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ALL ABOUT CONTROL: AN EXPLANATION OF AGRICULTURAL EXPERIMENTATION TERMINOLOGY

TUDO SOBRE CONTROLE: UMA EXPLICAÇÃO DA TERMINOLOGIA DE EXPERIMENTAÇÃO AGRÍCOLA

TODO SOBRE EL CONTROL: UNA EXPLICACIÓN DE LA TERMINOLOGÍA DE LA EXPERIMENTACIÓN AGRÍCOLA

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ABSTRACT
Occasionally, errors are made in statistics that can compromise the results of the experiment and, consequently, the real objective of the research. Knowing the terms used in statistics is essential to be able to set up and conduct an experiment that is appropriate for the objectives and to obtain results that are consistent with the research objective. With this in mind, this review aimed to understand and conceptualize terms commonly used in statistics in the field of agricultural science, emphasizing the importance of the control treatment. To this end, a search was conducted in the scientific literature regarding these terms and how they can be used correctly in scientific works in the field of agricultural science in order to promote results that are appropriate to the research objective. This research concludes that it is essential to understand the concept of statistical terms for successful planning and interpretation of research data. And how the use of the control treatment can reduce experimental errors and variations, when used correctly. However, it is necessary to understand the details of the parametric and non-parametric tests applied in the reference treatment conditions, both in the design of the experiment and in the analysis of the data. The fact is that by using this device, the researcher can obtain conclusions through a single experiment, something that would not be possible without the use of control treatments. Furthermore, its correct use reduces type I and II errors.

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Keywords: Statistics. Control treatment. Witness.

RESUMO

Ocasionalmente, são cometidos erros nas estatísticas que podem comprometer os resultados do experimento e, consequentemente, o objetivo real da pesquisa. Conhecer os termos utilizados em estatística é essencial para poder montar e conduzir um experimento adequado aos objetivos e obter resultados consistentes com o objetivo da pesquisa. Com isso em mente, esta revisão teve como objetivo compreender e conceituar termos comumente utilizados em estatística no campo da ciência agrícola, enfatizando a importância do tratamento controle. Para isso, foi realizada uma pesquisa na literatura científica sobre esses termos e como eles podem ser usados corretamente em trabalhos científicos no campo da ciência agrícola, a fim de promover resultados adequados ao objetivo da pesquisa. Esta pesquisa conclui que é essencial compreender o conceito dos termos estatísticos para o planejamento e a interpretação bem-sucedidos dos dados da pesquisa. E como o uso do tratamento de controle pode reduzir erros e variações experimentais, quando usado corretamente. No entanto, é necessário compreender os detalhes dos testes paramétricos e não paramétricos aplicados nas condições de tratamento de referência, tanto no desenho do experimento quanto na análise dos dados. O fato é que, ao usar esse dispositivo, o pesquisador pode obter conclusões por meio de um único experimento, algo que não seria possível sem o uso de tratamentos de controle. Além disso, seu uso correto reduz os erros do tipo I e II.

Palavras-chave: Estatística. Tratamento de controle. Testemunha.

RESUMEN

En ocasiones, se cometen errores en las estadísticas que pueden comprometer los resultados del experimento y, en consecuencia, el objetivo real de la investigación. Conocer los términos utilizados en estadística es esencial para poder diseñar y llevar a cabo un experimento adecuado a los objetivos y obtener resultados coherentes con el objetivo de la investigación. Teniendo esto en cuenta, esta revisión tuvo como objetivo comprender y conceptualizar los términos comúnmente utilizados en estadística en el campo de las ciencias agrícolas, haciendo hincapié en la importancia del tratamiento de control. Para ello, se realizó una búsqueda en la literatura científica sobre estos términos y cómo pueden utilizarse correctamente en los trabajos científicos en el campo de las ciencias agrícolas, con el fin de promover resultados adecuados al objetivo de la investigación. Esta investigación concluye que es esencial comprender el concepto de los términos estadísticos para planificar e interpretar con éxito los datos de la investigación. Y cómo el uso del tratamiento de control puede reducir los errores y las variaciones experimentales, cuando se utiliza correctamente. Sin embargo, es necesario comprender los detalles de las pruebas paramétricas y no paramétricas aplicadas en las condiciones de tratamiento de referencia, tanto en el diseño del experimento como en el análisis de los datos. El hecho es que, al utilizar este dispositivo, el investigador puede obtener conclusiones a través de un solo experimento, algo que no sería posible sin el uso de tratamientos de control. Además, su uso correcto reduce los errores de tipo I y II.

Palabras clave: Estadística. Tratamiento de control. Testigo.

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INTRODUCTION

In scientific research in various areas of knowledge, statistical analyses are used as tools to evaluate hypotheses (SOUSA et al., 2012) and for the experiment to be successful, it is necessary to choose a correct statistical model that meets the final objective. In agricultural science, it is no different. Agricultural experimentation aims to study experiments, planning, executing, analyzing data and interpreting the results obtained. According to Duarte (1996), experimentation aims to test alternatives, called treatments, which may represent variations of a single factor or combinations of factor levels.

The general procedure for any choice of statistics is to formulate hypotheses and verify them, directly or through their consequences. In addition, it is important to evaluate the experimental precision (quality) of the results of a test to validate the conclusions obtained (CARGNELUTTI FILHO; STORCK, 2007). And based on the statistical qualities, it is necessary to adopt the appropriate test for the objective, highlighting that a test must be chosen that is robust against some violations of the basic assumptions for its application, such as normality, homoscedasticity and independence of errors (SOUSA et al., 2012; MACHADO et al. 2005).

Statistics is a scientifically based method that collects, organizes and interprets data that can be used for decision making. It is subdivided into two main branches: descriptive statistics and sampling, and inferential statistics and probability (CORREIA, 2003).

Statistical tests can be divided into two types: parametric and nonparametric (Rank Test). These terms refer to the standard deviation and the mean, which are the parameters that will define populations that have a normal distribution. The difference between these two tests is that the parametric test requires samples to have a normal distribution, and is extremely affected by data that differs drastically from all others, called *outliers.* The parametric test, on the other hand, is not as demanding as the first and is performed for small samples, in addition to not being as powerful as the first and not being seriously affected by *outliers* .

When choosing between the various tests of the chosen statistical types, parametric or non-parametric, it should be taken into account that there are tests intended for samples that have independence between the variation factors and other tests for samples in which there is a link or dependence between them. In view of this, this review aims to understand and conceptualize terms commonly used in statistics in the field of agricultural science, emphasizing the importance of the control treatment.

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NON-PARAMETRIC TESTS

Nonparametric tests are most commonly used in the social and human sciences, as they do not require the population distribution to be characterized by a certain parameter. They are used when it is necessary to make a decision about a set of data, i.e., to deduce or measure the probability of nonparametric tests (" distribution-free"). test ") (PONTES, 2017).

Nonparametric tests are distribution-free and generally focus on the order of the variable rather than the numerical value, do not specify the shape of the distribution of the variable in the population, and can often be used in smaller samples and for ordinal data (DOANE; SEWARD, 2008).

Some authors have carried out work in agricultural science using the non-parametric method. Such as Zuchiwschi et al. (2010), who evaluated the knowledge and effective use, current and past, of plant species from the Seasonal Deciduous and Mixed Ombrophilous Forests by family farmers in the western region of Santa Catarina. Souza et al. (2014), who used a non-parametric production frontier to evaluate agricultural production in Brazilian municipalities.

Carmo Santos et al. (2017) analyzed the performance and marketing strategies of organic and/or agroecological farmers in the state of Pará, using descriptive statistics, Student 's t-test and Friedman's nonparametric test. Capone et al. (2016) evaluated the viability of combining parametric and nonparametric methods to infer the stability of soybean cultivars in the Tocantins Cerrado.

PARAMETRIC TESTS

Parametric tests are used to analyze population factors, in which the samples must meet certain requirements, such as normality, homogeneity and errors that must be independent. When these requirements are met, the parametric method becomes suitable.

Parametric tests are based on interim measurements of the dependent variable (a parameter or quantitative characteristic of a population) and the use of these tests requires that certain requirements be met, namely, normal distribution and homogeneous variance of the data, in addition to continuous and equal evaluation intervals (DÍEZ et al., 2017; BISHOP et al., 2011; TUCKMAN, 200).

Assuming that the frequency distribution of sampling errors is normal, the variances are homogeneous, the effects of the variation factors are additive and the errors are

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independent, it is very likely that the sample will be acceptably symmetrical and have only one maximum point, centered in the class interval in which the mean of the distribution is located, and its frequency histogram will have a contour that will approximately follow the bell-shaped design of the normal curve. Therefore, compliance with these requirements conditions the choice of using parametric statistics, whose tests are generally more powerful (GROVER et al., 2017; HU, 2015).

In agricultural experimentation, parametric tests are valid when applied to data that follow a normal distribution, this distribution being perfectly symmetrical around the mean and the results are easier to compare parametrically when the variance or variability of the data, in both groups, is equal or homogeneous.

If the two groups subjected to the same achievement test had equal means but different distributions, it would be difficult to interpret a parametric test, due to the differences in the dispersion or variance of the results in the groups. Therefore, parametric tests, as they are designed, can only be applied to data (measurements relative to the dependent variable) that constitute an interval scale, that is, have continuous and equal intervals between them (PEŘINA; KŘEPELKA, 2013; YANG et al., 2011; TUCKMAN, 2000).

IMPORTANT CONCEPTS

Some concepts are important for statistics and understanding them is essential for a good understanding of the area. Treatment is defined as independent variables, such as an imposed condition or object, which has different levels of each factor used in the test , and which must be measured and compared. These can be qualitative, when the aim is to understand the complexity and details of the information obtained, such as different types of fungicides or fertilizers, plant varieties, different culture media, among others. Or quantitative, when numbers are used to prove the objectives of the research, such as product doses, amount of sucrose, temperature levels, among others. The choice of the test to be performed, a priori, is decided based on these treatment concepts.

Plot or experimental unit is the place where the treatment will be applied, which will provide the data to be evaluated, and may be formed by groups or by an individual.

Repetition is the assignment of the same treatment to several experimental units, that is, the number of times the treatment will appear in the test. Each repetition generates a result independent of the others with the aim of estimating the experimental error

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(measure of the variation existing between observations of experimental units treated equally) and the effect of the treatment, and making it possible to estimate the parameters and test hypotheses. The number of repetitions will depend on several factors, such as the resources available, the type of design chosen and the variability of the experiment or response variable.

In order to reduce experimental errors, you should choose an experimental design based on the idea that it can reduce random variations as much as possible. Design can be defined as the way in which treatments or levels of a factor are assigned to experimental units or plots.

The experimental design is the model in which treatments are assigned to experimental needs. Another important function of the design is to minimize errors, thus avoiding confounding factors and other occurrences that may interfere with the interpretation of results. In agricultural science, the most commonly used designs are the Completely Randomized Design (CRD), in which there is a homogeneous or controlled experimental area, and the Randomized Block Design (RBD), in which there is a heterogeneous experimental area.

Lima et al. (2019) determined the efficiency of biostimulant application in *Urochloa* hibrida and Santos et al. (2017) evaluated the quality of yellow passion fruit grown with seedlings at different ages, and in order to reduce the interference of environmental variations, these authors used DBC. On the other hand, experiments that are carried out under controlled conditions, such as that of Barrozo et al. (2020), which verified the effect of chemical treatment on the physiological quality of corn seeds after heat stress, and that of Araújo et al. (2020), which selected potential growth promoters and the inoculation method of emerald grass plants comparing them with mineral fertilization, DIC was chosen to conduct the experiment.

Randomization or casualization is another important concept in statistics and is equivalent to the drawing of lots in the experimental units by a well-defined and fixed process. This drawing should be carried out to provide results that are less biased by experimental errors, that is, so that there is no benefit or harm to a given treatment due to a known or unknown cause, such as light intensity, genetic makeup, temperature, humidity, ventilation, etc.

Local control consists of forming groups of the most homogeneous plots possible. This group consists of a block and the treatments are randomly selected within the block.

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Local control is used to reduce experimental error and improve the precision of an experiment, in which the grouping of plots into blocks can be based on soil type, geographic location, among others (GOMES, 1987). This control is not mandatory, but is usually used in experiments in which DBC was chosen, with the aim of reducing experimental error. Thus, grouping is performed in such a way as to maximize variation between blocks, leaving the minimum variation between plots within each block (DUARTE, 1996). In homogeneous experiments, as in the case of DIC, it is not necessary to use a local control, since these are not affected by external variations.

The control treatment is used for comparison with the remaining treatments, and is used when the efficiency of the treatments under study is unknown or when the efficiency of the treatments is known, but is not consistent across all conditions.

CONTROL OR WITNESS TREATMENT

In statistics, there is no clear definition of what is a witness or control, but rather an establishment based on the researcher's experience. The term witness is usually used only in the area of agricultural science, while in other areas the term control treatment is generally used.

In the field of agricultural science, control treatment is widely used in factorial schemes. In which there are two types of control, negative and positive, and the definition of these is based on the treatment that each one receives. The negative control is the group that does not receive any type of treatment, while the positive control is used when there is a conventional treatment, that is, a gold standard.

The use of control or control treatments occurs mainly when the efficiency of the treatments under study is unknown and consists of using all the procedures performed in the experimental units of the other treatments, but the differentiation occurs due to the absence of the application of the effect under study. For example, in an experiment that uses additives in food, the treatment to be studied consists of a vegetable portion containing a particular additive that is served to a taster, and for a better evaluation of the additive, a control treatment is added to the experiment, which in this case would be the same vegetable portion, but without the use of any additive in the food. For the efficiency of the control treatment, it is essential that it be conducted under the same experimental conditions as the other treatments.

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In the area of agricultural science, the use of control treatments is necessary to reduce experimental errors and variations in experiments, such as temperature, shading, slope, among others. However, not all experiments require a control treatment, as is the case with cultivar competition (ANDRADE; OGLIARI, 2007). The study conducted by Lalla et al. (2010), who evaluated the performance of eight single-head broccoli cultivars available on the market for the soil and climate conditions of Campo Grande, did not show any reduction in efficiency due to the lack of a control treatment.

Rosa et al. (2017) evaluated changes in the levels of organic matter (OM) and humic substances in a Eutroferric RED LATOSOL, cultivated with cover crops in rotation with corn and soybeans. The authors carried out two experiments, under a no-tillage system, the first experiment in 2010, implanted the cover crops dwarf velvet bean (*Mucuna deeringiana*), dwarf pigeon pea (*Cajanus cajan*) and crotalaria juncea (*Crotalaria juncea*). And in the second experiment in 2011, corn crops and canola cover crops *(Brassica napus*), crambe (*Crambe abyssinica*) and forage turnip (*Raphanus sativus*) and, subsequently, the soybean crop. For a better comparison of the data, the same control treatment was used in both years of the experiment, fallow area, with the same management as the other treatments.

Charlo et al. (2020) evaluated the effect of doses and application methods of N, supplied through coated urea, on the nutritional status and production of American lettuce. The treatments consisted of the combination of six doses of urea coated with polyurethane and four application methods of the nutrient. For a better conclusion on the effect of the sources, conventional urea was used as the control treatment.

Therefore, whenever possible, a control treatment should be included, which will serve as a reference for the conclusions. And, to have a point of reference in the interpretation of experiments with quantitative groups, whenever possible, the quantity zero (control or witness) should be included in the list of treatments to be evaluated (CARGNELUTTI FILHO et al., 2009).

Jucá et al. (2020) evaluated the effects caused by artificial defoliation, through morphophysiological parameters in coconut seedlings in simulation of the attack of *Opsiphanes caterpillars invirae* , for a more conclusive evaluation of the effects caused by the pest attack, a control treatment was carried out, without defoliation.

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The impact of control treatment on results

The control treatment is usually used in experiments in the field of agricultural science, mainly in the areas of fertility, agricultural pesticides and plant breeding. Carvalho and Nascente (2018), evaluating the response of common beans to the combination of limestone and Gafsa phosphate (GF), used a control treatment in which no product was applied in order to evaluate the interference of the fertilizer combination in the variables analyzed over the years.

Dias et al. (2020) compared a mixed mineral fertilizer (MMF) produced with sedimentary natural phosphate added with limestone and sulfur sludge, with a simple superphosphate fertilizer, with the aim of evaluating the agronomic efficiency of MMF, and for a more conclusive result they used a factorial scheme, with two phosphate fertilizers (MMF and superphosphate), four doses of phosphorus (P) and a control treatment without phosphate fertilization. In the control treatment of this experiment, the same management was carried out as in the other treatments, differing in the absence of P application, to know the best source and dose of this for corn and bean crops.

In many experiments, more than one control treatment may be used, which is common in plant breeding. When studying a new variety or cultivar of a given species, researchers use several commercial varieties or cultivars as control treatments to understand whether the new variety has similar or greater potential than these. In experiments with several controls, some tests may be used, taking into account the nature of the treatments, whether quantitative or qualitative.

For quantitative experiments, it is common to use regression, which aims to verify how the behavior of the variable (y) will influence the behavior of the other variable (x). In this type of test, both the positive control and the negative control become data. The authors, Menegatti et al. (2017) evaluated the use of different doses of controlled-release fertilizer in the production of *Aspidosperma* seedlings. *parvifolium* A. DC. The controlled-release fertilizer (CRF) used was Osmocote ® in four doses that were subjected to polynomial regression analysis. Ribeiro et al. (2016) evaluated the behavior of different potato genotypes in different doses of fertilizer formulated 04-14-08, in which regression analysis was used to determine the best potato genotypes and the best doses of fertilizer.

For qualitative experiments, multiple comparison tests between treatment means are usually used (CONAGIN et al., 2008). Among these tests, there are: Tukey, Duncan, Dunnett tests and the LSD test, normally used to detail this information, allowing to show, specifically, which treatments differ, or not, statistically (SOUSA et al., 2012), in these tests, the control treatment behaves like the other treatments.

Souza et al. (2021), evaluating sorghum production according to different plant spacing and fertilization with organic sources, used 4 organic sources and 2 spacings, as the interest of the research was to evaluate which organic source would increase productivity and which is the best spacing for planting, the Tukey test was used.

When it is necessary to compare the control treatment with the other treatments, that is, to find out which treatment differs statistically from the control treatment, the Dunnett test is used. Oliveira et al. (2020) evaluated the acidity of soil cultivated with sugarcane fertilized with organomineral fertilizer from sewage sludge and biostimulant. The treatments consisted of 5 treatments, with and without biostimulant and a control treatment (mineral fertilizer), and for a better comparison of the other treatments with the control treatment, the Dunnett test was performed.

Contrast tests, such as the F test and the Scheffé test , are a simple and very efficient technique in the analysis of experimental data, such as in obtaining main effects, interaction effects and nested effects, in comparisons between groups of means and in obtaining specific residuals (NOGUEIRA, 2004).

Ferreira et al. (2018) evaluated the reaction of lettuce cultivars to early tasseling and root-knot nematodes (*Meloidogyne incognita , races 1 and 2) under high temperature conditions. The Scott-* Knott cluster test was used , as well as a contrast of interest (which compared the mean of the lettuce cultivars with the mean of the tomato plants) with significance verified by the Scheffé test ($p<0.05$).

Some studies that evaluate two types of factors, quantitative and qualitative, required testing for both factors. Such as the study by Aguiar et al. (2021), who evaluated different fertilization managements in the quantitative and qualitative aspects of beetroot crops, as well as their residual effects on corn crops planted in succession. Three types of fertilizers were used, where the Tukey test was applied, and fertilizer doses, where the regression test was applied. And since a control treatment was performed, the Dunnett test was used to compare these with the others.

Some authors do not understand the need for and how to use the control treatment, and end up using it in the wrong way. A classic example is the case of factorial experiments, in which there are different sources of some fertilizer or other pesticide, and doses of the product. In the literature, it is possible to find some studies in which the

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negative control treatment, called dose 0, is added repeatedly to all sources, promoting an experimental error, since at dose 0, there is no application of the product, and it should be treated as an additional treatment, making this experiment a double factorial with additional treatment.

Costa et al. (2010) evaluated the effect of nitrogen doses and sources on the recovery of marandu grass , for a period of three years, in pasture established for more than 10 years, with low forage production, in the plots used the 2 x 4 factorial, in which the factors were two sources of N (ammonium sulfate and urea) and four doses of nitrogen (0, 100, 200 and 300 kg ha $^{-1}$ year $^{-1}$). However, when analyzing the interaction of the factors in this experiment, it is found that the treatment called dose 0 is independent of the source because N was not applied, demonstrating that dose 0 should be characterized as a negative control treatment.

This example demonstrates that one must be careful when planning experiments with doses and sources of products, so that there is no error in naming dose 0, as one could make the mistake of qualifying it incorrectly and thus increase the variance, and consequently reduce the efficiency of the chosen statistical tests, masking the real result of the research.

FINAL CONSIDERATION

Understanding the concept of terms such as treatment, experimental errors and design, repetition, among others, is essential for successful planning and interpretation of research data. In this sense, the treatment called control can be called a witness or even additional, but this will not change the real meaning of adding it to the experiment. It is worth noting that the same experiment can have as many controls as necessary to reach the desired conclusion.

The terms control, witness, additional, or standard are chosen according to the area of science. Using these treatments requires basic knowledge of experimentation, an area of probabilistic statistics. However, it is necessary to understand the details of parametric and non-parametric tests applied in the conditions of reference treatments, whether in the design of the experiment or in the analysis of the data. The fact is that by using this device, the researcher can obtain conclusions through a single experiment, something that would not be possible without the use of control treatments. Furthermore, correct use reduces type I and II errors.

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