systems from a much wider range. In fact, physical models are usually restricted to a basic formula in a single environmental situation, or to few formulas in a few environmental situations, due to high costs and practical restrictions. Well-developed conceptual models are flexible, which allows their use to verify the different behaviors of systems under various technological alternatives and various environmental conditions. However, they need to be tested empirically, and for these tests the physical models are relevant. Thus, these two forms of modeling are neither alternative nor competitive: the physical model assists in the test of the conceptual model, and this collaborates in the generalization of that model.

Systemic research methods, particularly mathematical modeling, appeared and developed mainly in industry applications. In agriculture, the systems are usually more complex, which makes the construction of these models difficult and laborious. There are few examples of success in this area and much remains to be done.. The main difficulties to overcome are, mainly, the lack of training of researchers to understand the scientific methodology, particularly systemic research methods, and the lack of specialized personnel in this methodology.

The use of the various methods of scientific research has reciprocal implications. For a better understanding of the interrelated use of these research methods, it is convenient to classify them into three groups: 1) mathematical modeling, 2) case study and prototype study, and 3) experiment, survey and observational study. The main interrelationships of the use of these three groups of research methods are outlined below:

(1)→(2) Mathematical models suggest the assembly or modification of prototypes and supply recommendations to producers ("cases").

(2)→(1) Case studies and prototype studies allow to validate mathematical models, provide information for the development of these models and suggest new models.

(1)→(3) Mathematical models generate problems and hypotheses for experiments, surveys and observational studies.

(3)→(1) Experiments, surveys and observational studies supply information for the formulation and improvement of mathematical models.

(2)→(3) Case studies and prototype studies suggest problems and hypotheses for experiments, surveys and observational studies.

(3)→(2) Experiments, surveys and observational studies suggest recommendations for changing certain components of real systems (prototypes and cases).

It is also important to highlight the interrelationships between research within each of the two empirical research groups: surveys and observational studies are useful to suggest problems and hypotheses for experiments; case studies can supply information for use in prototype studies. At the end of this chain of research methods, prototype studies generate recommendations for producers (cases).

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