Principles of Design
Best for Africa
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1 Research and design of experiments

The essence of much scientific investigation is the setting up of an experiment to answer a specific research question. If a researcher uses a robust design then the project will potentially get the maximum amount of information from the available research resources (which includes physical resources, e.g time or money, use of labour etc).

1.1 Importance of random sampling

A sample is an important concept in biometry. In a plant study consider a population (all possible plants that could be theoretically sampled); the plants in your particular sample have been selected by you for measurement. To be useful we need the plants in our sample to be *representative* of all plants that could be selected.
We need to think about what could bias our results, for instance if we took predominately the larger ones or we chose predominately the smaller plants the sample mean would not be representative. Consider how you could randomly select animals to be entered into a feeding trial, or randomly select rural households to be selected for a survey, or other individuals to be part of a study.
Think about this in terms of samples you may have taken in research projects that you have been involved with. How would you take a random sample? In the practicals and demonstration material there is a demonstration on how to randomly select your units. This will be a one-stage randomisation, it is simple but the principle is that all plots or individuals have an equal chance of being chosen for that treatment.
In more complex studies a 2-stage randomisation is on occasions necessary. A nested design, a multilevel design or a split plot design requires more than one randomisation.

There are several ways to randomise simple experiments:

- Write the numbers (ID) of the individuals, place in a 'hat'. Take out the papers one by one, until you have your random sample. (Don't laugh this can still be used easily for small samples!)
- Use of Random number tables
- Use of Excel to randomise
- We will use R to randomise some designs in Module 2
- Use of Software - often quite involved and not widely used.

1.2 Planning an experiment

The types of questions in planning for an experiment are:

- How many treatments are to be studied?
- How many replicates are required?
- What time frame do I need to collect all the measurements?
- What will be the experimental unit? (treatments are applied independently and measured independently)
- How are the treatments to be applied? (considering all the practical limitations/specifications)
- If it is a large experiment, can we gather the data in a sensible time frame ?
- Can the design be analysed and can the comparisons of interest be made ?
- Do we have the resources (e.g. money, research assistants etc.) to adequately conduct the experiment ?
- Do I know and understand the methods required to analyse the data I have collected ?
- Have I verified my design with a statisticain?

1.3 Scientific method

The steps involved in research can be summarised as the scientific method. The steps taken include:

1. Understand the theory and the practical problem to solve
2. Develop a research hypothesis
3. Consider an appropriate experimental design
4. Select representative samples to collect data on
5. Decide on experimental treatments
6. Statistical analysis
7. Use the statistics to estimate parameters
8. Test hypothesis - to evaluate the results
9. Revise the theory or apply the information -often it gives rise to more research questions

The evaluation method used is statistical testing and this is where decision rules are set for when we analyse the results. These questions and rules are set at the start of the study, and include the accuracy associated with the decision (more on this in chapter 4).

1.4 Treatments

A treatment in an experiment may simply be one comparison, whereby something is controlled in one group differently to a second group. For example a simple variety trial of two breeds of wheat, we compare plots of one variety with a second variety.

In larger experiments we may consider comparing more than two treatments. In a fertilizer experiment we may wish to compare 3 different rates of fertilizer. Fertilizer in this study would be a **factor** with each rate being a treatment (high, medium and low). The three treatments are referred to as 3 **levels** of fertilizer.

In some experiments there are two factors- say we were interested in fertilizer **and** two irrigation treatments. So this would give us a second factor (irrigation) at two levels. We can consider 'treatment combinations' when we have variety A with low fertilizer and all combinations through to Variety B with high fertilizer. This is a 2 by 3 factorial design; there are two factors. Treatments are usually something we can control (such as adding something, change something. (for example water, fertilizer, mulch, type of tillage, type of pest control). In an agribusiness setting we might be comparing two marketing strategies for our products or services. We might be comparing two systems of production. In food science we could be comparing two processing methods, temperatures, cooling times, packaging etc.

1.5 Randomisation

This is important and assists in making our experiment robust (less likely to be affected by bias). So how do we randomise ? In a small study it may be OK to put numbers (in a hat) and pull out the treatments to assign to a plot one by one. But for large experiments (and to assist in forward planning) it is best to randomise ahead of going out in the field to collect the data. We can use Excel as it is faster, and you can save your randomisation in a file. Another way to randomise is to use a statistical package, they are often not that useful and Excel is often quicker and more intuitive. Using statistical software for randomisation is possible, but not taught in this course. The use of Excel to set up randomisation of most basic designs is adequate- and also allows a spreadsheet for data collection to be available. Plot plans can be printed and used for data collection in the field.

1.6 Replication

In some studies we may only have two treatments or groups. If we had just two values for yield - this is not enough information. Rather than take one value we need to sample to be able to do some statistical analysis. We formally set up replicates in many experiments. A balanced design is one where the replication is balanced and there are equal numbers of plots or units for each treatment. Figure **??** shows the progression from asking a research question, collecting some replicated data to get a mean and sd for one variety, and leading on to the testing of two samples, and then on to more than two groups.

1.7 Reduction of experimental error

When undertaking a study the experimental protocols are a vital part of good experimental design. We aim to reduce residual error, so anything we do to undertake a consistent and repeatable measurement, the lower the experimental error in our experiment. It is useful to get advice from other scientist that have collected measurements, or used the equipment before. Some equipment needs careful calibration or set up to collect good data. Environmental monitoring of glasshouses, laboratories and and other facilities allow conditions in the experiment to be monitored and controlled.

1.8 The value of a well conducted experiment

- Efficient use of research funds
- Valid research and attention to the scientific method
- Allows the method and results to be defended and withstand scrutiny
- The researcher can present results with confidence at meetings and conferences
- No time is wasted by being rejected due to statistical issues
- We are not embarrassed in front of peer groups or at public forums

1.9 Assumptions in statistical testing

- normality- the data is from a normal distribution, (this assumption is related to the use of 'parametric' statistical techniques). We are not covering non-parametric techniques in this course.
- homogeneity of variance - the variances are similar (we can test for this)
- independence of observations - data items are collected independently

1.10 Blocking and environmental gradients

It is often found that there are gradients of temperature, humidity, light levels or air flow that can affect plant growth.

In a field there are typically some gradients in soil depth, soil texture, soil moisture and soil fertility which may be important to consider. In field experiments it is also useful to know the past cropping and tillage history. Carry-over effects (in fertility, or water availability) across part of your field could affect plant yield in a subsequent year. These effects can obviously affect plant growth and yield - they affect biological variability and are an important consideration for researchers.

1.11 The experimental unit

The unit on which measurements are made such as a pot in a glasshouse, a plot of land in a field trial, a pen of several animals, or an individual animal or plant is called the **experimental unit**. In the laboratory this could be an item of packaged food, a product for testing or tasting, a petri dish, a DNA sample etc. This unit needs some thought for your *particular type* of experiment you may be looking at a different experimental units. For instance in an agronomy or crop physiology trial in the field the experimental unit is typically an area of land called a plot (e.g. In an agronomic trial it may contains 4 rows of crop by 2 m length of row), and in plant breeding trials a plot may be the length of a single row. In a glasshouse drought trial one plant in a pot or several plants in a pot can be the experimental unit. The experimental units are independent from one another since the treatment is applied to each experimental unit. In some studies it is very important to discuss the experimental unit with a statistician. In growth chamber studies, in laboratory studies using ovens, incubator, freezers etc. There are examples of incorrect analysis in the scientific literature (examples occur in growth chamber studies where several comparisons are made inside one chamber). In fact several chambers are required to undertake one experiment. Growth chambers are very controlled environments and the conditions need replicating.

1.12 Independent samples

In all of our analysis we assume the data items are independent. This means that if you know the value of one experimental unit you cannot predict anything about another unit. In our assumption for statistical testing, we assume individual values in our sample are independent.