

## Chapter 4. Statistical Design and Analysis

Readers of scientific publications must be able to understand how the authors designed and conducted their studies so that the results can be judged for validity and so that they may serve as a basis for the design of future research. Research studies include both controlled experimentation and observational studies. Analogous design issues arise for both types of studies. Research design may involve a design for imposing different treatments. It may also be a design for describing and improving our knowledge of how different physical, chemical, and biological processes occur within the landscape. Such studies may be observational in nature without imposed treatments.

The selection of a particular statistical method and its appropriateness depend on the questions or information sought, the validity of theoretical assumptions, the adequacy of the sampling design, and the type, quantity, and quality of the observations. The reporting of the results from each analysis should include a brief description of the statistical method and a literature citation providing its full detail, verification of the degree to which assumptions have been met, and complete descriptions of sampling design and experimental observations in relation to the efficacy of the statistical analysis. In all cases, a measure of the statistical confidence should be reported and interpreted in relation to the question answered or conclusion reached by the authors.

### TREATMENT AND EXPERIMENTAL DESIGN

Designing a controlled experiment requires two components: treatment design and experimental design. Treatment design includes the factors of interest, the levels of each factor, the relationship among the factors (e.g., a factorial treatment structure), and the selection of blocking variables and covariates. Experimental design refers to the method of arranging the experimental units and the method of assigning treatments to the units. Included should be any information about blocking, multiple experimental unit sizes (e.g., in split and strip plots), the number of sites and years or independent runs of the experiment, the number of replicates, a description of conditions at field sites and in greenhouse or controlled environmental chambers, and how measurements were made for specific traits. In studies where the experimental units and observational or sampling units were not the same, each should be clearly identified. The number of experimental units used and the number of samples taken from each unit should be clear to the reader.

The treatment and experimental designs dictate the proper method of statistical analysis and the basis for assessing the precision of the treatment means. A measure of the precision achieved, either as a standard error or a confidence interval, should be reported for all data on which conclusions are drawn.

### SPATIAL AND TEMPORAL STATISTICAL ANALYSES

Data observed at different points in space and/or time on the same experimental material are often correlated. Many methods of statistical analysis are available for examining such data. For observations that are temporarily or spatially independent, parametric and nonparametric statistical methods are available. For those that manifest temporal or spatial dependence, methods derived from regionalized variable analysis and applied time series may be selected.

## ABBREVIATIONS AND SYMBOLS

There are a number of widely used and accepted abbreviations in statistics. Those given in Table 4–1 do not require definition before use in ASA, CSSA, and SSSA publications. In contrast, the use of a particular symbol without definition is much more likely to lead to confusion or misunderstanding. For example, in statistical methods and experimental design textbooks, symbols used for the number of blocks in a randomized complete block design include  $r$ ,  $b$ ,  $J$ , and  $n$ . Further confusion can result when one or more of these symbols are used for another purpose. In some cases, the same symbol may be used for more than one purpose. In such cases, the meaning can usually be understood from the context. For example,  $\beta$  is used almost universally to represent the probability of a Type II error in hypothesis testing and is commonly used to represent population regression coefficients. Thus, an undefined symbol should be used with great care; if there is any doubt as to whether its meaning will be clear to the reader, it is best to define the symbol.

**Table 4–1. Some widely used statistical abbreviations and symbols.†**

Abbreviation or symbol‡	Explanation
ANOVA	Analysis of variance
$b$ ( $\beta$ )	Regression coefficient
CV	Coefficient of variation
df	Degrees of freedom
$F$	Snedecor's $F$ statistic
LSD	Fisher's least significant difference
$n$	Sample size
$P$ , $p$	probability
$r$ ( $\rho$ )	Correlation coefficient
$r^2$	Coefficient of determination
$R^2$	Coefficient of multiple determination
RMSD	Root mean square deviation
RMSE	Root mean square error
$s$ , $\sigma$ , SD	Standard deviation
$s^2$ ( $\sigma^2$ )	Variance
SE	Standard error
$s_{\bar{x}}$ ( $\sigma_{\bar{x}}$ ), SEM	Standard error of the mean
$t$	Student distribution (Student $t$ test)
$\bar{x}$ ( $\mu$ )	Arithmetic mean
$\alpha$	Probability of a Type I error
$\beta$	Probability of a Type II error
$\chi^2$	Chi-square statistic

† In addition, the symbols \*, \*\*, and \*\*\* are used to show significance at the  $\alpha = 0.05$ , 0.01, and 0.001 levels, respectively. Significance at other levels is designated by additional footnotes, using the next available symbol from the standard sequence (†, ‡, §, ¶, #, ††, ‡‡, etc.).

‡ Symbols in parentheses are for the population analog of the corresponding sample quantity.