Experimental Design

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Rule Number 1
You must never begin an experiment if you do not know, in advance, how you will analyse the data.

What is an experiment?

Experiments are fundamental to the progress of science. They are the means by which theories are developed, tested or refuted. What are the characteristics of an experiment? In these notes experiments are restricted to those that require some statistical consideration of the data.

Some definitions

1. 'we consider an experiment as a planned inquiry to obtain new facts or to confirm or deny the results of previous experiments, where such inquiry will aid in an administrative decision, such as recommending a variety, procedure, or pesticide.' (Steel and Torrie, 1980).
2. 'An experiment is a device to make Nature speak intelligibly' (G. Wald, Nobel Lecture 1967).
3. 'An experiment is any operation whose outcome cannot be predicted with certainty' (Unknown origin).

Must experiments be designed?

Experiments *need* to be designed, in the sense that they do not just happen'. (A.C. Wardlaw, 1985). It is obvious that experiments do not happen by a process of divine creation, but many are undertaken without a formal design. Failure to design experiments almost always leads to a waste of time and resources.

There is more than one type of experiment

Steel and Torrie (1980) recognised three types of experiment:

1. *preliminary*: a large number of treatments are tried in order to obtain leads for future work
2. *critical*: responses to different treatments are compared using sufficient replicates to give reasonable assurance of detecting meaningful differences
3. *demonstrational*: new treatments are compared with a standard.

Other workers recognise two broad classes of experiments:

Observational or Survey : experimental conditions are not manipulated, one or more responses are measured and correlated with one or more 'environmental' measurements. This type of experiment includes techniques such as questionnaire surveys. This approach to experimentation allows us to *induce* relationships but it is rarely possible to demonstrate cause and effect . However, the results may provide a useful source of hypotheses for manipulative experiments.

Manipulative : The experimenter manipulates and controls the experimental conditions in the hope that cause and effect relationships can be demonstrated. This approach allows use to *deduce* relationships.

Diamond (1986) highlighted the advantages and disadvantages of three types of experiment (from an ecological context - but the observations are more general). The following table is modified from Diamond (1986)

Feature	Laboratory experiment (Manipulative)	Field experiment	Natural experiment (Observational)
Control of independent variables	Excellent	Medium	Poor
Inference ability	Good	Medium	Poor
Scale (time & space)	Poor	Medium	Good
Scope (manipulation range)	Poor	Medium	Good
Realism	Poor	Good	Excellent
Generality	Poor	Medium	Good

How can a 'good' experimental design be identified?

A good statistical design should be able to satisfy the following criteria:

1. Null and alternative hypotheses were defined prior to collecting the data.
2. You understand the principles of the statistical analysis and will be able to successfully complete the calculations.
3. The experiment provides an unbiased estimate of experimental error.
4. Preliminary estimates of the inherent variability of the system are available to enable power estimates to be made.
5. Sufficient replicates have used to detect the smallest difference of practical importance.
6. Too many replicates have not been used, thus ensuring that unnecessary resources, e.g. animals, have not been used.
7. The populations that you are sampling have been carefully defined.
8. Where possible, all potential causes of variation have been incorporated into the design.

Some relevant definitions

Experimental Unit
Factor
Level
Treatment
Quantitative factor
Qualitative factor
Random factor
Fixed factor
Replication
Randomization
Restraint

Types of Design

There are a large number of classes of experimental design. They differ with respect to the relationship between the experimental treatment(s) and the measured response. The following summary table is based on Table 7.1 in Brown and Rothery (1993).

Population characteristics	**Experimental aims**	**Sampling design**	**Experimental design**
Homogeneous random variation	Estimating and comparing population parameters	Simple random sampling	Completely randomised design
Heterogeneous with systematic and random variation	Estimating and comparing means	Stratified random sampling	Randomised block design
Trends	Analysis of pattern and process	Systematic sampling	Response surface Repeated measures
Factorial structure	Estimating and comparing means for combinations of factors	Factorial designs	Factorial designs
Dependence relationship	Prediction of a value from a single predictor	Simple random sampling	Regression analysis
	Prediction of a value from more than one predictor		Multiple regression

These, plus other designs, will be illustrated by means of an example.

You are hoping to market a new foliar feed, especially designed for tomatoes. You wish to demonstrate its effectiveness by experimentation. Before you begin you need to answer some questions.

- What plant response will you measure: whole plant growth, tomato yield, flavour, photosynthetic rate, etc.?
- What treatments will you apply?
- How many replicates will you use?
- Which tomato variety will you select?
- What medium will you grow them in?
- Where will you grow them?
- How long is the duration of the experiment?

The experiment that you design depends on the what type of relationship, between the foliar feed and the plant, you are hoping to demonstrate. Some examples are described below.

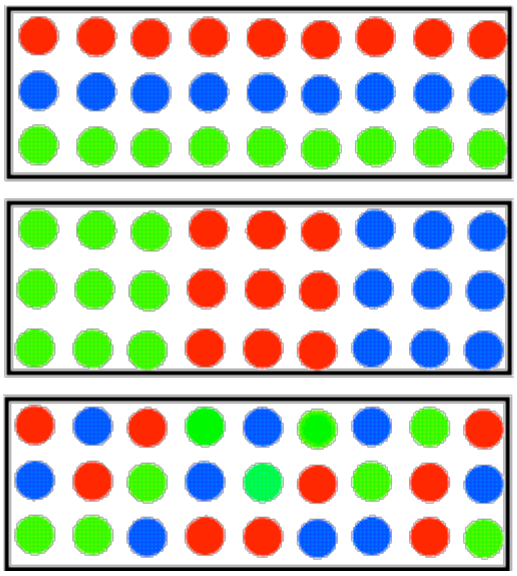
A. Is the foliar feed better than a 'standard' soil-based fertilizer?

In this simple experiment you apply 3 treatments:

1. Control : no fertilizer
2. Foliar feed applied at recommended rate
3. Soil-based feed applied at recommended rate.

You select the common variety 'Moneymaker' and replicate each treatment 9 times. The plants are grown for 5 weeks prior to starting the experiment, 1 plant per 20cm pot. The response will be tomato yield after 12 weeks. The plants are to be grown on a bench in a glasshouse. Some questions you may wish to think about.

- How will you arrange the plants in the greenhouse: 3 rows of 9; 3 columns of 9, 3 3x3 blocks, randomly positoned?



- How will you ensure that there is no cross contamination of the foliar feed (which is sprayed on)?
- How will you ensure that each plant receives exactly the same amount of fertilizer (a particular problem if you are spraying)?

Assuming that you randomly allocate and position the plants this would be a completely randomised design.

B. How is the yield related to the amount of foliar feed?

There are two approaches to this problem. If you know that relationship is linear, or can be made linear by a transformation, you could use simple regression. If you suspect that the relationship may be non-linear a more appropriate method would be *orthogonal polynomial partitioning* or response curve analysis.

C. How does the product act in conjunction with your red spider mite spray?

Red spider mites can be a major pest of glasshouse-grown tomatoes. You produce a leaf spray which is supposed to kill them. But, will they both function when used in conjunction. In order to test this you design an experiment which has the following four treatments.

	Foliar feed used	**No foliar feed**
Anti mite spray used	**1**	**2**
Anti mite spray not used	**3**	**4**

The appropriate analysis for these data would be factorial analysis of variance with both factors fixed.

D. Is the product effective with different tomato varieties?

In the previous experiments only one variety, Moneymaker, has been used. It would be interesting to test other varieties. Which varieties will you choose and why? Suppose that you decide to test four varieties, are you interested in these four or are they just four 'representative' varieties. In other words is variety to be a fixed or a random factor. The appropriate analysis for these data would be factorial analysis of variance with one fixed factor (foliar feed) and one random factor (tomato variety).

E. What do you do if you suspect that there is a strong light gradient in the glasshouse?

If you can recognise, but not control, some potential causes of variation you should attempt to incorporate these uncontrollable factors into the design. If there is one uncontrolled environmental factor a randomised block design may be appropriate.

F. What do you do if you suspect that there are strong light & temperature gradients in the glasshouse?

If you can recognise, but not control, some potential causes of variation you should attempt to incorporate these uncontrollable factors into the design. If there is more than one uncontrolled environmental factor a latin square design may be appropriate.

G. What do you do if you want to investigate the effects of the foliar feed, variety, spider mite spray simulataneously whilst taking account of environmental gradients in the glasshouse?

It is possible to design *fractional* factorial experiments where not all treatment combinations are represented. Minitab Release 11 has a facility for the design and analysis of this type of experiment. The Minitab approach is based on Plackett-Burman designs.

H. What do you do if you want to determine the effects of the foliar feed over time?

If multiple measurements are to be taken from one experimental unit the data are REPEATED measures and require appropriate analytical methods. Be warned that this type of data can be difficult to analyse.

Menu	**Univariate Statistics**