

Topic 1: **INTRODUCTION TO PRINCIPLES OF EXPERIMENTAL DESIGN**

1. 1. Purpose

"The purpose of statistical science is to provide an objective basis for the analysis of problems in which the data depart from the laws of exact causality. A general logical system of inductive reasoning has been devised that is applicable to data of this kind, and is now widely used in scientific research." **D. J. Finney**

1. 2. Types of reasoning

Deductive reasoning

Inductive reasoning: reasoning from the particular to the general

1. 3. The scientific method

The power of inductive reasoning is that it permits the scientist to formulate general theories about the world based on particular observations.

1. *Formulation of the hypothesis.*
2. *Planning the experiment.*
3. *Experiment: observation and collection of the data.*
4. *Analysis and Interpretation of the results.*

1. 3. 1. Important characteristics of a well-planned experiment

1. **Degree of precision**: high probability that the experiment will be able to measure the differences with desired of precision. **REPLICATION.**
2. **Simplicity**: simplest design for the desired objective.
3. **Absence of systematic error**: each experimental unit should have equal chance of receiving any treatment. **RANDOMIZATION**
4. **Range of validity of conclusions**: Conclusions should have as wide a range of validity as possible (e.g. replications in time and space)
5. **Calculation of degree of uncertainty**: the experiment should be designed so that it is possible to calculate the probability of obtaining the same results by chance.

1. 4. Experimental design

1. 4. 1. The role of experimental design

Experimental design concerns the **validity and efficiency of the experiment**. The experimental design in the following diagram (Box et al., 1978), is represented by a movable window through which certain aspects of the true state of nature, more or less distorted by noise, may be observed. The position and size of the window depend on the questions being asked by and the quality of the experiment.

Methods of experimental design are at least as important as methods of data analysis in a research program.

The process of continually updating the hypothesis and comparing the deduced states of nature with actual data can lead to convergence on the right answers.

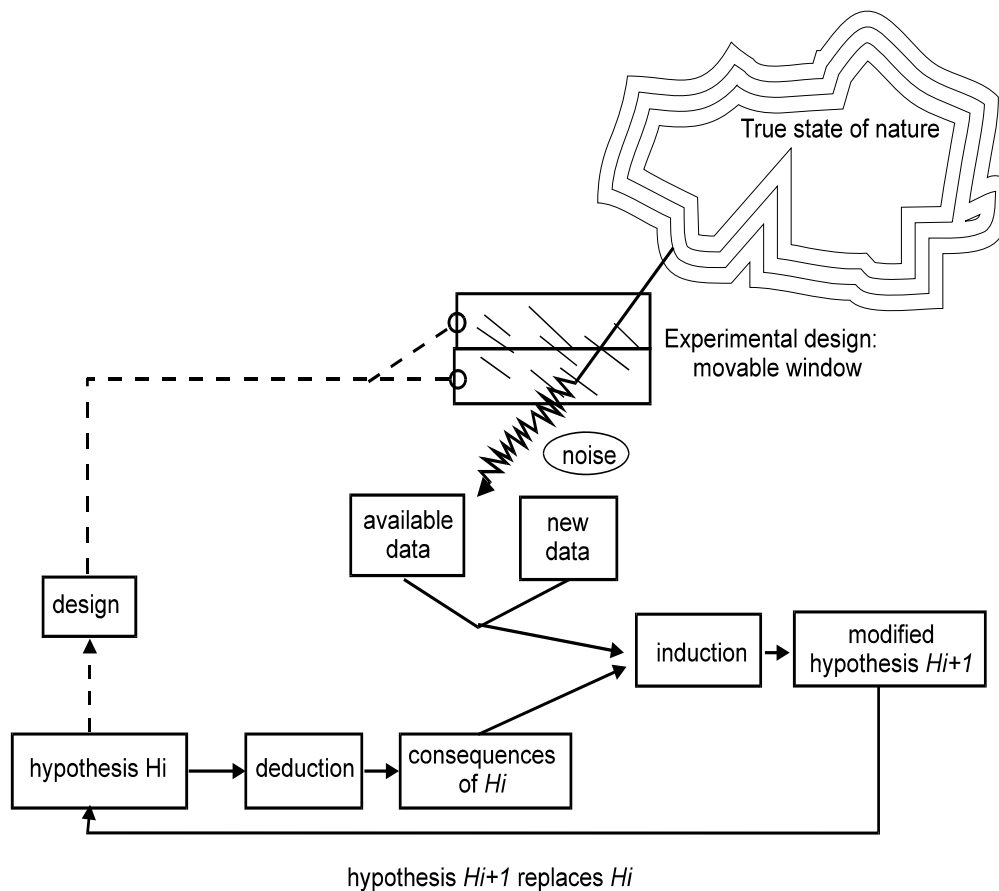


Fig. 1. Role of experimental design

The selection of the design depends on the objectives

1. 4. 2. Objectives and experimental design

The selection of experimental design depends on the objective.

Variety screening trial: maximize accession number (less replication).

Variety release trial: appropriate replication for high precision.

The *scope* of the experiment is also defined by the objectives: if the objective is to infer the future performance of varieties in the Central Valley, the experiment needs to include replications across the valley in multiple years.

1. 4. 3. Hypotheses and experimental design

1. 4. 3. 1. Concepts about hypotheses

A hypothesis is the simplest possible answer to a question, stated in a way that is testable and **falsifiable**.

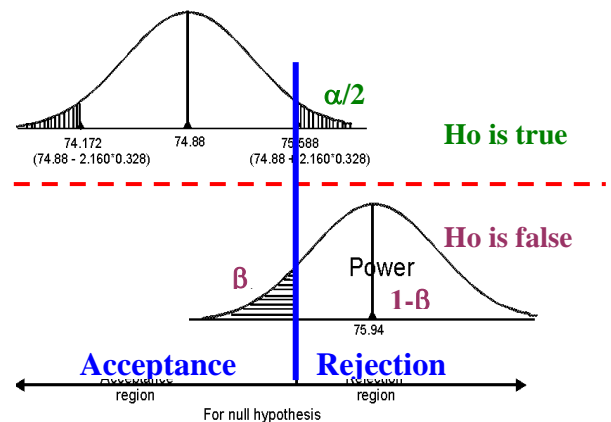
A null hypothesis (H_0) can never be proved correct, but it can be rejected with known risks of being wrong, i.e. falsifiable.

1. 4. 3. 1. Significance level of testing a hypothesis

If H_0 is true: Significance level is the probability that one rejects H_0 when it is correct. Generally $\alpha < 0.05$ (1 error in 20).

If H_0 is false: lowering α increases Type II error = β , which is the probability of concluding that H_0 is true when in fact it is not.

The only way to reduce both errors is to increase the number of replications of improve the experimental design to reduce the error.



		Null hypothesis	
		Accepted	Rejected
Null hypothesis	True	Correct decision	Type I error
	False	Type II error	Correct decision

1. 4. 4. Specific issues of experimental design

Once the objectives, interesting questions, and the hypothesis are defined, the scope, type, and requirements of an experiment are also more or less determined. Thus, *the experiment should be designed to meet those requirements*. Specifically, experimental design is concerned with the following issues:

1. 4. 4. 1. ***The size of the study***: number of replications, and the size and shape of experimental units.
1. 4. 4. 2. ***Type and number of measurements***: availability of a measuring device, precision and accuracy of the measurement, and the timing of making measurements.
1. 4. 4. 3. ***Treatments***: the type of treatments, the levels of treatment, and the number of treatments.
1. 4. 4. 4. ***Assignment of treatments to experimental units***: completely random, restricted randomization, etc.
1. 4. 4. 5. ***Error control***: the error control can be accomplished by blocking techniques, the use of concomitant observations, the choice of size and shape of the experimental units, and the control of the environment using a growth chamber or greenhouse.
1. 4. 4. 6. ***Relative precision of designs involving few treatments***: to compare two experimental designs one compares amounts of information.

Among the above considerations, **replication** and **randomization** are the most important basic principles in designing experiments.

1. 4. 4. 1. Replication .

Functions of replication.

- To provide an estimate of the experimental error. The *experimental error* is the variation which exists among obs. on e.u. treated alike.
- To improve the precision of an experiment by reducing the standard deviation of a treatment mean.
- To increase the scope of inference of the experiment by selection and appropriate use of more variable experimental units.
- To effect control of the error variance.

Distinguishing between replications, subsamples, and repetitions

Replication refers to the number of experimental units that are treated alike

- (1) Each replication must be **independent** of every other.
- (2) Each replication must be part of a **randomized** trial

Example: Field trial. Comparison among 3 fertilizer treatments, A, B, & C.

1	2	3
4	5	6
7	8	9
10	11	12

N
↑

Case 1: 4 plots are selected at random for each fertilizer. This is a *completely randomized design*. There are 4 replications for each treatment. If the experiment is run in succeeding years then each year provides a different set of replications.

Case 2: Same as case 1 except the crop is a perennial. In this case the succeeding years are not replications. The fact that the crop is a perennial violates the independence requirement above. This is a repeated measures experiment.

Case 3: Same as case 1 except each of the 12 plots are further divided into three subplots. These subplots are *not* replications, they are subsamples. The randomization requirement above is violated.

Case 4: The numbers 1, 2, and 3 are arranged in a random order. Each treatment is applied to all plots in a north-south column containing the randomly selected number (e.g. tr. 1 is applied to plots 2, 5, 8, and 11). In this case each experiment is one column. The separate plots are subsamples.

1. 4. 4. 2. Type and number of measurements

Practical considerations

- Practical considerations are availability of measuring device and costs.
- Sometimes *indirect measurements* are cheaper than direct measurement.
- At times it is not practical to make an observation on the complete experimental unit and the unit is sampled.

Theoretical considerations

Precision of a measurement has to do with the concept of random errors. Precision, sensitivity, or amount of information is measured as the reciprocal of the variance of a mean.

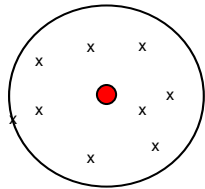
If we let I represent information per replication, then

$$I = 1 / \sigma_Y^2 = n / \sigma^2$$

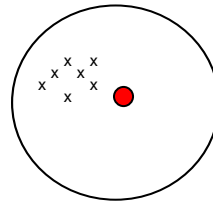
If s_Y^2 is used as an estimate of σ_Y^2 $\rightarrow I = (n + 1) / (n + 3) s_Y^2$

when $n \rightarrow \infty$ $(n + 1) / (n + 3) \rightarrow 1$

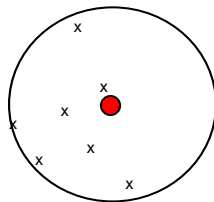
Accuracy is associated with the concept of bias or systematic errors.



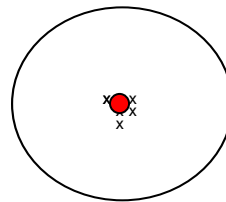
Accurate but not precise



Not accurate but precise



Not accurate and not precise



Accurate and precise

1. 4. 4. 2. 2. Number of measurements

If subsampling is used, the optimum number of samples and samples needs to be calculated. We will learn to do this calculation using the sample and subsamples cost and variance.

1. 4. 4. 3. Type and level of treatments

The actual levels and number of treatment levels are important considerations, particularly when the treatments are quantitative.

- Separation of levels at similar intervals facilitate mean comparisons
- The number of levels is important to determine the nature of the response (for example linear or curvilinear response).

1. 4. 4. 4. Assignment of treatments to experimental units

The functions of **randomization** are

- To have a valid estimate of experimental error and treatments means
- To neutralize systematic biases
- To determine independent errors that is an assumption of ANOVA

1. 4. 4. 5. Error control [ST&D p. 130]

- **Blocking**: some of the natural variation among e.u. can be extracted from the error term by blocking
- **Covariates**: the use of accessory observations and analysis of covariance can be used to adjust environmental differences and increase precision.
- In field plot experiments, the size and shape of the e.u. are important in relation to precision. Long and narrow blocks with long sides of the plots parallel to the direction of the gradient increase precision.

1. 4. 4. 6. Relative precision of designs involving few treatments

Relative efficiency of design 1 relative to design 2

$$RE = \frac{\text{Information}_{\text{design}_1}}{\text{Information}_{\text{design}_2}} = \frac{(n_1+1)/(n_1+3)s_1^2}{(n_2+1)/(n_2+3)s_2^2} = \frac{(n_1+1)(n_2+3)s_2^2}{(n_2+1)(n_1+3)s_1^2}$$

Where s_1^2 and s_2^2 are the error mean squares of the first and second designs, and n_1 and n_2 are their degrees of freedom. This is for $n_1=n_2$.

If $n_1 \neq n_2$ then replace s^2 by $s_{\bar{y}}^2$

If the ratio is >1, design 1 provides more information and is more efficient than design 2