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Department of Primary Industries

Experimental design and analysis

Stage 6 Agriculture

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Supporting document

NSW DPI Schools Program

Authors: Meg Dunford (Project Officer School programs, NSW DPI Orange), Lorraine Spohr (Biometrician, NSW DPI Central Coast Primary Industries Centre), Elizabeth Mudford (former NSW DPI Biometrician and Education Officer).

Editors and Advisors: Michelle Fifield (Education Officer Schools, NSW DPI Orange) and Jo Hathway (Project Officer School programs, NSW DPI Tocal College).

Acknowledgements: Co-authors of NSW DPI Biometrics Basic Statistics course, Stephen Morris (Biometrician, NSW DPI Wollongbar), Beverley Orchard[1] and Sharon Nielsen[1] ([1]former NSW DPI Biometricians).

Experimental design and analysis

Syllabus context - Stage 6 Agriculture

This supporting document uses a holistic approach to cover all syllabus outcomes relating to experimental design and analysis in the NSW Stage 6 Agriculture course and as a result its application may extend to other syllabus areas.

Resource description

This workbook has been designed as a digital resource, therefore, to use all aspects, students will require access to the internet to follow embedded links throughout the document.

Past questions

All sample HSC examination questions used or adapted in this resource are identified and linked to the NSW Educational Standards Authority (NESA) website.

HSC verbs and key words

It is essential students address the following key terms and verbs when answering questions. The following glossary developed by the NSW Education Standards Authority is provided to assist with the answering of activities throughout this booklet.

Key Word	Definition
Account	Account for: state reasons for, report on Give an account of; narrate a series of events or transactions
Analyse	Identify components and the relationship between them; draw out and relate implications
Apply	Use, utilise, employ in a particular situation
Appreciate	Make a judgement about the value of
Assess	Make a judgement of value, quality, outcomes, results or size
Calculate	Ascertain/determine from given facts, figures or information
Clarify	Make clear or plain
Classify	Arrange or include in classes/categories
Compare	Show how things are similar or different
Construct	Make; build; put together items or arguments
Contrast	Show how things are different or opposite
Critically (analyse/ evaluate)	Add a degree or level of accuracy depth, knowledge and understanding, logic, questioning, reflection and quality to (analyse/evaluate)
Deduce	Draw conclusions
Define	State meaning and identify essential qualities
Demonstrate	Show by example
Describe	Provide characteristics and features
Discuss	Identify issues and provide points for and/or against
Distinguish	Recognise or note/indicate as being distinct or different from; to note differences between
Evaluate	Make a judgement based on criteria; determine the value of
Examine	Inquire into
Explain	Relate cause and effect; make the relationships between things evident; provide why and/or how
Extract	Choose relevant and/or appropriate details
Extrapolate	Infer from what is known
Identify	Recognise and name
Interpret	Draw meaning from
Investigate	Plan, inquire into and draw conclusions about
Justify	Support an argument or conclusion
Outline	Sketch in general terms; indicate the main features of
Predict	Suggest what may happen based on available information
Propose	Put forward (for example a point of view, idea, argument, suggestion) for consideration or action
Recall	Present remembered ideas, facts or experiences
Recommend	Provide reasons in favour
Recount	Retell a series of events
Summarise	Express, concisely, the relevant details

Source: NSW Education Standards Authority, 2019

Experimental design and analysis glossary

The following terms are specific to statistics and experimental design.

Key word	Definition
Aim	A formal statement of the purpose of the investigation.
Analysis of Variance (ANOVA)	ANOVA tests the hypothesis that all treatments means are equal. The technique assesses differences in means by comparing the amount of variability explained by different sources. (Ramsey & Schafer 2002)
Biometry	Biometry is the application of statistical experimental design and analysis methodology to the life sciences.
Blinding	Blinding refers to taking measurements without knowing which sample received which treatment. Blinding reduces assessor bias, to attain objective measurements or assessments.
Blocks	Blocks are groups of experimental units that are formed to be as similar as possible. The term block comes from the agricultural heritage of experimental design where a large block of land was selected for the various treatments, which had uniform soil, drainage, sunlight, and other important physical characteristics.
Continuous data	These observations have a numeric value which occurs in a continuous range. For example height, weight and temperature, increasing or decreasing numeric values.
Conclusion	A summary based on the investigation results and how these match the hypothesis stated.
Control treatment	This is the treatment in an experiment that does not receive any treatment or represents the current practice or industry standard. The control is a baseline or reference point which allows for comparison.
Controlled variable	A variable that is kept constant (or changed in constant ways) during an experiment.
Descriptive statistics	Deals with methods of organising, summarising and presenting numerical data in a basic form.
Dependant variable	The variable that is measured and changes in response to the independent variable. For example: crop yield changes dependant on the amount of fertiliser applied. The dependant variable is usually plotted on the y axis (vertical axis) of a graph.
Discrete data	Discrete data observations are distinct and separate i.e. they can be counted (for example, 1, 2, 3, etc.). For example: the number of piglets in a litter, or the number of farms in a district.
Discussion	An in-depth discussion of the scientific significance of the results. The discussion also provides an evaluation of the investigation, including limitations.
Distribution	The distribution of a variable tells us what values the variable takes and how often it takes these values.
Experiment	Any process which results in the collection of data to discover something about a particular process or system.
Experimental design	The process of planning a test or series of tests to meet specified objectives.
Experimental unit	An experimental unit is the physical unit to which a treatment is applied.
Extraneous factors	All variables, which are not the independent variable (what you are testing), which could affect the results of the experiment.
Independent variable	The variable that is changed on purpose in an investigation to see what effect it has on the dependent variable e.g. time, temperature, type of fertiliser, type of feed, amount of water and age. The independent variable is usually plotted on the x axis (horizontal axis) of a graph.
Hypothesis	A statement of the expected outcome made prior to the experiment.
Mean ($\bar{x}$)	Average of the observations. Numerically it equals the sum of the observations divided by the number of observations. Mean = sum of observations ÷ number of observations
Measures of central tendency	Summarise data into a single value which represents the centre (middle) of all the values in the data. Examples include mean and median.
Measures of spread	Summarise data in a way which shows how scattered the values are and how much they differ from the mean value. Examples include the range, variance and standard deviation.
Median	The observation that falls in the middle of a set of measurements when the measurements are arranged in order from lowest to highest to.
Method	A procedure describing the sequence of steps, or process of the investigation.

Observational unit	The smallest unit on which a measurement of the dependent variable is made.
Outlier	An observation in a data set which is far removed in value from others in the data set.
Population	The entire group of individuals of interest. Agricultural experiments rarely look at data from a whole population but use data from a sample.
Probability	The proportion of times the event occurs in repeated trials.
Qualitative data	Data which can be sorted into distinct categories. Examples include data relating to colour, flavour, tenderness, softness, appeal and ease of use. Qualitative data can be nominal (e.g. hair colour) or ordinal (e.g. disease score with clear ranking).
Quantitative data	Data obtained by measuring the amount of some trait in an individual plant or animal. Some examples of quantitative data are number of pods, height, size, weight, yield, percentage and length.
Range	A measure of the spread of the data. It is the difference between the largest and smallest observed value. Range = largest value- smallest value
Randomisation	The condition that the probability of an experimental unit receiving a treatment is exactly the same for all units. The purpose of randomisation is to reduce bias.
Replication	Replication is the process of repeating the same treatment a number of times.
Sample	A sample is a group of individuals which are part of the population chosen for use in an experiment.
Significance	Usually refers to 'statistical significance'. A result is statistically significant when the probability of it occurring by chance is very small. The level of chance that is well accepted is 0.05 (5%)
Significance level	The significance level of a hypothesis test is the probability that the result has occurred by chance. Usually it is 0.05 (5%).
Standard deviation (s.d.)	Standard deviation of a sample is calculated by taking the square root of the sample variance. It indicates how the individual observations in a data set are dispersed or spread out around the mean.
Standardisation	Ensures that all treatments in the trial are subjected to the same conditions (other than the independent variable being investigated). It helps ensure that one part of a trial is not advantaged, or disadvantaged by an external factor.
Statistical inference	The process of drawing conclusions about a population based on information in a sample.
Title	A concise description of the project.
Treatment	The independent variable studied in an experimental study and assigned to an experimental unit. The experiment determines whether the treatment has an effect on the dependent variable of interest.
Validity	An extent to which tests measure what was intended, an extent to which data, inferences and actions produced from tests and other processes are accurate.
Variance	Variance of a sample is the average of the squared distances between each data value and the sample mean. The square root of the variance is called the standard deviation.
Variables	In an investigation, a factor that can be changed, maintained or measured e.g. time, distance, light and temperature.

Syllabus point

Outline the role of a control, randomisation, replication and standardisation of conditions in a simple plant or animal trial

DPI Rice trials at Yanco, NSW Courtesy of Tina Dunn, Technical Officer (Water and irrigation)

Experiments or trials are carried out to discover something about a chosen subject matter. The terms 'experiment' and 'trial' will be used interchangeably throughout this resource. An experiment is a systematic test or series of steps to investigate or answer a research question in a scientifically valid manner. Experiments are carried out by scientists and researchers in virtually all fields of inquiry.

The scientific process used to design and conduct a simple trial is summarised in Figure 1. Experimental design is an essential part of the scientific process. This resource will consider each of the steps used in the process individually.

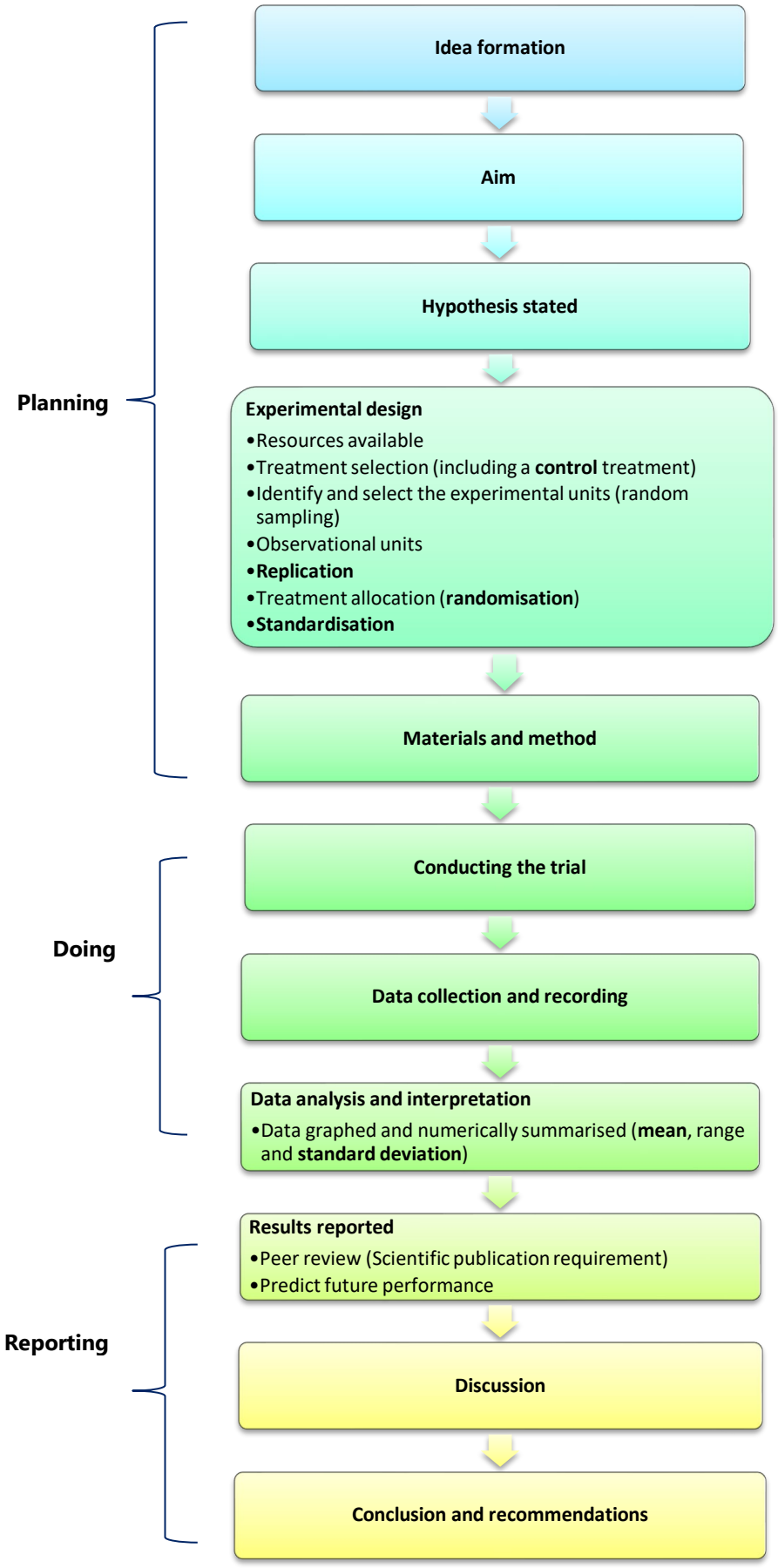


Figure 1 Steps required to design and conduct a simple trial based on the scientific process

Idea formation

The idea for a trial usually arises from a research question we would like to answer. This could be the identification of a problem which requires a solution or seeking greater knowledge of a subject which is not well understood.

Once the research question has been decided a literature search is undertaken to determine the existing knowledge related to the research question. This background information will be used to help plan the trial. It is important to undertake a thorough literature search to determine if the research question has already been answered and what further investigation is required. The outcome of a trial should be to expand or confirm existing knowledge.

The findings of a literature search may be summarised by writing a literature review which will provide background information for the trial. The key points from the literature review are usually included in the introduction section of a scientific report. The sources of information found during your literature search are recorded as references for your final report.

Aim

The aim is the formal statement of the purpose of the trial. The aim of the trial is written in terms of the independent and dependent variables.

Independent variables are factors changed on purpose in an investigation e.g. temperature, type of fertiliser, type of feed, amount of water. An independent variable is changed in an investigation to see what effect it has on a dependent variable.

Dependent variables are the responses measured in an investigation e.g. weight, length, yield, micron etc. The dependant variable changes in response to the independent variable, for example, crop yield depends on the level of fertiliser applied.

An example of an aim would be 'To investigate the effect of the amount of nitrogen fertiliser on the yield of wheat' where the independent variable would be the amount of nitrogen fertiliser applied and the dependent variable would be the wheat yield.

Hypothesis

The hypothesis is a statement predicting the outcome of the trial. A hypothesis is developed using the knowledge gained through the literature search. A hypothesis is written in terms of the independent and dependent variables stating the predicted effect the independent variable will have on the dependent variable.

An example of a hypothesis would be 'increasing the amount of nitrogen fertiliser applied will increase the yield of wheat'.

Experimental design

In junior science, when carrying out investigations, the term 'fair test' is used. Carrying out a fair test relies on the principles of experimental design.

Experimental design includes:

1. Selecting the treatments to be applied, responses to measure and number of replicates;
2. Defining experimental and observational units;
3. Determining the physical arrangement, or layout, of treatments and replicates.

In agriculture, experiments should be designed to account for natural biological variability.

In simple animal and plant trials at the school education level, the fundamental features of good experimental design are:

- Randomisation
- Replication
- Standardisation and
- Inclusion of a control treatment.

These four features allow for meaningful results to be captured, valid comparisons to be made and reliable conclusions to be formulated.

Resources available

When designing a trial it is important to identify the resources which are available to ensure the design is practical and can be conducted within the resource constraints. Time and resources always limit experimental design, and in some instances, there are ethical and legal constraints as well (Articles.extension.org, 2019).

Often physical resources such as the amount of land or number of animals will be limited. There may be limited funds available for purchasing resources such as fertiliser or feed. Having more resources available places less limitations (constraints) on the experimental design.

It is useful to develop a list of all the resources available or that can be acquired before planning the details of the experimental design. All of the required resources must be available before conducting the experiment. Resources include everything from measuring instruments to labour and skills.

Treatment selection (including a *control treatment*)

Once the research question and hypothesis have been settled, the researcher chooses a set of treatments to impose on the experimental material with the hope that the research question can be answered with confidence. The treatments are based on the independent variable identified in the aim and hypothesis. Examples of treatments for plants are different fertiliser rates, light intensities, or plant varieties. Examples for animals include protein levels in feed and stocking density.

When selecting treatments a control treatment must be included. The control is the treatment in an experiment that either:

- Does not receive any treatment (untreated control) or
- Receives a standard treatment or current practice that can be understood as a baseline for comparison. For example, treated control such as water only in a chemical spray trial, or an industry recommendation for sowing depth, row space or fertiliser rate.

The control treatment provides the baseline for comparison of treatment effects. For example, a project is set up to determine if a new treatment is better than the current practice. If this is the case then the current practice becomes the control treatment.

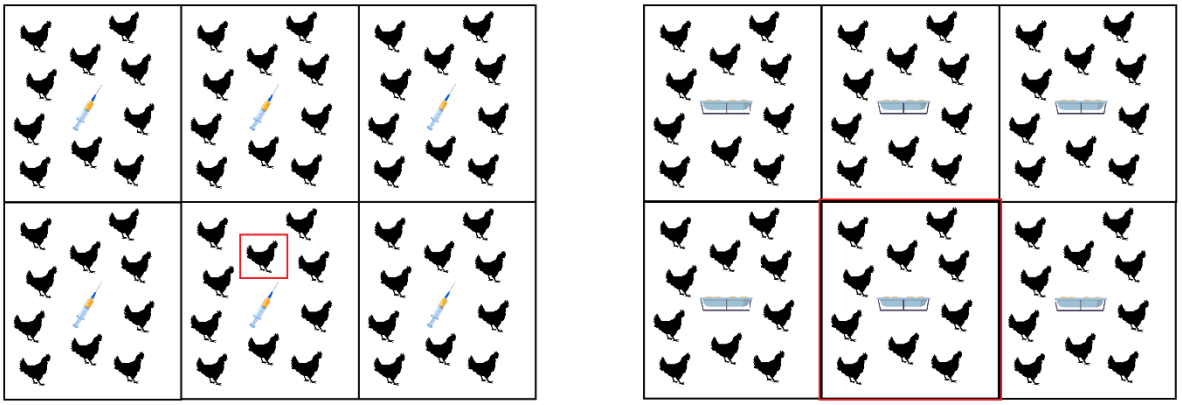
Identify and select experimental units

The experimental unit is defined as the physical unit to which a treatment is applied.

Example

In a trial comparing different vaccines for a disease that affects chickens, the vaccine is applied to individual chickens, so each chicken is the experimental unit. However, in a trial comparing chicken feeds with different protein levels, where all chickens in the pen use one common feeder, the experimental unit is the pen of chickens, not each individual chicken.

These examples show the experimental unit can be different in different contexts, even when the physical layout may appear the same. Both trials could have used six pens with ten chickens in each pen, but the experimental unit is different in each trial.



Vaccine trial: vaccine applied to each chicken individually.
Experimental unit = individual chicken
In this trial there are 60 experimental units

Feed trial: feed trial comparing feeds with different protein levels.
Experimental unit = individual pen
In this trial there are 6 experimental units

Figure 2 Experimental unit

Once the experimental unit has been decided, the population to be studied needs to be identified to determine how the experimental units will be selected.

Population and sample

A population is the entire group of individuals that we are interested in.

It is often too expensive, physically impossible and unnecessary to measure every individual in a population so a smaller sample is selected. The purpose of a trial is to find out something about a sample and relate this finding back to the wider population.

A sample is that part of the population that is chosen for use in the trial.

A representative sample is selected at random from the population. For example, to determine the germination rate of canola seed from a farmer's crop a sample from the canola seed is collected. The population, in this case, would be all the canola seed from that crop. The results give an indicative germination rate for all of the farmer's canola seed. If 10 samples of seed were randomly chosen from the crop, each sample would likely give a different germination rate. Think of the results from a single sample as just one example of the many possible results.

Random sampling

When a random method is used to select the sample, the conclusions obtained from the sample can be validly related back to the broader population.

The word 'random' in experimental design has a specific meaning; it is not just a haphazard process. Random sampling ensures that the experimental units in the sample are chosen from the population of interest with equal probability.

For example, a researcher wants to conduct a trial using a sample of 60 fish from an aquaculture pond containing hundreds of fish. The researcher must have a random sampling method to capture the fish, otherwise, the sample could be biased with only the slowest moving fish being captured. This would not give a true representation of fish from the whole population.

Eliminating bias in selecting a sample is reduced by using randomised sampling methods such as:

- Simple random sample: each member of the total population has an equal chance of selection. Examples include: every member within a population is allocated a unique number and a random number generator is used to select the sample. Individuals are chosen if their number matches the randomly selected numbers. Another method is using random point sampling which involves drawing a grid over an area, using randomly generated co-ordinates (grid reference points) to identify samples to be studied.
- Stratified sampling: the population is divided into similar (homogenous) groups, known as sub-groups (called strata) and then a sample is randomly drawn from each strata. For example, the study population is divided into differing strata based on characteristics such as weight, sex, age, breed, variety, number of tillers, agricultural region so that the members in each strata are similar. Random samples are then selected from each strata.
- Systematic sampling: samples are chosen through a systematic or uniform method. For example, the first animal or grain sample is randomly selected and then every 'nth' sample from the population is selected afterwards. For example, in a field study investigating insect damage in a crop, after randomly selecting a starting point, samples are then taken at two metre intervals along a transect.

Observational units

During the planning stage of a trial, it is important to decide what response is measured for each of the dependent variables and if the measurement will be from the whole experimental unit or just part of the experimental unit.

The observational unit is the unit on which a measurement is made. Sometimes the observational unit and the experimental unit is the same, other times they are different. When the observational unit is not the same as the experimental unit, the technique for the selection of the observational unit must be specified. It is important that the selection of the observational unit is not biased.

The selection of the specific observational unit should be set prior to the start of the trial. For example, if the observational unit is a single leaf from each plant, the leaf used could always be third leaf from the top of the plant. This prevents the researcher selecting a leaf (intentionally or subconsciously) because its appearance fits the expected result.

Alternatively, the method for selection of the observational unit could use a random selection technique. For example, if the observational unit is single sheep from a pen, the tag number of the sheep could be randomly selected from the list of all tag numbers in that pen.

Replication

Natural biological variability will occur between individual plants or animals, even when these individuals are given exactly the same treatments. Trials using responses from plants and animals account for this variability so that response differences caused by treatments imposed by the researcher can be compared to the naturally occurring variability between individuals.

Replication is integral to experimental design to account for natural variability. Replication is the process of repeating the same treatment a number of times. Replication can occur by applying the treatment several times in one experiment or repeating the experiment several more times. For each treatment, the repeat of each experimental unit is called a replicate.

The experimental unit can be comprised of any number of observational units, but the number of replicates for the treatment stays the same regardless. The number, shape and size of replicates depend upon the nature of the experiment.

When treatments are applied to only one experimental unit each (no replication), then any difference between treatments that is observed may be due to the natural variability and not necessarily due to the treatment.

Example

In a wheat variety trial where the yields for several varieties are compared in order to recommend the best variety for a particular region, the treatments are different varieties. If each variety has only one replicate then we cannot be sure about the cause of any observed yield differences. A high yield might be because that variety was grown on a more fertile part of the paddock, not because it is a better variety. When variety A is applied to three experimental units, which are referred to as replicate 1, replicate 2 and replicate 3 of Variety A, each replicate would be grown in a different part of the paddock giving three yield measurements. Replicating the varieties in more than one place helps us to validly answer the research question - which variety has the highest yield on average.

It is the replication of a treatment which allows an average value to be calculated. Replication also provides an estimate of the variability for a treatment. This estimate of variability is essential in the statistical tests used to compare the relative performance of the different treatments after the data has been collected.

Replication can also be thought of as providing insurance against chance events affecting results. For example, in a variety trial with only one replicate if the grain from variety A was eaten by mice before harvest then there would be no results for variety A.

Number of replicates required

A sufficient number of replicates are needed to obtain a reliable outcome from an experiment.

If there are too few replicates statistical results may not be accurate, however, on the other hand, too many replicates can needlessly complicate the experiment without improving the results. The number of replicates needed depends on the variability that you expect in your experimental units. If this is unknown, then starting with 4 or 5 replicates is common to agricultural research. If the variability is expected to be quite large, then the number of replicates should be increased. A rule of thumb is to do as many replicates as practical within the physical constraints of the research.

Treatment allocation using *randomisation*

As part of the experimental design you need to allocate treatments to the experimental units using randomisation. Randomisation is needed for sound experimental design as it allows valid comparisons between treatments to be made.

Randomisation relies on known random processes to allocate treatments to experimental units. Remember the use of the word ‘random’ in experimental design has a specific meaning; it is not just a haphazard process.

Randomisation is used to ensure treatments are allocated to the experimental units with equal probability. When this occurs, it is valid to claim the effects observed in the results are caused by the experimental treatments. It is sometimes impossible or unethical to randomly allocate treatments to experimental units. For example, if a proposed treatment was potentially harmful to animals, it may be more ethical to find groups of animals that are already exposed to that treatment and compare observations on those animals to a control group. Such a study is referred to as ‘observational’. Cause and effect of treatments cannot be validly claimed easily in an observational study because the observed outcomes could relate to other factors associated with each group

Many statistical software programs can be used to assign treatments to experimental units.

Common Designs for allocating treatments

Completely randomised design (CRD) – all treatments are randomly allocated to experimental units

Advantages:

- Simple technique

Disadvantages:

- Lack of any restriction to the allocation of treatments to experimental units could result in bias where, for example, the best experimental units are all allocated the same treatment.
- All treatments being grouped together from the random process.
- Results may be influenced by unrelated variables or factors such as variations in soil fertility, soil type, border effects, environmental factors, or age, condition score and number of offspring in animals since the CRD has no control of those factors.

Example

A scientist is testing two treatments (A and B) each applied to 5 experimental units; giving a total of 10 experimental units (plots). The experimental units are numbered, then a treatment is randomly allocated to each plot number. The following is a potential design for the trial. Note that in this CRD each experimental unit has the same chance (50%) of being treatment A or treatment B. Each treatment location is completely unrelated to the treatments in the locations surrounding it.

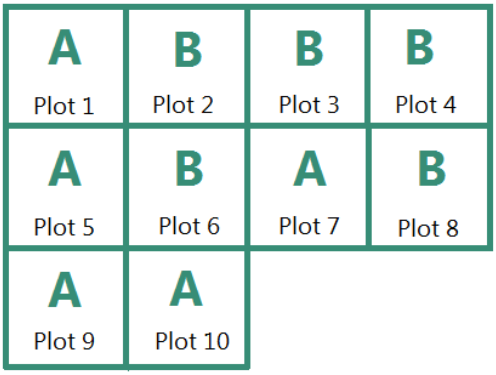


Figure 3 Completely randomised design (CRD) for two treatments (A, B) replicated five times.

Randomised complete block design (RCBD)

Randomised complete block designs (RCBD) are one of the most widely used designs in agriculture. The term 'block' comes from the agricultural heritage of experimental design when researchers conducting field trials selected large blocks of land for 'complete' sets of the various treatments.

In RCBD, blocks of experimental units are formed according to known or suspected variations such as soil fertility, soil type, environmental factors, age, variety or breed, condition score and number of offspring in animals. It is expected that within a block the experimental units are as similar as possible.

Block effects are the factors which you are not intentionally studying.

In RCBD:

- There are as many blocks as there are replicates
- Each block is divided into as many sections (commonly known as plots) as there are treatments
- The treatments are assigned to plots within the individual blocks at random, with a separate treatment randomisation for each block
- Individual blocks are often referred to as replicates. Each block contains all the treatments representing a complete replicate (block 1 contains the first replicate of each treatment, block two contains the second replicate of each treatment etc.)

For example, in a trial using RCBD with 2 treatments (A and B) arranged in 5 blocks, each block contains a replicate for each of the 2 treatments.

Advantages of RCBD:

- Within each block, the conditions are as similar (homogeneous) as possible, but between blocks, differences may exist.
- Even if there are differences between blocks, we can compare treatments using the appropriate statistical analysis that accounts for block effects, since each treatment appears in each block.

Disadvantages:

- Not appropriate when a single block contains considerable variability.

Consider previous CRD example

The simple experiment from the previous example is altered. It is set up as seen in Figure 4 below using five blocks. RCBD is used to randomly allocate the pairs of treatments (either A or B) to each block. Note in RCBD, randomisation is restricted so that experimental units are grouped into blocks and randomly allocated treatments within the block. See how you never get AA or BB within a block, this is due to RCBD.

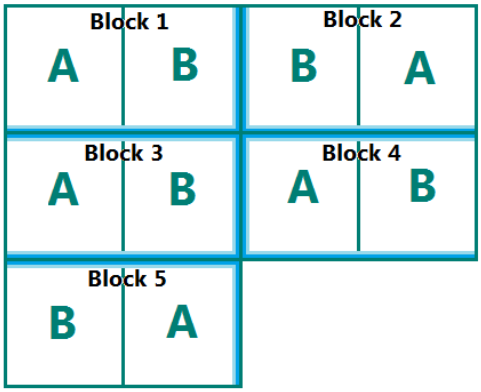


Figure 4 Randomised complete block design (RCBD)

Standardisation of conditions

Standardisation of conditions involves controlling all experimental variables other than the one under investigation. This is important to help ensure that any differences observed between the treatment groups are due to the variable being investigated and not some other factor.

Differences in the dependent variable not due to the treatment could be from natural variability or because of external non-treatment factors. For example, in a fertiliser trial external non-treatment factors could include sowing depth, plant variety, weed control used, plant density and irrigation practices. In an animal feeding trial external non-treatment factors could include animal health treatments (vaccination, worming), stocking rate and animal husbandry practices.

As far as possible, all experimental units (plots, plants or animals) in the trial should be managed in exactly the same way - apart from the treatment being applied. Similarly, when measuring the dependent variable the technique used must be the same for all observational units.

Example

In a fertiliser trial investigating the effect of fertiliser on plant height with two treatments. Treatment A is no fertiliser applied (control treatment) and Treatment B is fertiliser applied. Other variables such as sunlight, soil quality, water supply and plant variety should be the same (i.e. standardised). When standardisation occurs we can be confident that any differences observed in plant height are due to the fertiliser treatment, and not something like one treatment receiving more sunlight than another or using a set of uncalibrated measuring scales.

Equipment use also needs to be standardised. Considerations include:

- Using the same equipment for all treatments
- Taking the time to calibrate equipment
- Ensuring all operators are trained properly to use a consistent methodology

When all methods and equipment use is the same it helps ensure that any part of a trial is not advantaged (or disadvantaged) by external factors.

Standardisation within a block

When standardisation across the whole trial is not practical, the design should incorporate standardisation within a block. A key feature of a blocked design is that each block contains all treatments. For example, harvesting a trial may take 2 days so the use of an experimental design which included blocks is recommended so whole blocks can be harvested on the same day. In a RCBD with 4 blocks and 5 treatments, blocks 1 and 2 could be harvested on day 1 and blocks 3 and 4 harvested on day 2. Harvesting conditions on day 1 are standardised (or the same) for all treatments in blocks 1 and 2. And similarly the other 2 blocks can be harvested the next day. Standardisation within a block is essential.

Materials and Method

This section of a scientific report lists all the materials required and their source, describes the methodology, including details of how each variable was measured, and the experimental design used.

For any trial it is crucial that the method gives enough detail so that the trial can be repeated at another time and place. The method also needs to identify how conditions will be standardised.

Summary

Good experimental design involves managing variables to ensure valid and reliable results. The results should be unaffected by bias or the influence of any other external factors. Good experimental design allows for valid comparisons between treatments and enables researchers to relate the experimental results from their sample data back to the wider population.

Many experiments could be improved with better experimental design. Badly designed experiments can lead to incorrect conclusions, wasted time and resources and cannot be rescued by even the most sophisticated statistical analysis.

Since the validity of results is directly affected by the construction and execution of the experiment, attention to experimental design is extremely important. Good experimental work also considers the way measurements are collected and the data analysed.

Features of good experimental design:

- Inclusion of a control treatment, replication, randomisation and standardisation
- Clear description of study design and methodology so that it can be repeated at another time and place and provide similar results to the original experiment
- Use sound methods for selection of experimental units
- Selects experimental units from the population of interest using random selection. Allocates treatments to experimental units using randomisation
- Follows a clearly defined procedure to prevent unintentional bias
- Attempts to standardise all external factors which may influence the experiment
- Variables within the experiment are clearly identified (for example, independent and dependent variables)
- Provides sufficient data for a meaningful statistical analysis

Features of poor experimental design:

- Lack of replication, randomisation, standardisation and a control treatment
- Lack of a specific hypothesis
- Failure to give sufficient methodological detail to allow for repeatability of the experiment.
- Selection and sampling bias are not managed. This undermines the ability to generalise or make connections of the results to a target population
- Lack of reliability and repeatability due to too few experimental units.

Learning activities

1. **Outline the role of:**

- **A control treatment**

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- **Randomisation**

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- **Replication**

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- **Standardisation**

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Activities 2-6 are adapted from past NESA HSC agriculture questions.

2. **What is the component of experimental design that involves the management of variables? (NESA, 2015 Q4)**
   - **a)** Control
   - **b)** Replication
   - **c)** Randomisation
   - **d)** Standardisation
3. **In a research paper, what is the principal reason for including a section that details the research methodology? (NESA, 2013 Q14)**
   - **a)** Readers can interpret the results of the research.
   - **b)** The researcher can patent the research methodology.
   - **c)** It allows readers to evaluate the validity of the research methodology.
   - **d)** It allows readers to make informed opinions about how the results were analysed.
4. **What is the role of standardisation in experimental design? (NESA, 2013 Q7)**
   - **a)** To reduce the effects of biological variability
   - **b)** To reduce the effects of bias by the experimenter
   - **c)** To provide a basis for comparison between experiments
   - **d)** To ensure that factors other than the variable under investigation do not affect the results
5. **Complete parts a and b using your knowledge of good experimental design (NESA, 2017 2017 Q21a-b)**

a) A trial investigating the effect of light on plant growth is to be conducted. Outline TWO ways in which the conditions of the trial could be standardised.

_____

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b) Describe a trial that could be used to evaluate a new variety of a grain crop. In your answer, show how the trial demonstrates sound experimental design.

_____

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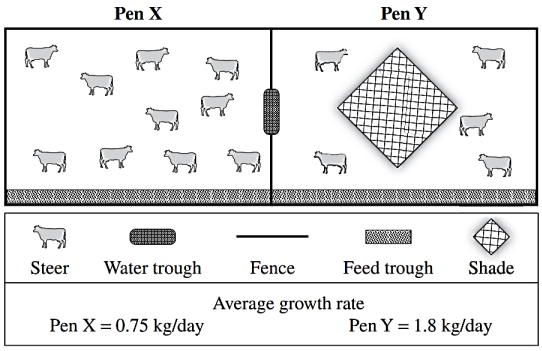
6. The diagram shows two equal-sized pens of feedlot steers and gives the average growth rates obtained over 100 days (NESA, 2009, Q5b)



Source: NESA, 2009, Q5b

Propose reasons to explain how the differences between Pen X and Pen Y lead to the variation in average growth rates.

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Syllabus point

Analyse and interpret agricultural data by calculating a mean and a measure of variability (standard deviation)

Conducting the trial

The method includes all the details that were decided in the planning stage about how to conduct your trial. This includes selection of experimental units, application of treatments and specified measurement methods.

Conducting your trial involves ensuring the method is strictly followed. It is important to remember that changes to the experimental design could prevent valid conclusions being made from the trial. If there are any variations to the planned method it is important to record details of what was changed and why.

Data collection and recording

The data to be collected is specified in the method. Recording the data collected from your experiment accurately is an important step in the experimental process. Ensure that the data you collect is traceable by clearly labelling each experimental unit with a unique identifier to avoid confusion.

Digital capture of data in the field is sometimes not practical so data may be recorded by hand. Data collected this way must still be recorded in the same format using clear and legible handwriting.

A copy of the data collected should be made as soon as possible.

An example format for recording results from the experimental layout in Figure 5 can be found in Table 1 below.

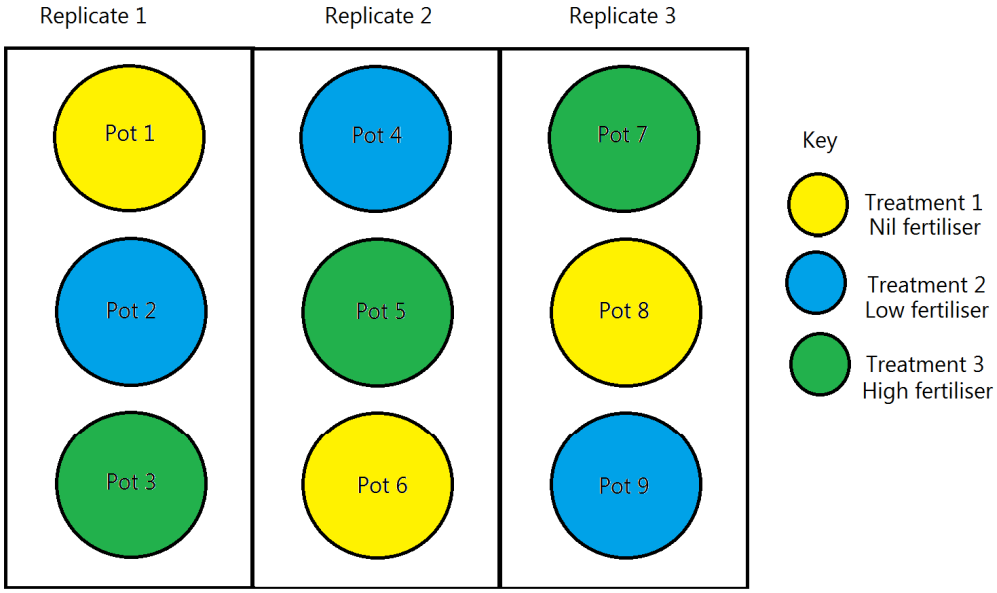


Figure 5 Diagram of experimental layout for three fertiliser treatments replicated 3 times in an RCB design

Table 1 Data recording sheet for three fertiliser treatments replicated 3 times in an RCB design

Identifying factors (e.g. treatment name, site, replicate, plot, pot ID or animal ID)			**Dependent variables (e.g. height, weight, plant health score, etc.)**		
Pot	Replicate	Treatment	Dry weight (grams/pot)	Grain weight (grams/pot)	Notes e.g. bird damage
1	1	Nil fertiliser			
2	1	Low fertiliser			
3	1	High fertiliser			
4	2	Low fertiliser			
5	2	High fertiliser			
6	2	Nil fertiliser			
7	3	High fertiliser			
8	3	Nil fertiliser			
9	3	Low fertiliser			

Data analysis and interpretation

The purpose of an experiment is to gather data to test the hypothesis by comparing treatments. Once the data has been collected a good first step in data analysis is to calculate summary statistics for each treatment.

Summary statistics are used to:

- Quantitatively describe and summarise data
- Help draw conclusions about treatments
- Objectively analyse differences and relationships between data.

This section covers summary statistics to describe your data and help to compare the treatments in your experiment.

Summary statistics that describe the centre of the data, also known as 'measures of central tendency', include:

- Mean or average
- Median

Statistics that summarise the variability or spread of the data, also known as the 'measures of variability,' include:

- Range
- Variance
- Standard deviation

Measures of central tendency- *mean*, median

Measures of central tendency summarise the data into a value that represents a typical result for the group, but this is only part of the 'picture'.

Example: the dataset of values below were observed in an experiment with two treatments (A and B). There are 25 values for each treatment, ordered from smallest to largest.

Treatment A	3	4	4	5	5	5	6	6	6	6	7	7	7	7	7	7	8	8	8	8	9	9	9	10	11	$\bar{x}$ =6.88
Treatment B	3	4	4	5	5	5	5	5	6	6	6	7	7	7	7	7	7	8	8	8	9	10	11	11	11	$\bar{x}$ =6.88

Median: the middle value for each treatment is highlighted in yellow and is the value 7.

Mean ($\bar{x}$): the mean for each treatment is calculated by adding up all values and dividing by the number of data values in that treatment (n=25).

	Median	Mean
Treatment A	7	6.88
Treatment B	7	6.88

It may be assumed from the central tendency summary statistics in the example above, that data for both treatments are the same. However when we look at Figure 6, the graphs show that the observations for each treatment are different. This confirms that measures of central tendency alone do not provide enough information to understand the data.

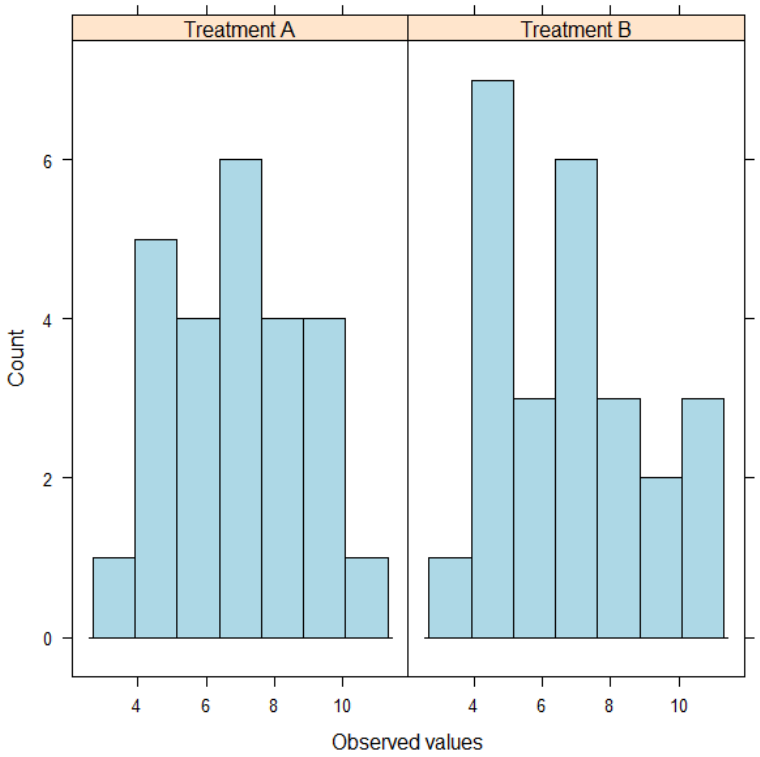


Figure 6 Treatment A and treatment B observed values

Measures of variability- range and *standard deviation*

A measure of the centre of the data does not provide a complete summary of the data. It is also important to understand how the data varies from that central measure (usually the mean) as the variability or spread of the data can help assess the precision of the mean. In other words the measure of variability describes how similar or varied the data values are to each other. Measures of variability include the range, variance and standard deviation. Variance will be discussed in the *Extended learning* section at the end of this chapter.

Interpreting range

The range is the difference between the smallest and largest values.

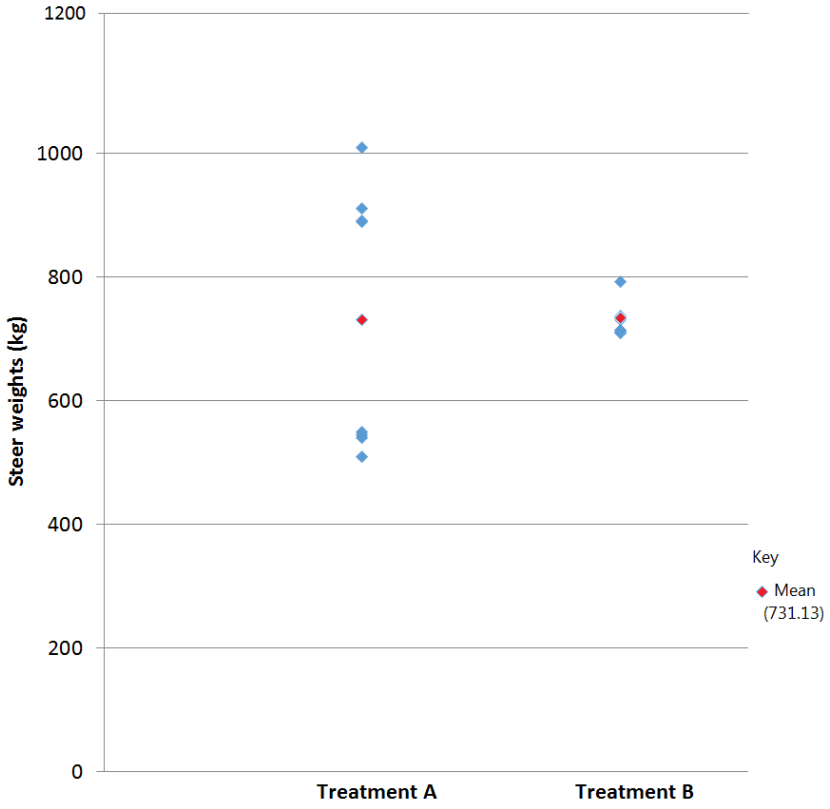
Range = maximum value - minimum value

The larger the difference between the minimum and maximum value, the higher the range. The lower the difference between the minimum and the maximum value the lower the range. When an extreme value (i.e. outlier) is part of the dataset the range will be affected.

Example: comparing steer weights from two treatments with the same mean and different ranges illustrates the importance of measuring the spread of the data.

The weights (kg) of steers from two different treatments, where eight steers were given each treatment is shown in the scatter plot and table below Figure 7.

Treatment A:	510	540	545	550	890	892	912	1010	(n=8)
Treatment B:	710	712	714	715	732	735	738	793	(n=8)



The horizontal axis indicates Treatment A and Treatment B. Both treatments have the same mean weight (731.13 kg) and different ranges (Treatment A range=500 kg, Treatment B range=83 kg).

Figure 7 Steer weights (kg) from two treatments.

	Mean	Range
Treatment A	$\bar{x} = \frac{510 + 540 + 545 + 550 + 890 + 892 + 912 + 1010}{8}$ $\bar{x} = \frac{5\,849}{8}$ $\bar{x} = 731.13\text{kg}$	Range = 1 010 – 510 = 500
Treatment B	$\bar{x} = \frac{710 + 712 + 714 + 715 + 732 + 735 + 738 + 793}{8}$ $\bar{x} = \frac{5\,849}{8}$ $\bar{x} = 731.13\text{kg}$	Range = 793 – 710 = 83

Even though the mean weight is identical for steers from both treatments ($\bar{x}$= 731.13kg), there is a big difference in the range from each treatment. Treatment A has a range of 500kg, and Treatment B has a smaller range of 83kg. Therefore the mean for Treatment B is more precise than Treatment A's mean since the range for Treatment B (83kg) is smaller than Treatment A (500kg). Comparing the size of the ranges shows that the two herds are not alike, even though the means are the same.

The range relies on only two data values, the minimum and the maximum. When an extreme value, known as an (outlier), is part of the dataset, the range will be affected. A dataset can also have treatments with the same mean and range but their variability is not the same. Although the range is useful to describe a dataset, there is a better measure of spread based on all the data values, not only two. This measure of variability is called the variance (See *Extended learning*).

Standard deviation of a sample

Standard deviation of a sample is calculated by taking the square root of the sample variance (see Extended learning). The formula to find the standard deviation of a sample (s.d.) is:

$$s.d. = \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{n-1}}$$

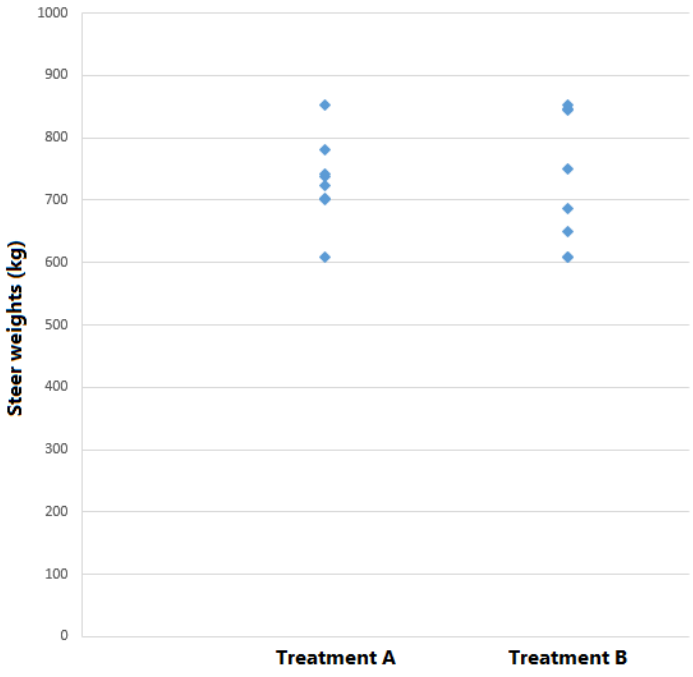
Explaining the symbols:

- In mathematics the Greek letter Σ means "the sum of"
- each data value is represented by x_i (with $_i$ going from 1 to n) e.g. n=4 and x_1=3, x_2=2, x_3=6, x_4=3
- the mean of n values is represented by $\bar{x}$ e.g. n=4, $\bar{x}$= 3.5
- n represents the sample size. e.g. n=4
- the brackets ( ) indicate that the subtraction needs to occur before squaring

Experimental data is rarely from a population and usually from a sample. For this reason the term standard deviation always refers to the sample standard deviation in this resource.

Standard deviation shows how the data is spread out around the mean and in the same units as the mean. For example, are all your cattle weights close to the mean weight? Or do the cattle weights spread a lot around the mean weight? A mean is not much use without knowing the standard deviation.

- A low standard deviation indicates that the data values are close to the mean.
- A high standard deviation indicates that the data values are spread further from the mean.
- The smaller the standard deviation, the more precise the mean.
- The larger the standard deviation, the less precise the mean.

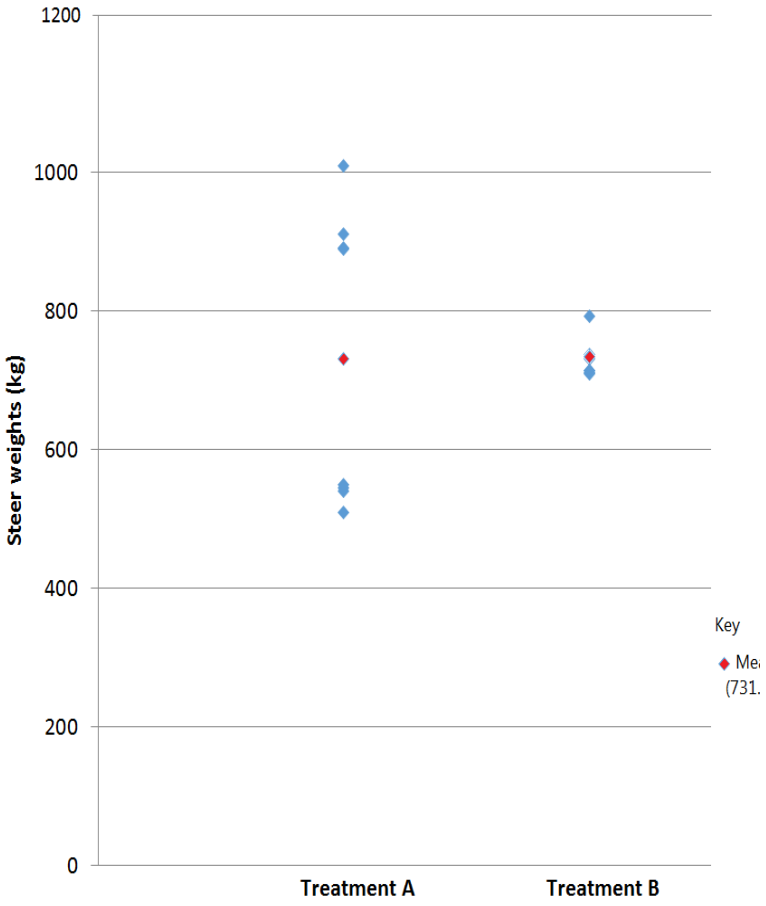


Both treatments have the same mean weight (731.13 kg) and same range (minimum=608.6, maximum=853.6), but different standard deviations (Treatment A s.d.=70.2, Treatment B s.d.=106.9).

Figure 8 Steer weights (kg) from two treatments

Figure 8 above shows an example dataset with two treatments with the same mean and range, however the variability (standard deviation) is different for each treatment. Treatment A has a smaller standard deviation than Treatment B. The steers mean weight for Treatment A is more precise than the mean weight for Treatment B. Figure 8 shows that while both groups have the same range, the observations for Treatment A are more clustered around the mean.

Figure 9 shows an example dataset that has two treatments with the same means and very different standard deviations. The mean for Treatment A is not as precise as the mean for Treatment B, as seen in Figure 9.



Both treatments have the same mean weight (731.13 kg) and different standard deviations (Treatment A s.d.= 211.95, Treatment B s.d.= 27.40).

Figure 9 Steer weights (kg) from two treatments

Calculating the sample standard deviation

Example of calculating the sample standard deviation by hand (using a calculator without STATS function)

Example data set 30, 67, 22, 12, 36, 28, 11, 16

Recall s.d = $\sqrt{\frac{\sum(x_i-\bar{x})^2}{n-1}}$

- Step 1 Calculate the mean

  Mean = $\frac{\text{total of all data values}}{\text{number of data values}}$

  Mean = $\frac{30+67+22+12+36+28+11+16}{8} = \frac{222}{8} = 27.75$

- Step 2 Calculate $\sum(x_i - \bar{x})^2$

  $\sum(x_i - \bar{x})^2 = (30 - 27.75)^2 + (67 - 27.75)^2 + (22 - 27.75)^2 + (12 - 27.75)^2 + (36 - 27.75)^2 + (28 - 27.75)^2 + (11 - 27.75)^2 + (16 - 27.75)^2$

  $= 2.25^2 + 39.25^2 + (-5.75)^2 + (-15.75)^2 + 8.25^2 + 0.25^2 + (-16.75)^2 + (-11.75)^2$

  = 5.0625 + 1540.5625 + 33.0625 + 248.0625 + 68.0625 + 0.0625 + 280.5625 +138.0625

  = 2313.5

- Step 3 Calculate $n - 1$

  $n - 1$ = 8-1 = 7

- Step 4 Calculate the standard deviation

  s.d = $\sqrt{\frac{\sum(x_i-\bar{x})^2}{n-1}} = \sqrt{\frac{2313.5}{7}} = \sqrt{330.5}$ = 18.1796...

Mistakes are easily made when working out standard deviation by hand so it is useful to use a calculator to find the standard deviation. Scientific calculators approved for use in the HSC have a statistical (STAT) function which is used for the standard deviation calculation. Different brands and models of calculators have different steps for the calculation. Calculating the standard deviation using a calculator is included in the Standard Mathematics Preliminary Course. The method for each calculator can be obtained from the calculator manual or a maths teacher in your school

Example of calculating the sample standard deviation using the STATS function on a calculator

Example data set 30, 67, 22, 12, 36, 28,11, 16

The steps to calculate the sample standard deviation using a Casio fx-82AU calculator follow. The steps may be different for a different brand or model of calculator.

Always start with the calculator turned off to be sure the statistics memory is empty (any data is cleared automatically when the calculator is off).

Preparing the calculator

Turn on calculator.

Press [SHIFT] then [SETUP] then

Press the bottom edge of the replay button 

Press [3] to view the options for statistics

Press [2] to enter data that is a list of numbers

The calculator now has the correct settings to begin calculating the sample standard deviation

Calculating sample standard deviation (and mean)

Press [MODE] then

Press [2] to select STAT mode

Press [1] for 1-variable statistics

To enter the data press [3] [0] [=] [6] [7] [=] [2] [2] [=] [1] [2] [=] [3] [6] [=] [2] [8] [=] [1] [1] [=] [1] [6] [=] then

If there is a mistake in the data entered use the replay button to scroll up (and down) to the incorrect score and type the correct value over it.

When all the data is entered correctly press [AC] to indicate the completion of the data entry

Press [SHIFT] [1] then

Press [4] this screen gives the options to display the mean (2) and sample standard deviation (4)

Press [4] [=] the sample standard deviation will be displayed

The standard deviation is 18.1796…

To view other summary statistics press [SHIFT] [1] [4] to return to the options

Press [2] [=] the mean will be displayed

The mean is 27.75

Learning activities

Activities 1-7 are adapted from NESA, past HSC Agriculture exams.

1. **What is the statistical measure which provides information about the spread of data? (NESA, 2014, q13)**
   - **a) Mean**
   - **b) Median**
   - **c) Mode**
   - **d) Standard deviation**

2. **The table shows the weights of a group of lambs (NESA, 2016 Q7).**

Lamb	1	2	3	4	5	6	7	8	9	10
Weight (kg)	16	16	16	18	18	18	19	16	18	15

What is the mean weight for this group of lambs?

a) 16
b) 17
c) 18
d) 19

3. **A student performed an experiment to investigate how shading affects the growth of a plant species. The results of the trial are shown (NESA, 2016 Q16).**

	Location 1: Indoors/shade house	Location 2: Outdoors/full sun
Pot	Height after 14 days (cm)	Height after 14 days (cm)
1	7	9
2	5	11
3	8	10
4	6	13
5	4	12

What is the average (mean) height of the plants in the control treatment?

a) 5 cm
b) 6 cm
c) 8.5 cm
d) 11 cm

4. **The table shows the weights of four different groups of lambs (NESA 2012, Q15).**

	Group A	Group B	Group C	Group D
Mean (kg)	23.0	26.0	27.2	22.8
Standard deviation	1.60	2.16	1.64	1.72
Range of weights (kg)	20-26	23-28	26-29	21-25

Which group of lambs has the least variable weights?

a) Group A
b) Group B
c) Group C
d) Group D

6. **Table shows dry matter weights for five pasture samples (NESA 2012, Q22a).**
Calculate the mean and standard deviation and write them in the spaces below.

Sample Number	Weight
1 2 3 4 5	220 218 200 215 212
Mean	
Standard deviation	

7. **The growth rate (kg/day) for each animal in a pen of steers is shown (NESA 2011. Q7)**

2.7	2.1	1.7	2.0	1.8	2.5	2.5	1.7	2.0

a) What is the mean growth rate for the pen of steers?

_____

b) What is the sample standard deviation for weights in this group of steers?

_____

8. **Students designed a trial to investigate the effect of the level of a fertiliser on the growth of lettuce. 30 pots of equal size were filled with the same potting mix and placed in the school glasshouse in the following arrangement. There was one plant in each pot.**
The results of the trial are shown in the table (NESA, 2018, Q25c).

	Higher fertiliser level	Lower fertiliser level	Recommended fertiliser level
Mean dry matter yield (grams/plant)	8.3	4.5	7.9
Standard deviation	0.51	2.1	0.23

a) What information about this experiment is provided by the standard deviations?

_____

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Extended learning

Variance of a sample

The mean is required to calculate the variance. Once, the mean has been calculated, the next step is to calculate how far each data value is from the mean. If the data value is smaller than the mean this difference is negative. If the data value is larger than the mean then the difference is positive. By squaring each of these differences (positive or negative) we get a positive quantity. The total of all the squared values is then calculated.

The next step is to find the mean of the total, but instead of dividing by the number of values (n) we divide by n-1. We use n-1 because we have a sample rather than the whole population. Experimental data is rarely from a population and usually from a sample. For this reason the term variance always refers to the variance of a sample in this resource.

The formula to calculate the variance of a sample is: $s^2 = \frac{\sum(x_i - \bar{x})^2}{n-1}$

Explaining the symbols:

- In mathematics the Greek letter Σ means "the sum of"
- each data value is represented by x_i (with $_i$ going from 1 to n) e.g. n=4 and x_1=3, x_2=2, x_3=6, x_4=3
- the mean of n values is represented by $\bar{x}$ e.g. n=4, $\bar{x}$= 3.5
- n represents the sample size. e.g. n=4
- the brackets ( ) indicate that the subtraction needs to occur before squaring

The variance is expressed in squared units. It is more straightforward to communicate results in the same scale as the original data. For example, a sample with mean= 12.6 kg has a variance = 4.41 kg^2. The squared units, such as kg^2, are not meaningful or easily interpreted. The next step is to take the square root of the variance to overcome the problem, which gives the standard deviation of a sample.

Standard deviation is the same formula for the variance, with an added step of calculating the square root. Taking the square root of the sample variance gives a quantity in the same units as the measured variable. This quantity is known as the standard deviation. For example, mean=12.6 kg, standard deviation (s.d.)= $\sqrt{4.41}$ kg^2= 2.1 kg. The standard deviation is now also in kilograms.

Normal distribution

Many populations of biological variables can be described by the normal distribution (e.g. animal weight, fruit diameter). The normal distribution curve can be used to test for differences between groups of observations. The curve defines a mathematical relationship between a data value and its probability of occurrence.

Example: The weights of a sample of 1000 steers are summarised in Figure 10. Most of the weights are clustered around the mean (300kg), with a similar number of values on each side of the mean. The standard deviation of the data in this sample is 5 kg. The histogram shows that the observed data looks like a normal distribution (yellow curve); it is bell-shaped and symmetrical.

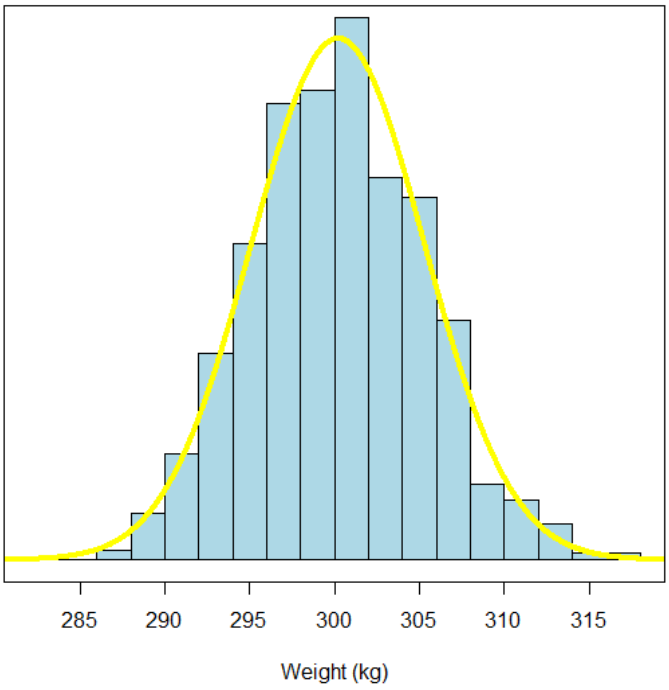


Figure 10: Normal distribution, mean=300, s.d.=5 and 'bell curve' of steer weights (kg)

Other attributes of the normal distribution include:

- Due to the symmetry (equal numbers of values on either side of the mean) it has identical measures of central tendency (mean, median)
- The standard deviation is extremely useful

When the mean and standard deviation of a normal distribution are known then the proportion of the population within a defined range can be determined by the area under the curve for observations within that range.

When your data follows a normal distribution the standard deviation can help to figure out where data values in the population (all measurements) are likely to fall.

- 68% of all measurements fall within one standard deviation either side of the mean.
- Approximately 95% of all measurements fall within two standard deviations on either side of the mean. Conversely, 5% of all measurements fall outside this region.
- Approximately 99% of all measurements fall within three standard deviations on either side of the mean. With less than 1% of values being greater than three standard deviations from the mean. Values which fall within the fourth standard deviation from the mean are unusual.

These properties are illustrated in Figure 11 below.

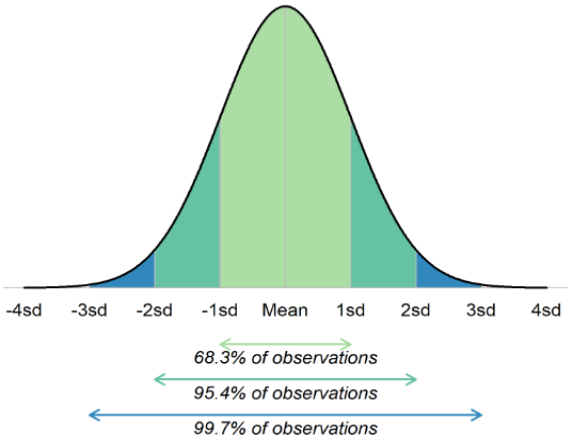


Figure 11 Standard normal distribution curve and standard deviation properties (mean=0, s.d.=1)

The normal distribution curve illustrates how tightly data is clustered around the mean. The size of the standard deviation is a measure of the variability in the sample.

Comparing treatments using normal distribution curves

The characteristics of the normal distribution can be used to compare the data for different treatments in a trial and determine if the differences in the means are a real difference or due to natural variability. This can present in a number of way:

a. Same means, different standard deviations (Figure 12)
b. Different means, same small standard deviation (Figure 13a)
c. Different means, same large standard deviation (Figure 13b)

Figure 12 illustrates two curves which compare two scenarios. The flattened bell curve (dotted line) has a larger standard deviation and the steeper curve has a smaller standard deviation. Data from the population with the dotted curve has a larger variability than the steeper curve (solid line).

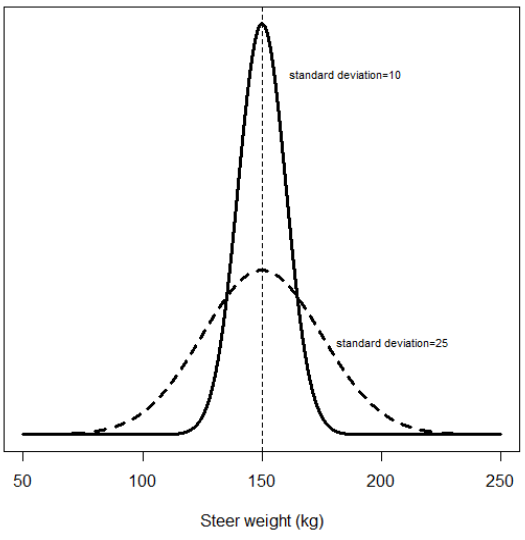
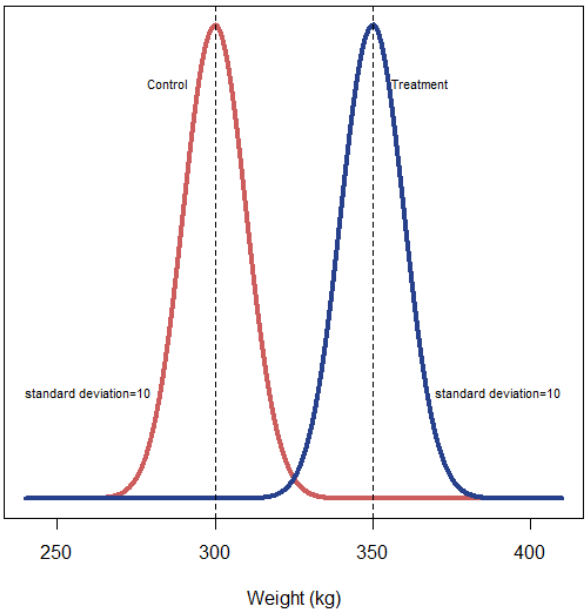


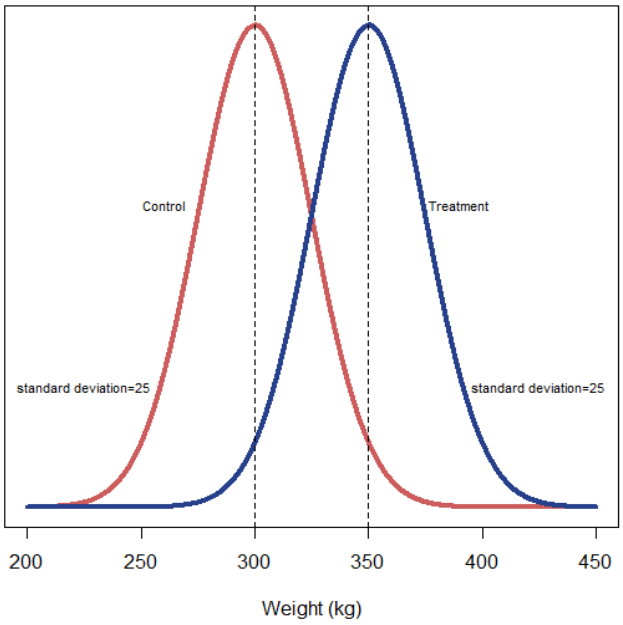
Figure 12: Two normal distribution curves with the same mean (150 kg) and different standard deviations. Solid line s.d.=10; dotted line s.d.=25.

The characteristics of the normal distribution can be used to compare the data for different treatments in a trial and determine if the observed differences between the treatment means could have occurred by chance. Consider the live weights (kg) from a steer feeding trial with two treatments; control (no feed supplement) and treated (received feed supplement). The control group had a mean weight of 300 kg and the treated group had a mean of 350 kg. Two possible scenarios are shown below



In Figure 13a the normal distribution curves represent the results for two different treatments with different means (300 kg for Control and 350 kg for Treated), and the same, small standard deviation (s.d.=10) for both groups. The size of the difference between the treatment means is 50 kg. As there is only a small amount of variability (s.d.=10) for each treatment group this would indicate a real treatment difference since the curves only overlap by a very small amount. It is easier to identify a real difference when the variability (measured by s.d.) is small.

Figure 13a Different means, same small s.d. of steer carcass weights



In Figure 13b the normal distribution curves represent the results for two different treatments with different means (300 kg for Control and 350 kg for Treated) and the same, large standard deviation (s.d.=25) for both groups. The size of the difference between the treatment means is also 50 kg. As there is a larger amount of variability (s.d.=25) for each treatment group this would NOT indicate a real difference since there is considerably more overlap between the curves. It is harder to identify a real difference when the variability (measured by s.d) is larger.

Figure 13b Different means, same large s.d. of steer carcass weights

Significance test for comparing two groups using standard error of the difference (SED)

These scenarios indicate the basis for significance tests to determine if the difference in the means is likely to represent a real (or significant) difference or if it is likely to be due to natural variability. The one described here is appropriate for comparing the mean response from each of two treated groups. A significance test to help decide whether the difference between the means from two treatments groups is caused by a true treatment effect or could have occurred by chance. is based on comparing the size of the difference to the variability of each group.

To work out the standard error of the difference (SED), you will need to calculate:

- Mean of each treatment group
- Standard deviation (variability) of each treatment group
- Standard error of the difference (SED) between the two groups = $SED = \sqrt{\frac{(s_1)^2}{n_1} + \frac{(s_2)^2}{n_2}}$
- s_1 = standard deviation of treatment group 1
- s_2 = standard deviation of treatment group 2
- n_1 = number of individuals in treatment group 1
- n_2 = number of individuals in treatment group 2

Imagine an experiment was carried out 1000 times - it would result with a 1000 differences (mean 1 - mean 2) in a dataset. This dataset of these differences would follow a normal distribution similar to Figure 11 and 95% of all differences would fall within a region bounded by 2 standard deviations away from the mean of the differences. The other 5% of differences (considered to be 'large') would fall outside this region. Differences this large only happen rarely (5% of the time). If an observed difference between means could only happen less than 5% of the time, the means are unlikely to belong to the same population. These differences would be considered 'real' differences due to the effect of the treatment.

A useful rule of thumb

When the absolute difference between the means of the two treatment groups (mean 1 - mean 2) is greater than two times the standard error of difference (SED), the difference is considered significant and not due to chance or natural variability. The probability, or chance, that is commonly used in scientific publications is 5% (0.05). This probability is also known as the significance level of the test.

- If |mean 1 -mean 2| > 2 x SED then we conclude the difference is due to the different treatments
- If |mean 1 -mean 2| < 2 x SED then we conclude the difference is NOT due to the different treatments
- Note: |x| = absolute value of x e.g. |-5| = 5; |+5| =5

The value of two in the formula corresponds to the 5% area under the normal curve in Figure 11.

Significance tests should be included in the results section. When the effect of the treatment is not significant it is usual to report that no evidence of an effect was found, rather than that the treatment had no effect. When completing your discussion it is important to comment on the size of the difference between treatment means.

Example:

Stripe rust is one of three rusts that attack wheat. It affects the yield by reducing the green leaf area of the wheat plant which decreases photosynthesis reducing the sugar supply to the developing seed. Limited data was available for use by agronomists to advise farmers on control methods for stripe rust in wheat. A trial was conducted across several locations using wheat varieties of different susceptibility to stripe rust and different methods of controlling stripe rust. As the trial was large and complex this example uses only some of the data available from the trial.

The moderately susceptible wheat variety Chara was used in this field trial to investigate the effect of a seed dressing. There were four replicates with two treatments in a randomised complete block design. Treatment 1 had no seed dressing (control) and treatment 2 had the seed dressing applied. At harvest the yield of each plot was recorded. The results for the trial are given in Table 2.

(Adapted from McMullen G and Haskins B (2005) Evaluating stripe rust management strategies for wheat in SW NSW in 2004 and 2005, GRDC Updates - Southern Region.)

Table 2 Effect of seed dressing treatment on yield of Chara wheat variety mildly susceptible to stripe rust

Treatment	Yield (t/ha)
Control	2.87
Control	2.98
Control	3.04
Control	2.72
Dressing	3.08
Dressing	1.89
Dressing	3.25
Dressing	2.25

Step 1: Calculate the mean yield (to 2 decimal places) for each treatment:

Mean Control treatment = (2.87+2.98+3.04+2.72)/4 = 2.90 t/ha

Mean Seed dressing treatment = (3.08+1.89+3.25+2.25)/4 = 2.62 t/ha

The Control treatment appears to have the highest yield since it has a larger mean.

Step 2: Calculate the standard deviation for each treatment:

$$\text{s.d.} = \sqrt{\frac{\sum(x_i-\bar{x})^2}{n-1}}$$

Standard deviation Control treatment

$$= \sqrt{(((2.87-2.90)^2 + (2.98-2.90)^2 + (3.04-2.90)^2 + (2.72-2.90)^2)/ (4-1))} = 0.141 \text{ t/ha}$$

Standard deviation Seed dressing treatment

$$= \sqrt{(((3.08-2.62)^2 + (1.89-2.62)^2 + (3.25-2.62)^2 + (2.25-2.62)^2)/ (4-1))} = 0.653 \text{ t/ha}$$

The seed dressing treatment has a larger standard deviation (more variation around its mean) than the control treatment.

Step 3: Calculate the standard error of difference

$$\text{Standard error of difference} = \sqrt{\frac{(S_1)^2}{n_1} + \frac{(S_2)^2}{n_2}}$$

$$= \sqrt{\frac{(standard\ deviation\ of\ \ seed\ dressing\ treatment)^2}{number\ of\ samples\ in\ seed\ dressing\ treatment} + \frac{(standard\ deviation\ of\ control\ treatment)^2}{number\ of\ samples\ in\ control\ treatment}}$$

$$= \sqrt{\frac{(\ \ 0.653\ \ )^2}{4} + \frac{(\ 0.141\ )^2}{4}}$$

= 0.334 t/ha

Remember, if the difference between the two means is greater than 2 x the standard error of difference then there is a significant difference between the means at the 5% level.

Step 4: Calculate the difference between the two means

= |seed dressing treatment mean - control treatment mean|

= |2.62-2.90|

= 0.28

Step 5: Calculate 2 x the standard error of difference

= 2 x 0.334

= 0.668

0.28 < 0.668

- Since |mean 1 -mean 2| < 2 x SED then we conclude the difference is not due to the different treatments.
- We can conclude that the seed dressing treatment did not have a significant effect on the yield of wheat, compared to the control treatment.

  If |mean 1 -mean 2| > 2 x SED then we would have concluded the difference is due to the different treatments.

  These results could be displayed as shown in Table 3.

Table 3 Effect of seed dressing treatment on yield of a wheat variety mildly susceptible to stripe rust

	Yield (t/ha)		
	Control	Dressing	
	2.87	3.08	
	2.98	1.89	
	3.04	3.25	
	2.72	2.25	
Mean	2.90	2.62	Step 1
Standard deviation	0.141	0.653	Step 2
Standard error of difference	0.334		Step 3
Difference between means	0.28		Step 4
2 x SED	0.668		Step 5

A conclusion for the experiment could be:

This experiment provided no evidence that the seed treatment applied reduced the impact of stripe rust on the yield of wheat.

The impact of stripe rust in wheat on yield was not affected by the application of the seed treatment. There was no significant difference between the yield of the wheat which had seed dressing applied compared to wheat which had no seed dressing applied. Results from this experiment suggest that there was no benefit in using the seed treatment.

(Note: This example is only using a portion of the data so the conclusion given should not be considered a true reflection of the full trial.)

This SED test (similar to a t-test) is not recommended for trials with more than two treatments. As the number of treatments increases, the number of treatment pairs increases at a great rate. The potential for declaring a statistically significant effect, when one truly does not exist, increases with the number of significance tests.

If you were completing a trial in Stage 6 Agriculture with more than two treatments you may wish to repeat this test for each combination of pairs of treatments such as Treatment 1 and Treatment 2, Treatment 1 and Treatment 3, Treatment 2 and Treatment 3 in a trial with three treatments.

More complex tests would be used by statisticians. For example, when there are more than two treatments being compared the method of 'analysis of variance' (ANOVA) is often used. The F-test is the test of significance used in ANOVA. Most researchers use statistics software (free or commercial) to analyse their data rather than calculate all statistics by hand as shown in this resource. It is important not to use statistical software for your data analysis unless you fully understand the method being used. This is likely to lead to incorrect conclusions based on flawed analyses.

Syllabus point

Explain the need for a test of significance to be performed before valid comparisons can be made.

Need for Significance Tests to make valid comparisons

Significance tests are used to determine if the differences between the means of various treatments in an experiment are real or just the result of chance due to natural variability. These chance differences are also known as sampling error, however 'error' in this term does not mean mistake.

Although graphical data summaries, means and standard deviations are extremely useful as a basis for comparing the performance of different treatments, a formal significance test is usually required to support conclusions and justify recommendations that will be given to industry. Significance testing provides a common language used all over the scientific world to communicate the importance of experimental results.

Significance tests are also known as 'statistical hypothesis tests'. The tests use known probability results to link conclusions from the sample data back to the broader population. The branch of statistics used to evaluate the stated hypothesis and draw conclusions based on the observed data is called inferential statistics.

There are several statistical hypothesis tests commonly used in agricultural research, for example Chi-squared, *t*-test and analysis of variance (ANOVA) *F*-test.

Significance testing is important because natural variation occurs between all individuals, not only between treatments. When making conclusions we want to find out if the trends or differences observed in the data are really due to the treatments that were applied, or if they are due to natural variation between

individuals. A significance test helps us to determine if the differences are due to the treatment being applied in the trial.

A statistically significant result does not necessarily mean that the differences between treatments are important, biologically or practically. A significant difference that is small may not be important practically, particularly if there is a cost involved in using the treatment. For example, a new type of fertiliser may result in a very small but statistically significant increase in a crop's yield. However, if the cost of the new fertiliser is more than the extra income produced by the additional yield it would not be economically sensible to change to the new fertiliser.

Valid comparisons between treatment groups in a plant or animal trial depend on data that has been gathered from experiments which feature these four key experimental design features:

- Randomisation
- Replication
- Standardisation and
- Inclusion of a control treatment.

These features ensure meaningful results can be captured, reliable conclusions be made and researchers can confidently relate their conclusions from their sample to the wider population.

Significance tests are a guide to allow valid conclusions and recommendations to be made.

Summary

- Significance tests are statistical tests which rely on probability to determine whether there is an important difference between means from different treatments.
- Statistical tests take into account the treatment means and the spread of the data for each treatment as well as the number of replicates.
- The particular test used will depend on the experimental design and the number of treatments. Examples include a significance test using standard error of difference when there are only two treatments and ANOVA *F*-test when there are more than two treatments.
- When an experimental design includes replication, randomisation, standardisation and inclusion of a control treatment, then tests of significance are appropriate.
- Valid comparisons cannot be made unless the experiment has been set up and carried out following the principles of good experimental design.

Learning activities

1. **Explain the need for a test of significance to be performed before valid comparisons can be made.**

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Syllabus point

Present data in an appropriate form

Reporting results

The next step in the experimental process, covers the reporting of results. The report will often be in the form of a scientific journal article that will be reviewed by other independent scientists (peer review) and will usually include statistical significance tests. In the scientific report the results need to be summarised in a concise way that can be related to the hypothesis. This section will concentrate on tables and graphs in scientific reports.

Tables, diagrams, images and graphs are used to present, organise and condense data in a meaningful way. The choice of table or graph to best represent data depends on the type of data. The wrong choice of a graph or table can confuse the reader more than assist with data interpretation.

When reporting results, units which are meaningful to the audience should be used. This may be different to the units used when taking measurements. For example, when reporting on crop yield it would be more appropriate to use tonnes per hectare rather than kilograms per square metre.

Usually experimental data is presented in summary form. It is not necessary to include every measurement that was made during the trial in the final report.

Tables

Tables are a useful way to present data. They can show details about the results, allowing actual values to be presented and used to make graphs. Multiple columns can be used to show detail.

Tables are better than graphs for giving structured numeric information. The table should be self-explanatory. The title should be informative and rows and columns of tables should be clearly labelled. The text in the caption (or heading) should always include the key points in a table or figure.

Table 4 contains EBV data for four individual animals.

Table 4. Breedplan estimated breeding values (EBV) for Charolais heifers at 200, 400 and 600 days

Animal Identification code	200 day weight (kg)	400 day weight (kg)	600 day weight (kg)
A100	+12	+17	+28
A101	-4	-6	-9
A102	+9	+19	+25
A103	+1	+6	+18

Table 5 summarises the statistical analysis for the data from the experiment shown in Figure 14.

Table 5. Mean weights and standard deviations for three treatments where n=8.

Treatment name	Mean weight (kg)	Standard deviation
Control	731.13	211.96
Half rate	731.13	27.40
Full rate	1462.25	235.17

Data can be presented in multiple ways. In agricultural science and statistics, graphs are frequently used. Commonly used graphs include dot plots, line graphs, bar graphs, histograms, box plots, scatter plots, and pie charts. The type of graph is dependent on the data being presented and the visual impact for the target audience.

Graphs

In selecting how to present data, think about the purpose of the graph or chart and the information that needs to be communicated, and then decide which variables to include.

When selecting the type of graph or chart the type of data must be considered.

- Categorical data is grouped into non-overlapping categories (such as grade, colour and yes or no responses). Bar graphs, and pie charts are useful for displaying categorical data.
- Continuous data are measured on a scale or continuum (such as weight or test scores). Histograms, dot plots, line graphs and scatter plots are useful for displaying continuous data.

Dot plots, scatter plots, bar graphs, line graphs and histograms have an x axis and y axis. The x axis is the horizontal part of the graph and the y axis is the vertical part. The independent variable is usually plotted on the x axis and the dependent variable is usually plotted on the y axis.

If using software it is important to keep it simple and present only essential information. Avoid using options such as three-dimensional bars, which may confuse the reader. If the graph is too complex, it will not communicate the important points.

Types of graphs and charts

Dot plots

This type of graph is used to display numerical values for levels of a categorical variable. Each dot represents an individual data value. A dot plot shows the variability for each treatment. Overlapping of dots occurs when data values are close. Figure 14 was made using the data in Table 5 above and the scatter plot function in Excel.

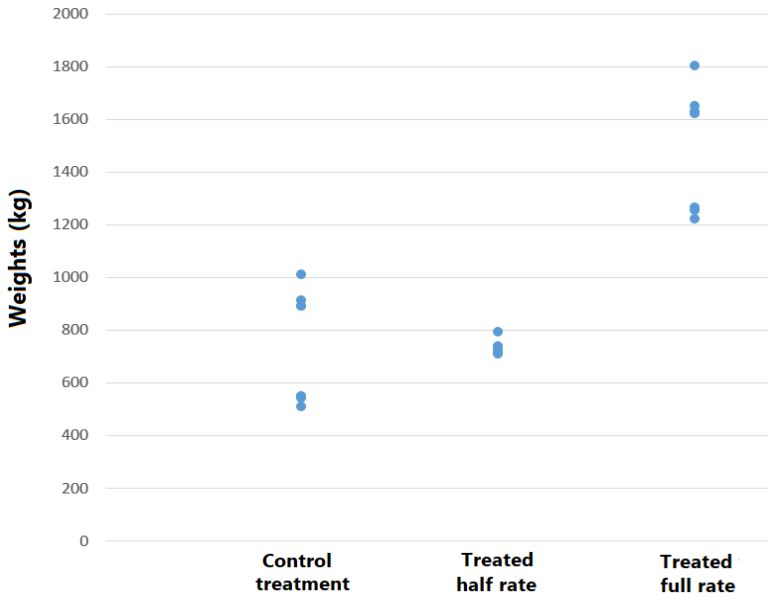


Figure 14: Dot plot of weight data for 3 treatments (n=8).

Histograms

Used to display continuous or discrete numerical data. A histogram divides the dataset into a number of intervals and each bar represents the number of values in the intervals. The number of intervals can be chosen by the researcher or automatically set by the graphing software.

Figure 15 shows a histogram of the weights for 1000 animals with each bar representing the number of animals in a weight class. The 13 classes on the x axis represent 10 kg intervals. The y axis shows the number (frequency) of animals in each class. For example, there are 46 calves weighing between 110kg and 120kg; and 204 weighing between 140 kg and 150 kg.

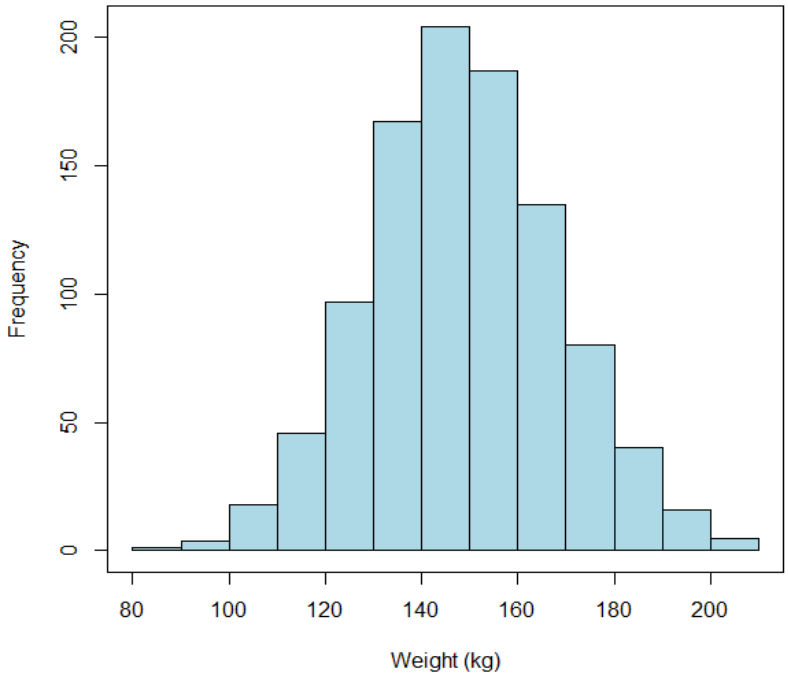


Figure 15: Histogram of 1000 weights with 10 kg intervals.

The y axis represents the frequency (number) of values in each interval on the x axis.

Bar graphs

Composed of discrete bars that represent the responses for different categories of data. The height of the bar is equal to the quantity of interest within each category of data. Bar graphs are best used to compare values across categories (e.g. months) and allow you to focus on the individual values (e.g. mean rainfall). Bar graphs are often used in scientific reports to visually compare treatment means. Figure 16 shows the results from an experiment comparing mean bollworm counts for three varieties of cotton.

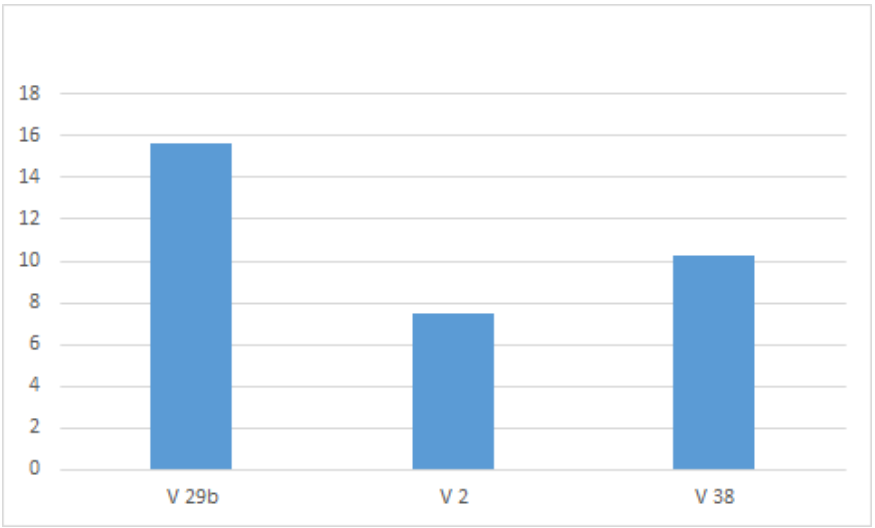


Figure 16: Bar chart showing mean bollworm count for 3 varieties of cotton

Line graphs and scatter plots

Both line graphs and scatter plots display the relationship between two sets of numerical data, such as growth rate (y axis) over time (x axis). They are particularly useful for illustrating trends over time. Both graph types plot individual points (x,y). A line graph then connects the points. These graphs allow you to focus on the pattern of the response variable.

A line graph is used in Figure 17 to highlight the pattern of the yield response (y axis) to increasing rates of fertilizer (x axis). The line joining the points also allows visual estimation of the values between the rates of fertiliser on the x axis.

The scatter plot in Figure 18 shows the growth of ten individual chickens as the relationship between age (x axis) and weight (y axis).

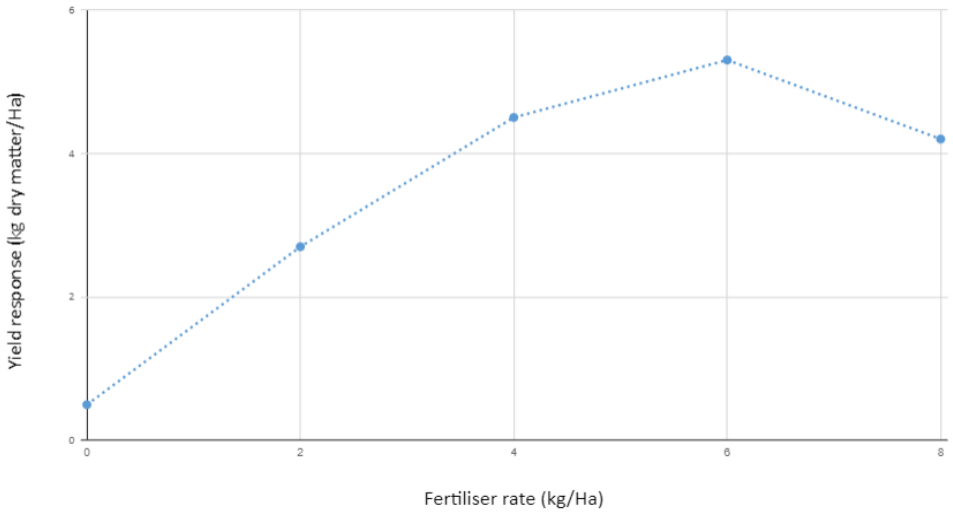


Figure 17: Line graph of mean yield at five different rates of fertiliser

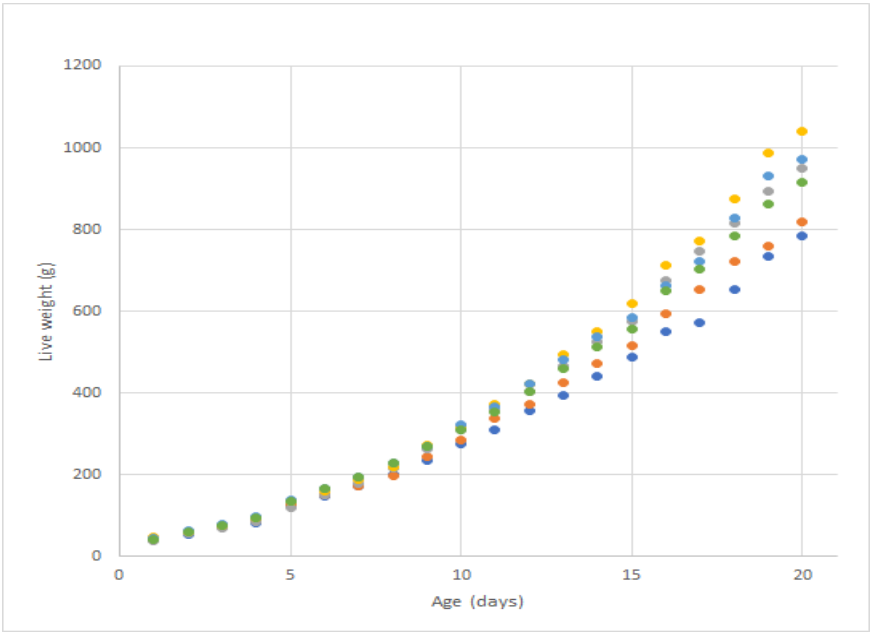


Figure 18: Scatterplot of daily chicken weights for ten chickens.

The y axis represents the live weight of each chicken at each age on the x axis

Pie charts

Used to compare parts of the whole, Pie charts are circles divided into sectors that correspond to the proportion of the total quantity that each sector represents.

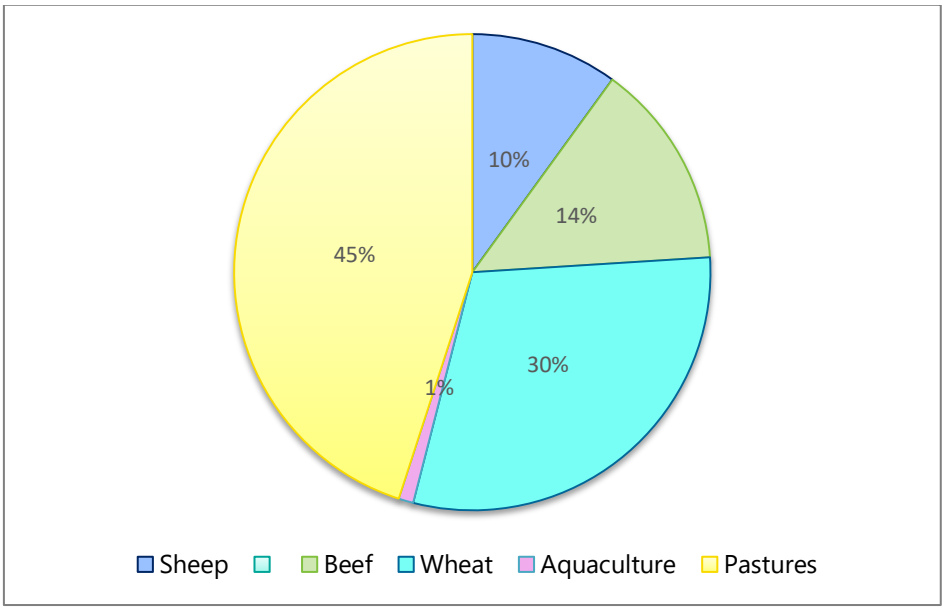
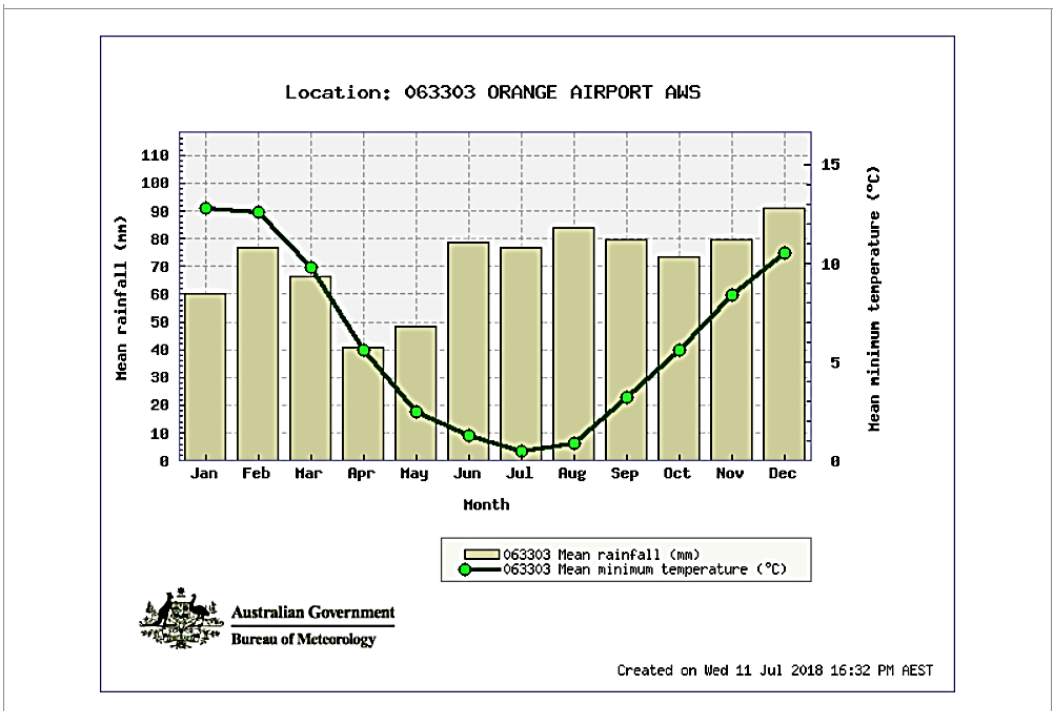


Figure 19: Pie chart of land distribution per enterprise

Climate graphs

Climate graphs can be a combination of a bar graph and a line graph. The climate graph below shows average annual rainfall and temperature for Orange, NSW.



Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years
Mean rainfall (mm) for years 1996 to 2018	60.3	77.0	66.4	40.9	48.2	78.6	76.6	84.1	79.8	73.6	79.4	91.0	852.8	22
Statistics	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**	**Years**
Mean minimum temperature (°C) for years 1996 to 2018	12.8	12.6	9.8	5.6	2.5	1.3	0.5	0.9	3.2	5.6	8.4	10.5	6.1	22

Figure 20: Average annual rainfall and temperature for Orange, NSW (1996-2018). Source: Bureau of meteorology, Climatic data for Orange NSW.

Summary

Type of graph	When it is used	Advantages	Disadvantages
Dot plots	To display small sets of numerical data	Shows all data values Shows the variability for each treatment	Can be hard to differentiate dots when data close together
Histograms	To display continuous or discrete numerical data Shows the distribution (shape and spread) of the data	Data can be grouped Can graph a large amount of data in easy-to- read format Shows how data is spread	Need to calculate frequency of data in each interval to construct
Bar graphs	To display responses for different categories of data To compare values across categories	Can graph a large amount of data Exact values for categories can be read from graph	Can only be used for categorical data
Line graphs and scatter plots	To display relationships between two variables Often used to show trends over time	Can graph a large amount of data Exact data values can be read from graph Shows trends and differences	Can only be used to graph numerical data
Pie charts **(sector graphs)**	To display categorical data To compare parts of a whole	Easy to compare proportions	Doesn't show exact values Not clear when there are a large number of categories or small proportions
Climate graphs	To display multiple types of climate data on one graph often using a combination of bar and line graphs	Summarises climate data on one graph Easy to see trend and differences	Only suitable for climate data

Checklist: Drawing graphs

When drawing graphs by hand use this checklist

- ☐ Select a suitable graph type specific to your data
- ☐ Identify the variables. Independent usually on the x axis and dependent usually on the y axis.
- ☐ Determine the range. For each axis subtract the lowest values data point from the highest value data point.
- ☐ Select the scale units. Divide each axis uniformly into appropriate units using the maximum amount of space available.
- ☐ Use a ruler and lead pencil for marks and connective lines. In case you need to make a correction. Use pen only for titles and labels.
- ☐ Number and label each axis. Remember to include units. For example, time (days)
- ☐ Plot the data points as ordered pairs (x,y)
- ☐ Draw the best straight line or smooth curve for line graphs or columns for bar graphs and histograms. Use a ruler!
- ☐ Title your graph. The title should clearly describe the information contained in the graph.
- ☐ Include a key (legend) if appropriate.

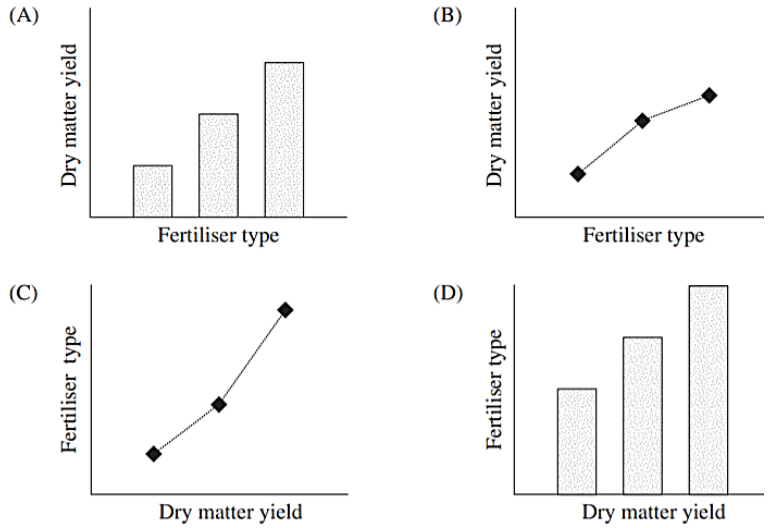
Checklist: Interpreting tables and graphs

Skills for interpreting graphs and data are developed through practice. Use the following checklist to help structure your approach, when interpreting tables and graphs.

- ☐ Read the title or caption on the chart/table to find out what content is being presented.
- ☐ Read all the headings and labels in the chart/table to determine what is being grouped and presented in each subcategory (each column and each row). Begin by reading the headings at the top to find out what categories of information they contain.
- ☐ Identify similarities, differences, and other relationships among the data. Remember that some kind of relationship always exists between each column heading and each row.
- ☐ Identify patterns and relationships in order to reveal information and connections about the subject/topic. Ask the question, “What patterns or relationships does the data show?”
- ☐ Use the data to make generalisations, draw conclusions, or make inferences. Ask the questions, “How can the information in the chart/table be summarised?” and “What conclusions can be drawn or inferences made from the information in the chart/table?”

Learning activities

1. **A researcher conducted an experiment in which three different types of fertiliser were applied to a pasture. The dry matter yield was measured. What is the most suitable graph to represent the data from such a trial? (NESA, 2014 Q18).**



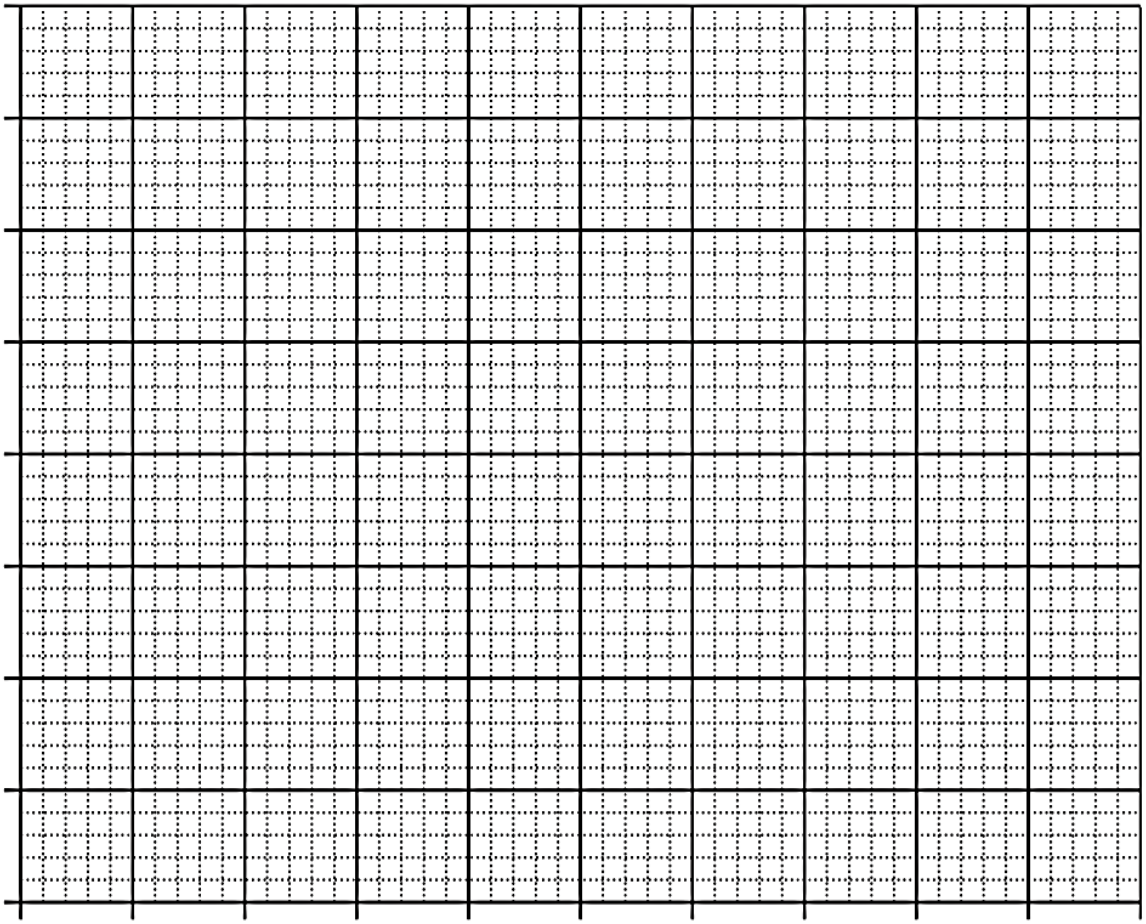
2. **Research was conducted to determine the effect of irrigation on the yield of cherries over one growing season. Two farms were selected for the research project. Farm 1 was located in southern NSW with NO irrigation. Farm 2 was located in northern NSW with irrigation (NESA, 2013 Q24).**

Yield of Cherry Trees

	Farm 1		*Farm 2*
Individual tree identification	*Yield* (kg/tree)	*Individual tree identification*	*Yield* (kg/tree)
A	3	A	7
B	10	B	11
C	7	C	13
D	8	D	15
E	7	E	14
Average	7	Average	12

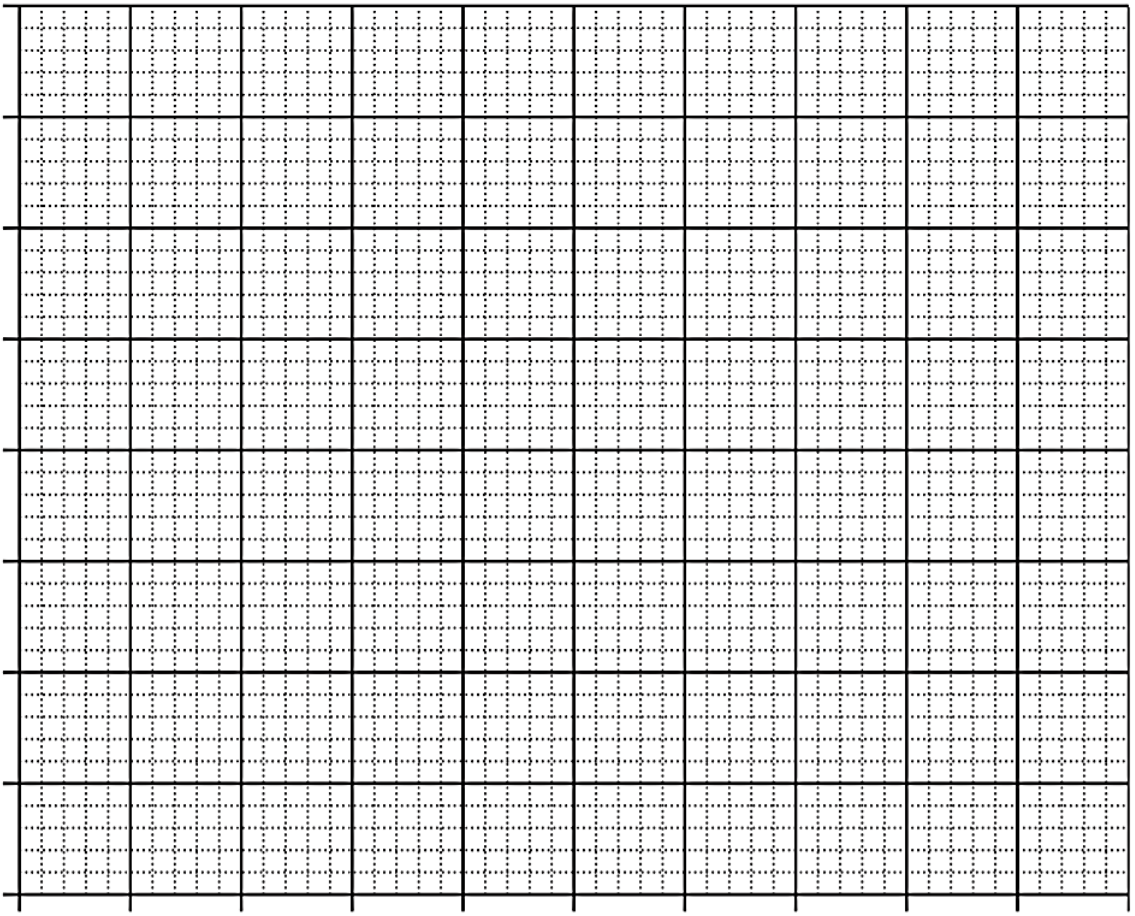
Source NESA HSC Ag 2013 Q24

Graph the average results from the table.



3. **The following set of data was collected during an experiment studying the effect of light on the process of photosynthesis. Graph the data below then answer questions a) and b).**

Time (minutes)	Percent Transmittance (%)
0	32.5
5	54.3
10	63.5
15	65.0



a) Identify the dependent variable in this graph. Explain.

_____

_____

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b) If the experiment were continued for 30 minutes, what trend in the results could be expected?

_____

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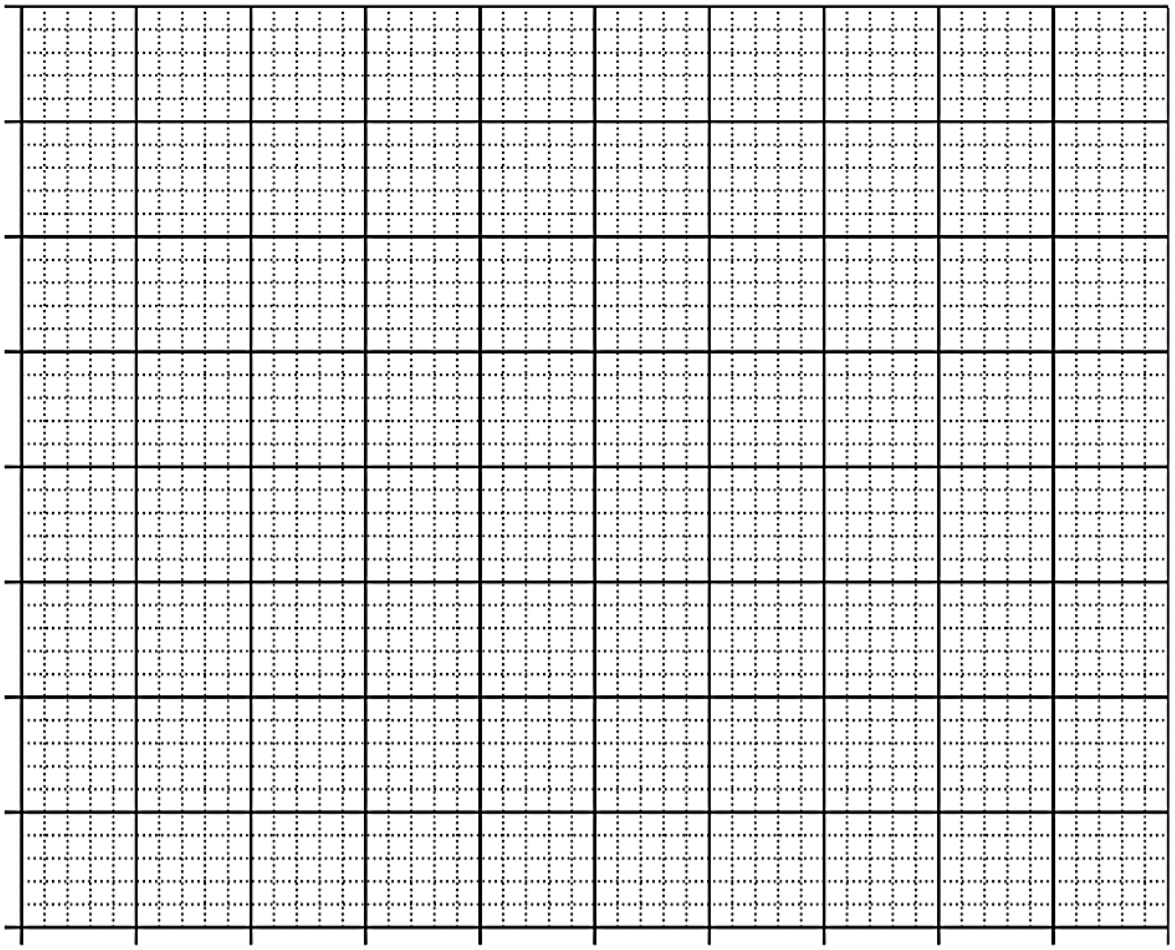
4. **The results of an experiment conducted to compare the yields of five varieties of corn are provided. (NESA, 2010, Q3,a).**

Variety of corn	Yield (t/Ha)
A	**12**
B	**13**
C	**8**
D	**11**
E	**10**

Construct a graph representing the data from the table.



Syllabus point

Propose recommendations based on the interpretation of the results of agricultural experiments

Discussion

Whenever an experiment is carried out, the researcher conducts the investigation to test a basic hypothesis. The next step in the experimental process, is the discussion of results. In research science, the report will often be in the form of a scientific journal article that will be reviewed by other independent scientists (peer review) and will usually include statistical significance tests.

The discussion will clearly and logically:

- State the findings,
- Interpret the results
- Address any limitations of the study and
- Relate the findings to existing knowledge as identified in the literature review.

Conclusions and recommendations

Conclusions and recommendations are made following the discussion. The conclusion will directly relate to the original hypothesis and state whether the hypothesis is supported by the outcome of the experiment. For example, 'The impact on wheat yield of stripe rust was not affected by the application of the seed treatment. The experiment provided no evidence that the seed treatment applied reduced the impact of stripe rust on the yield of the wheat variety Chara.

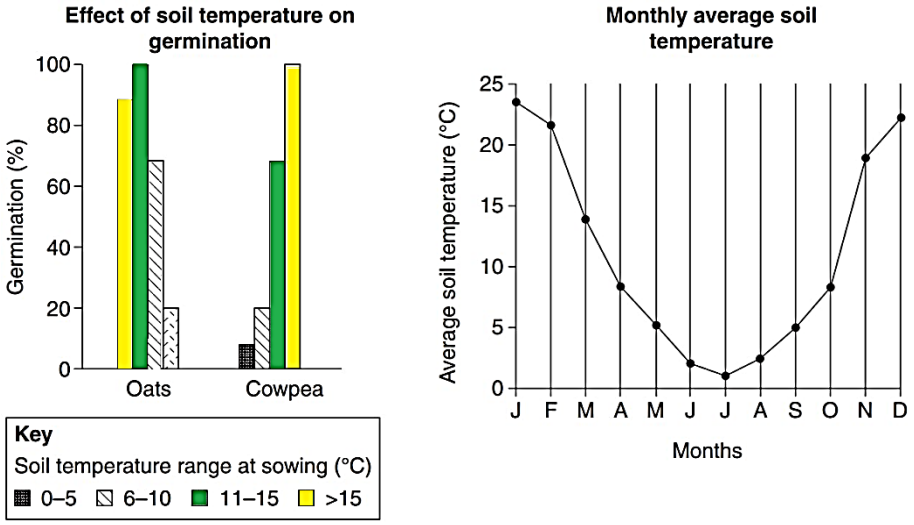
Recommendations should:

- Provide guidance on how the research could be applied
- Identify any significant findings and their application for the field
- Suggest further research that might be required. For example, to repeat the experiment using more replicates or with different standard conditions

Recommendations must always be logical and developed after interpreting all data, graphs, images, results and statistics supplied.

Learning activities

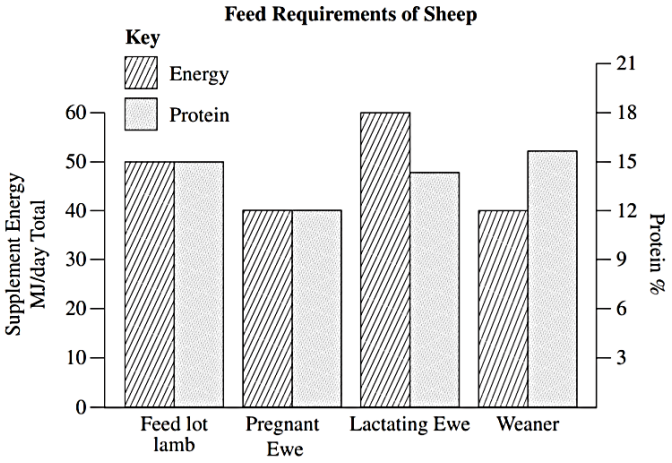
1. Use the data provided to determine which months cowpeas should be planted to maximise germination percentage? (NESA, 2013, Q20)



Source NESA HSC Agriculture 2013, Q20

a) February, March, April, May
b) January, February, March, April
c) April, May, June, July
d) November, December, January, February

2. The graph shows the feed requirements of four types of sheep (NESA, 2014 Q20).



Information about a supplement feed

Supplement Feed			
Protein	15%	Phosphorous	0.5%
Urea	1.2%	Fibre	7%
Calcium	1.0%	Energy MJ/kg	10.5

Consumption of supplement feed

	Sheep Type			
Supplement Feed Consumption kg/day	Feed lot lamb	Pregnant ewe	Lactating ewe	Weaner
	5	4	5	4

Using the information above determine which pair of sheep types the supplement feed is suitable for?

a) Pregnant ewes and weaners
b) Lactating ewes and weaners
c) Feed lot lambs and pregnant ewes
d) Feed lot lambs and lactating ewes

3. A vegetable grower has a number of strategies available to control a pest in a crop of cucumbers. The following information is provided to her by an agronomist. (NESA, 2016 Q20).

Strategies available to the farmer	*Effect on the pest population*	*Cost of the treatment* ($/Ha)
No treatment	Nil	0
Pest oil	30% kill	200
Soft insecticide	80% kill	600
Hard insecticide	100% kill	1200

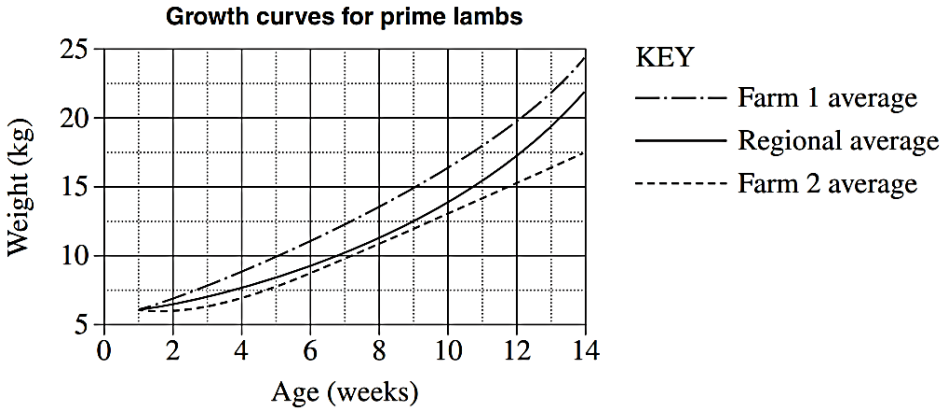
Pest population (moths/trap)	*Cucumber quality*	*Market price/box* ($)
<4	Premium	8
4–18	Good	6
>18	Poor	4

Source NESA HSC Agriculture 2016 Q20

The farmer measured the pest population in the cucumber crop at 25 moths per trap. Which of the strategies would be the most profitable to use on the cucumber crop?

a) No treatment
b) Pest oil
c) Soft insecticide
d) Hard insecticide

4. The following growth curves compare the growth of lambs on two farms with the regional average growth rate for lambs. (NESA, 2017, Q9)



Source NESA HSC Agriculture 2017 Q9

5. What is the difference in weight between lambs from Farm 1 and the regional average at 9 weeks of age?

a) 1.0 kg
b) 2.5 kg
c) 3.0 kg
d) 5.0 kg

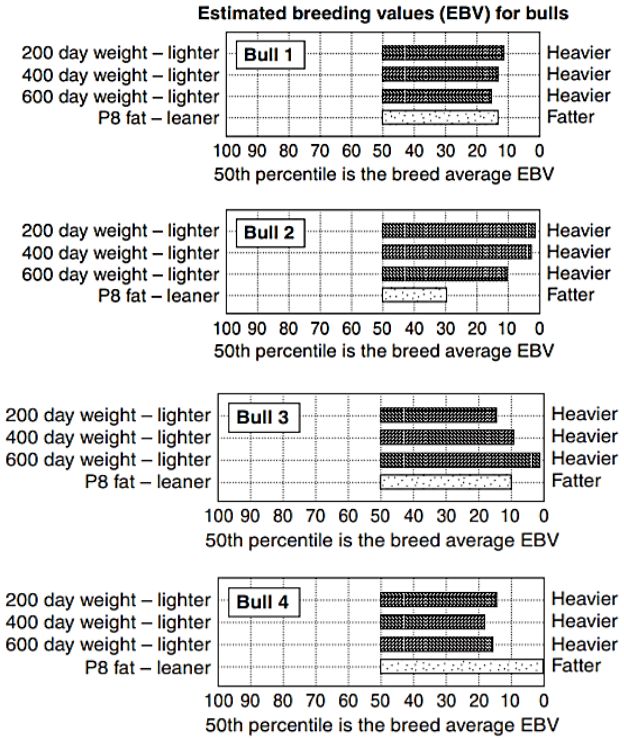
6. What does this table represent? (NESA, 2017, Q13)

Weight range (kg)	Live weight price (c/kg)	Carcase price (c/kg)	Estimated value ($/head)
0-200	385	700	693
200-280	382	696	1053
280-300	372	676	1190

a) **A market report**
b) **Supply of a product**
c) **Demand for a product**
d) **A gross margin analysis**

7. The following table shows market specifications for Australian cattle. Below the table are graphs showing the estimated breeding values (EBV) for four bulls (NESA, 2018 Q20).

Target market	*Description of animal*	*Age range* (months)	*Liveweight* (kg)	*P8 fat* (mm)
Domestic supermarket	Heavy weight for age and lean	12–18	390–500	5–16
Export market	Very heavy weight for age and moderate to high fat	24–60	525–750	10–24



Which row in the table identifies the bull which should produce offspring to best meet each target market specification? Circle the answer.

Answer	Best bull for breeding for the domestic market	Best bull for breeding for the export market
A	1	3
B	2	3
C	1	4
D	2	4

8. A farmer observes that daily milk production from her cows is variable. She decides to record daily milk yield per cow over a period of time. A summary of the results is shown in the table (NESA, 2015 Q10).

Breed	Feeding regime	Average milk production (litres/day/cow)
Holstein	Pasture only	32
	Pasture + grain	38
Jersey	Pasture only	26
	Pasture + grain	30

Which of the following correctly reflects these observations about the daily milk yield?

a) It is influenced only by genetics.
b) It is influenced only by environment.
c) It is influenced by many unrelated factors.
d) It is influenced by the interaction between genetics and environment.

9. A trial was conducted to investigate the effect of day length on the growth of meat chickens. The features of this experiment are listed below (NESA, 2016 Q23c)

- **Four similar sheds each housing 5000 chickens were used.**
- **Each shed received a different number of hours of light per day by using electric lights.**
- **The industry standard stocking rate of 30 kg/m2 was used in each shed.**
- **Chickens in each shed received the same diet.**
- **After 48 days 100 chickens in each shed were randomly selected and weighed.**

10. The industry standard for day length was chosen as one of the treatments. The results of the trial are shown in the table.

Day length (hours)	Average weight (kg)
14	3.2
17	3.5
20	3.5
23	3.1

a) Based on the trial outlined, propose a day length that could be recommended to chicken meat producers AND justify your choice.

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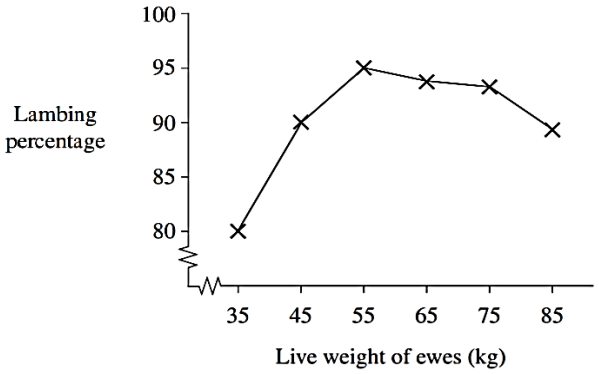
11. A method that farmers may use to calculate lamb percentage is:

$$Lambing\ percentage = \frac{number\ of\ live\ lambs\ born}{total\ number\ of\ lambs\ born} \times \frac{100}{1}$$

The graph shows the effect of the live weight on merino ewes (kg) at the time of lambing, on the lambing percentage, for a typical sheep property in the central west of NSW (NESA, 2009, Q5a).



Source: NESA, HSC Agriculture 2009, Q5

a) Describe the effect of the live weight of ewes on lambing percentage as shown in the graph.

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b) Explain how information in the graph can assist farmers to manage ewes, in order to maximise lambing percentages.

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12. Interpret the following data to complete the questions below (NESA, 2008 Q3)

- **A farmer conducted a trial on 18 pigs to determine the effect of three different feed types on their final weight.**
- **The 18 pigs were randomly divided into 3 equal groups and placed in different pens. Each group was fed a different feed type.**
- **The final weight of each pig is shown.**

	Final weight of pigs (kg)						Mean final weight (kg)	Standard deviation (kg)
Pen 1 feed X	105	112	99	97	104	107		5.4
Pen 2 feed Y	107	108	104	112	105	106	107.0	
Pen 3 feed Z	100	107	100	113	109	110	106.5	5.4

a) Calculate the mean final weight of pigs in Pen1.

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b) Calculate the standard deviation of the weight of pigs in Pen 2.

_____

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c) Based on the results of this trial, which feed should be selected? Justify your answer.

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d) Why is it important to consider other information before using this feed?

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13. The results of an experiment conducted to compare the yields of five varieties of corn are provided. (NESA, 2010, Q3.b)

Variety of corn	Yield (t/Ha)
A	12
B	13
C	8
D	11
E	10

a) Justify why a farmer might choose to grow Variety C.

Syllabus point

Outline the impact of research on agricultural production systems

Australia's primary industries have a strong tradition of being innovative and adaptive to new challenges. They have proven to be highly efficient and competitive in domestic and international markets. Agriculture today is a highly scientific and business orientated industry. It upholds a strong balanced focus on consumer requirements, profitability, environmental sustainability and resource management. As a result, the outlook for the Australian primary industries sector is strong, driven by population growth, world food demand and consumers needs for high quality food and fibre (Australian Government, Department of Agriculture and Water Resources, 2018).

None of this is achievable without research and development in agriculture and primary industries production systems. Scientific research is a key driver of innovation, uptake of new technologies and improved resource management which in turn drives growth and profitability, both on-farm and for the nation's economy and society.

In agriculture, research surrounds discovering and developing procedures, varieties, breeds and technologies that will:

- Increase livestock and crop production
- Develop more efficient equipment
- Develop more efficient use of labour
- Improve Work Health and Safety (WHS) outcomes
- Meet government legislative requirements
- Increase overall food and fibre quality

- Support environmentally sustainable management practices and natural resource management
- Enhance productivity and the economic viability and sustainability of agricultural production and commodities
- Ensure food security for an ever-increasing population
- Address changing consumer demands and preferences
- Improve animal husbandry practices and animal welfare standards
- Decrease reliance on external inputs such as water and chemicals
- Increase the reliability of climate and weather predictions
- Help producers prepare for and adapt to climate variability
- Protect our industry, environment and society from the impacts of pests and diseases and
- Spur economic growth and development; research and technology transfer

Long term impacts of research and development include higher profits for farmers, more high-quality food supply with less inputs and at a lower cost for consumers, and more opportunities and a higher quality of life in rural communities for current and future generations.

Investment in research, development and extension (R, D & E) innovation is vital for meeting targets of ongoing growth and improvements in productivity, profitability, competitiveness and sustainability of Australia's agriculture, fisheries, forestry and food industries (Australian Government, Department of Agriculture and Water Resources, 2018).

Historical structure of R, D & E investment in Australia

Historically Australian agricultural R, D & E investment has been provided by various government and public-sector agencies. These include:

- The Australian Federal government: investing in CSIRO, universities and matching funding for agricultural Research Development Corporations (RDC's)
- State and territory governments: investing in research funding for state agriculture agencies such as the NSW Department of Primary Industries
- Research and Development Corporations (RDC's) which invest levy funds contributed by farmers.

The provision of government and public sector funding and investment into Australian agriculture and primary industry R, D & E has been identified as critical to the sustainability and productivity for Australian society and for our agriculture in the global market (Australian Farm Institute, 2017).

Over the past decade, however, both globally and within Australia, there has been increased focus and development on the role of the private sector in agricultural R, D & E investment. This has risen due to a number of factors, especially the development of intellectual property (IP) and patent rights which enable the private sector investors to obtain an economic return from their investments (Australian Farm Institute, 2017).

Learning activities

1. **Outline the need for agricultural research and development.**

2. **Why is research required when developing new agricultural technologies? (NESA 2016, Q30a, i)**

Syllabus point

Design and conduct a simple plant or animal trial using appropriate methodology

As a requirement of the Stage 6 Agriculture syllabus, students must perform a minimum range of first-hand investigations, including:

In the Stage 6 Agriculture HSC course students:

- Perform a first-hand investigation to analyse and report on the physical and chemical characteristics of a soil
- Perform a first-hand investigation to determine the effect of light on plant growth
- Perform a first-hand investigation to determine the effects of planting density on plant growth and/or yield
- Design and conduct a simple plant or animal trial using appropriate methodology

In the Stage 6 Agriculture Preliminary course, students:

- Conduct a simple plant trial using appropriate methodology
- Conduct a simple animal trial using appropriate methodology within animal welfare guidelines

When and how these investigations are conducted will depend upon teacher preference and school resources available. Use the following scaffold (checklist) to complete the experimental design and investigation.

Experiment design scaffold

Follow the steps below to ensure correct experimental design is used when completing an investigation.

Planning

- ☐ Formulate a problem or question to investigate
- ☐ Research the problem or question to identify findings in the area and find methods you can use for your investigation
- ☐ Decide on the treatments that you are going to use, make sure you include a control treatment
- ☐ Formulate a hypothesis. Make *sure* you state the consequences and reasoning for the hypothesis

Identify variables

- ☐ List the dependent variable
- ☐ List the independent variable
- ☐ Consider an adequate size for your experiment. Ensure there are enough replicates for a meaningful statistical analysis.
- ☐ Consider that the sample you use will be representative of a whole population
- ☐ Identify the experimental unit (e.g. a $2m^2$ plot or 3 leaves on a single plant)

Random sampling

- ☐ Identify and describe how you will randomly select your sample

Randomisation

- ☐ Identify and describe how you will randomly allocate treatments to experimental units

Replication

- ☐ Describe how you will carry out replication of treatments. Provide a diagram.
- ☐ Will the number of replicates you have chosen give meaningful statistical results?

Standardisation

- ☐ Identify how you will carry out standardisation in terms of all samples receiving the same conditions. Consider factors such as water, sunlight, time, feed, nutrients, soil type, shade, animal dominance, predation, interference, equitable allocation of resources and nutrients etc.
- ☐ Identify how you will standardise the method for setting up, carrying out and collecting results from the investigation (Quality Assurance)
- ☐ Identify how you will standardise equipment (calibration) and equipment use (procedure) (for example calibrating pH to standardised buffer solution)
- ☐ List any border effects and identify how their effect will be minimised e.g. use of buffer zones and blocking

Inclusion of a control treatment

- ☐ Does your investigation require a control treatment?
- ☐ If yes, identify the control treatment and explain why it is needed in the investigation
- ☐ Formulate a detailed methodology

Doing

- ☐ Measurement and method strictly followed.
- ☐ Include detailed descriptions, images, photos, tables etc. for results capture
- ☐ Measurement order should follow field experimental design order
- ☐ Multiple measurements needed? (Standardisation of equipment)

- ☐ Collection and recording of data
- ☐ Identify statistical analysis methods used (such as mean and standard deviation)
- ☐ List them and explain why they were used
- ☐ Present data in an appropriate form (e.g. graphs, table)
- ☐ Make conclusions from your findings
- ☐ Did your results reflect your hypothesis?

Reporting

- ☐ Write a full experimental report using the following titles: aim, hypothesis, materials, methodology, results, discussion and conclusion, references. Provide appropriate detail.

Extra considerations when conducting animal-based investigations

Prior to setting up an animal-based investigation, follow the link to the NSW Animals in Schools site to read more about considerations, legislation, responsibilities, approved activities, health and welfare and animal management requirements.

- ☐ Is the investigation necessary? Could you instead replace your findings with other people's research, mathematical modelling or running a simulation?
- ☐ Only use the minimum number of animals to obtain reliable data. Reduce the number of animals used where possible.
- ☐ Ongoing refinement of the study is needed to minimise the overall impacts on animal treatments.
- ☐ Does a treatment really work as it is intended to?
- ☐ Does the treatment itself cause harm now or later?
- ☐ Is the treatment better compared to other potential treatments?

If you answer no to more than 1 consideration above. Reconsider the investigation.

References and further reading

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Syllabus outcomes

Agriculture Stage 6 HSC course

Outcomes	Content
H4.1 justifies and applies appropriate experimental techniques, technologies, research by methods and data presentation and analysis in relation to agricultural problems and situations	Experimental design • Design and conduct a simple plant or animal trial using appropriate methodology • Outline the role of a control, randomisation, replication and standardisation of conditions in a simple plant or animal trial The collection and analysis of data • Analyse and interpret agricultural data by calculating a mean and a measure of variability (standard deviation) • Explain the need for a test of significance to be performed before valid comparisons can be made • Present data in an appropriate form The role of research • Propose recommendations based on the interpretation of the results of agricultural experiments • Outline the impact of research on agricultural production systems

Agriculture Stage 6 Preliminary course

Outcomes	Content
P4.1 applies the principles and procedures of experimental design and agricultural research	Elements of experimental design • Recognise elements of experimental design including control, randomisation, replication and standardisation of conditions Collection and simple analysis of data • Conduct a simple plant trial using appropriate methodology • Conduct a simple animal trial using appropriate methodology within animal welfare guidelines • Calculate mean and standard deviation using trial data