# Research in Your Growing Space Handbook

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# Contents

# Introduction

Humans are naturally curious and experimentation is how we learn. At some point most people shift to the mindset that science is something done by 'experts' in institutions.

Despite that outlook, it cannot be denied that all growers experiment - techniques or crops are tried, results assessed, reviewed and perhaps even shared. Their findings change how they grow in the future, either dropping something which didn't work out well, or continuing with those things that are successful. However, growers don't always recognise the science in their approaches, and self-confidence in scientific abilities can be low. Tools for exploring and analysing data can also be difficult to access and use. This guide is intended to support growers in designing and running their own research projects in their growing space.

# What is your question?

Defining the purpose of your research, and developing a clear and answerable question is very important to get right from the beginning. The question is what drives the whole scientific process. Investing time in setting a clear question this will save you a lot of time and effort later on. There are three steps in the process:

- **Decide your research area**
- **Define your question**
- **Refine your question**

## Decide your research area

First, decide broadly what you want to know about; then, define your question or theory. This is an iterative process and you might need to go around more than once, depending on how clear the question you are starting from is.

You will need to look up what is already known on the topic - you might find your answer and not need to investigate. Then you need to see what you can realistically do with the time and resources you have. From there, you might need to read up a little more to fill in the gaps on the best way to go about it, or to understand any other aspects that could influence what you do.

You might start with a general area of interest. For example, finding about companion planting, or growing several crops together in the same place. Or you might already have a more specific question, like "what are some good crop combinations to grow where I live?"or "how can I benefit biodiversity whilst growing food?" Wherever you start from, a good first step is simply to get all your thoughts and ideas together. Many people like to do this in writing, such as a brainstorm, but you can use whatever method works best for you. Take five minutes to write down everything you can think of about your topic area.

Giving yourself a limited amount of time for this part means that you are likely to first write down the things you find most important or interesting. It is good to start with simple ideas and topics. You can develop and add details to these as you go. You might make observations, like: "I tried this, but it does not work", or you might include questions like 'what would happen if..?" or "Is there a link between..?". The next step is to arrange these initial thoughts - group similar ideas and draw arrows between linked concepts.

Now, you have got a lot of great thoughts, ideas, and questions, and have started to group and link these. Is there a particular aspect that stands out as most interesting to you, or something that would be really useful to investigate? You might need to learn more before you can be sure on this and that is an important part of the process. Once you have some initial ideas, it's great to discuss with others, if you can. Have they had similar problems or challenges? Would this be useful or relevant to them? They might also suggest ways to improve or refine it. Finally, try to form your thoughts into questions or hypotheses. For example, you might think that increasing the number of crops you grow will increase insect diversity. That is a hypothesis. Another example might be, what happens if I add compost to my soil, will it increase soil nutrients?

## Define your question

Once you have an outline question or hypothesis, it is time to start to define it more clearly. First discover what is already known about this topic - you can do that by reading, speaking with gardening friends, asking on forums or using online searches. Searching online has become a common starting place for most of us.

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Here are some good tips to finding quality information. Firstly, consider what you're typing in your keywords - try to be specific. You might add your location, to make sure you get results that are relevant to you. Using the scientific names of plants usually gets more informative results, if you do not know the scientific name, Wikipedia is a great place to look those up.

You can use quotation marks to enclose words, to search for them together, for example, "three sisters" or "companion planting." You also add additional words to give a more specific context or use a minus sign at the start of a word, without a space, to exclude it. Try searching for "three sisters" -corn to see how that changes your search results.

Once you have your search results, the next step is to look at the source and context to determine how good and reliable they are. Try to choose results from trusted sources and people who have expertise on the subject. Domains ending in .ac, like .ac.uk or .ac.nl, are academic organisations, like universities. In America, these are .edu domains, .gov for governments. These types of sites tend to have information that has been vetted by others before publishing online. You can also see if the information is accurate - try to determine is it well written or are there are errors. Does the website state the source of the information? Good websites will also have a date on articles or will tell you when the page was last updated or maintained. You can use this to determine if the information is likely to be current. The final test is to determine whether the website is objective - be cautious of sites that are trying to sell something, have a political agenda or are an individual's opinion. Look for content that presents balanced information, showing all sides of an argument, and includes good evidence.

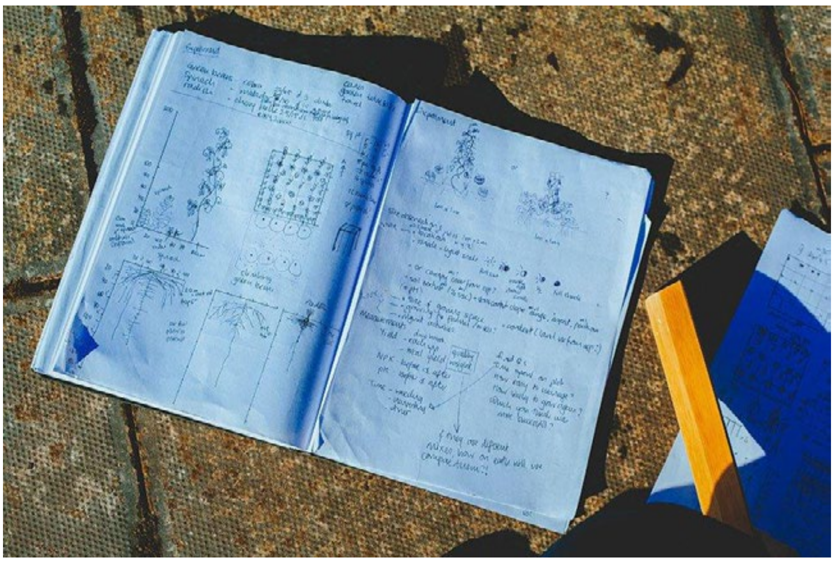
Google Scholar is an academic search engine; it works like Google or Ecosia, but returns academic papers and books in the results. These academic papers are generally peer reviewed, which means at least two other experts in the field have read and commented on the paper before it is published - someone else has done the hard work in assessing the quality of the information for you! However, these papers can be quite difficult to read, if you are not familiar with the subject and the terminology. Each paper has an abstract, which is a summary of the content. For most papers, this follows a specific format: why the topic is interesting and relevant; what they were investigating, their question; what they did, the method or approach; and what they found out, the results; and what this means in a wider context. Most papers follow the same structure, too. Remember, you don't have to read all of it. The introduction can be useful for getting started, as a summary of the existing knowledge.

Once you've done some reading and note taking, you can revisit your original idea and add depth and detail. You might have more questions and ideas, too. It could be good to do another mind map or brainstorm to organise this or make lists.

Once you have narrowed your question, do a quick check of feasibility: will you have enough time to answer it? Are there other people who can help out? Can you bring in their ideas to create an even better investigation together? Can they help you carry it out? What key equipment will you need? Can you access the tools and resources you need? What is critical to success? Once you have been through all of this, you will have taken your initial area of interest, found out more, and started to define a question that is feasible to investigate. The final step is to refine your question into something which is clear, answerable, and achievable.

## Refine your question

Our question, or hypothesis, is what drives our investigation – everything we do should lead us to be able to answer it. To do this, the question needs to be clear and answerable.



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That is, we need to know what that answer will look like. This step of refining the question is one of the most important parts of designing an investigation. It is also the part that many people find quite difficult. It is worth putting the time in to get this right because it will make everything else that follows it much easier.

Here are our example questions again:

- **What are some good crop combinations to grow in my location?**
- **How can I get more from a small garden?**
- **What can I grow that will benefit biodiversity and feed me?**

Although these might have looked quite specific questions, they will actually be quite hard to answer as they are. Taking the first one, there are three parts where we can be more specific.

## 1. in the location or scope (or limits):

What are some good crop combinations to grow in **my location**?

Location could cover several important considerations:

**Where in the world you are** - this could be your coordinates, how far north or south of the equator, how far from the coast you are, or how high up. These factors and more will influence the climate you are growing in and limit what you can grow, or how well certain crops will grow.

**What kind of place or site you are growing in** - this could be whether you are growing on a balcony, in a garden, allotment, or community garden, or on farm, or somewhere else. This can also influence what and how you can grow. The size of your site and any restrictions on use like not being able to plant trees or use pesticides could influence what you can investigate.

**Where on your plot you are growing** - this could be if you plan to grow in a shady site, on a steep slope, or adjacent to your neighbours who use herbicides. It is important to consider these smaller scale factors so you can design something that will work for your site.

**How big your growing area is** - although this might not be obvious from 'location', this is implied in the question. What you can grow and how much will be influenced by the size of your site.

## 2. In the content focus of the study:

What are some good **crop combinations** to grow in my location?

Here, it is really worth thinking about what you mean by 'crop combinations':

**What kinds of crops do you want to grow?**

Think about what you like to eat, or any other benefits you are looking for. You might also consider how different crops complement each other in terms of space. For example, what space is there along the ground, up in layers and for the roots? And how different crops influence each other or the environment, for example, by shading, by making nutrients available, or by attracting pollinators.

**How many different crops do you want to investigate at once?**

It might be really tempting to try out a high diversity mix with many different species. Most scientific studies just look at two crops. Whilst there can be logistical reasons for that, like limitations to planting or harvesting machinery, it's also because it is easier to plan, carry out and analyse. It can be quite difficult to understand why you might see the results you do when there are too many differences (or 'variables') to choose from. It's best to start as simple as you can, especially if this is your first trial.

**How many different combinations of that number of crops can you try?**

This is going to be limited by how much total space you have to play with. You will then need to divide your space based on:

- How much space each plant will need and
- How many of each plant you will have
- How many different crops there are

With this information, you can see how many combinations you have space for.

**How many plants of each crop?** is an important consideration. If you grow six different crops, but only plant one of each, and that one plant doesn't germinate, then you won't know whether the location is unsuitable, or whether there was a problem with that one seed. You need to have enough of each crop type to give them a reasonable chance to grow.  It's good to think ahead about what your results might look like and how you could interpret them. For example, if you planted two seeds and one didn't grow, that's a 50% success rate. If you sowed 100 seeds and 50 didn't grow, that's also a 50% success rate. However, if 50 seeds fail, then you can be much more certain that's a genuine result of 50% than you can if only one of two fails to grow.

**How are they going to be combined?** this is where it can get tricky. How you arrange your plants can influence how well they grow. You might consider:

- How close together they are ('crop density')
- What the sowing pattern or arrangement is. For example, are they placed in rows, a uniform grid spacing, or broadcast (scattered randomly in an area)?
- Where they are in relation to each other, for example, underneath or on the sunny side

Unless you are specifically investigating one of these factors, it is important to be as consistent as possible between the different crop combinations. Try to have the same planting arrangement and number of plants in all of your experimental plots. You want to be sure that your results are due to the combinations (mix of species), and not because the plants were really close together in one plot, but had more space in the other.

## 3. In the aspect of evaluation or comparison in the study:

What are some **good** crop combinations to grow in my location?

This is the most important part to qualify as it gives your question a meaning and a way of knowing if you have answered it. You might already know your location and have some thoughts about the kinds of crops you want to grow but what do you mean by "good"? At the moment, "good" could mean lots of things:

- They grow (in that climate or soil)
- They grow well together
- You get an abundant harvest

- You get a better harvest growing together than growing each on its own
- They are good to eat
- They support a high number of pollinators over a long period
- They help to improve your soil structure, soil nutrients, and soil organisms

Hopefully, you can see why it is important to define this really clearly. You would do different things in your investigation if you were looking at pollinators rather than yields. From our question, we will start to see what approach will be taken, what limitations we need to consider, and what the answer(s) might look like.

## With more specific answers to these sections, we could refine our original question in many ways. For example:

**Refined question version 1** -*which three food crops can I grow in 2 m2 (2 m x 2 m) in northern Hungary to maximise my total harvest?*

*Approach* - try different combinations of three crops determined by what can grow in the size of the plot.
*Limits* - the total area available will determine how many plots of 2 m2 we can grow and how many combinations can be tested.
*How to answer* - measure the harvest and see which is the greatest.

**Refined question version 2** - *which five crops can I grow in 5 m2 (5 m x 1 m) to give me the most sustained harvest from June to August in south-west Ireland?*

*Approach* - try different combinations of five crops.
*Limits* - total area determines how many combinations.
*How to answer* - calculate the length of the harvest period and see which is longest.

**Refined question version 3 -** *does growing in a polyculture increase the amount of food I could get from my plot compared to growing the same crops in a monoculture?*

*Approach* - grow the same crops on their own and in combination. Decide how many crops, and which crops.

*Limits* - need enough space to grow monocultures and polyculture, this will limit the number of different crops that can be grown.
*How to answer* - measure the total harvest of each crop and compare each grown alone with that crop in a mixture.

This is the process of defining a question from a starting idea to something where we can see clearly what we need to do and what answer we might expect For example, are we looking for weight, a number of days, or a number of butterflies? We can also start to see some of the limitations and other factors to consider.

- **How would you refine the other questions?**
- **How can I get more from a small garden?**
- **What can I grow that will benefit biodiversity and feed me?**

## Safety guidelines

Please keep safe! These are general safety guidelines to follow at all times when in the field carrying out experiments

- If you are carrying out experiments in a growing site other than your own garden or farm, you will need to consider if you require permission and long term access from the homeowner or landowner.
- Before starting, make sure the site is safe, e.g. locate yourself away from roads, check for any uneven surfaces, glass, litter, etc.
- Check your tools and make sure they are in good condition.
- If young children are present, make sure they are closely supervised at all times.
- Be aware of other people, vehicles, or animals that are close by.
- Make sure you wear suitable clothing adequate to the weather of your region.
- When digging for soil, look out for sharp objects that might be present in the ground and take care in the use of digging tools.
- Consider wearing gloves. Avoid carrying out the activities if you have open cuts or wounds. There is

a low risk of contracting tetanus, a bacterial infection, through soiled cuts or wounds made by plant thorns.

- Be aware of any prickly or stinging plants, biting insects or other creatures that may be living in the soil or undergrowth.
- Think about wearing eye protection to protect your eyes from splashes or soil particles, and old clothes or an apron to avoid getting dirty.
- Wear proper shoes to protect your feet from cuts and stings. Bare feet, sandals, or flip flops are not recommended.
- Always wash hands thoroughly after carrying out activities outdoors. Use a hand sterilising gel if clean water is not available.

# Setting up your experiment

### Your method

Science is brilliant because you can never get a wrong result! We might not get the result we expected or disprove our hypothesis but that is still a result and worth sharing.

While your results cannot be wrong, your method can be. Your method is what you do, where and when in the investigation. Someone else should be able to follow your method and do the same. For outside experiments and observations the method usually comprises:

- Study site - a description of the location and key site characteristics
- Sampling design - how many samples, how many replicates and how they are arranged
- Measurements - what you measure and how
- Analysis - how you are going to use the data you get to answer the question. For example, you could graph it, map it, or do a statistical analysis.

It is possible for there to be errors at any of these stages, but the most common errors occur in sampling design and data analysis.

## Choosing a study site

The study site is the location(s) in which our investigation will be carried out. It must be a site that you have permission to use for the duration of your study, and where it is safe to work. It should be suited to the purpose of the investigation.

For example, if we are investigating regenerative growing food, then it needs to be a place where food can be grown and those practices can be carried out. For most of us, choosing the study site is quite simple - it will be where we have access to a growing space.

For some studies, however, we may need to select a suitable study site from a range of possibilities. In this case, it's best to define a set of criteria in advance to determine suitable sites. From that selection, the actual sites should be selected in advance at random. This approach helps prevent the researcher from influencing the site choice. Choosing a site because it is appealing or convenient can introduce bias into our study and make it harder to know if the results we get are 'true'.

**Example: Bee-friendly: community gardens or oilseed fields?**
Imagine you wanted to investigate whether community gardens attract more bees than fields growing oilseed rape (*Brassica napus*). To have good replication, you will probably want to compare a number of garden plots with several fields. How will you decide which plots and fields to use?

*Remember that we also need to account for other factors that could influence how many bees we see. This could include:*

- Weather
- Time of year
- Time of day
- Nearby land use

A way to minimise differences in these factors is to have community gardens and fields relatively close together. But, we need to make sure they are far enough apart that they can't influence each other - the foraging area for honeybees can extend for two miles (3 km) from their hive.

The observations of bees at each site should be done at the same time of day and year. You might need to visit all sites several times during the year to account for seasonal variation. Oilseed may flower only for a short period compared to allotment sites. Will you visit only when it is or is not flowering or spread your visits over the year to build up a more complete picture?

**We might set our criteria as:**

- Gardens which you have permission to access
- Fields which you have permission to access
- Accessible garden more than 1 mile and less than 5 miles from an accessible field
- Fields and gardens with at least 75% of the adjacent land use as urban or peri-urban

These criteria give us a list of possible sites. If there aren't enough options, then we might have to relax the criteria, for example, we could look for sites up to 8 miles apart, widen the total area we are looking in, or change the land use constraints. If there are too many, we can select the amount we need at random. A simple way to do this is to assign each field-garden pair a number and use a random number generator, for example at: www.random.org or the function =RAND() in most spreadsheet software. You could also use a friend who does not know which number is for which set, to select them.

## Site description

Once we have selected our site, it is useful to note down some key features that describe it. This might include:

- Location (for example, place name and coordinates and height above sea level)
- Climate (for example, average rainfall and average temperature each month)
- Underlying geology
- Soil type

These features can also be used to compare to other sites where similar investigations have taken place.

### Open data

Open data are data made freely available to everyone to use and republish as they wish, without restrictions from copyright, patents or other mechanisms of control.

Open data can be useful for obtaining characteristics for your study site which are difficult to measure. A list of useful open data sites is below, but make sure you read the limitations of such data (such as the location and resolution it covers) and any licencing requirements before using it for your investigations.

**Find your coordinates** https://www.latlong.net/
**Find your nearest weather station** https://wow.metoffice.gov.uk/
**Geology of the UK** http://mapapps.bgs.ac.uk/geologyofbritain/home.html
**Geology of Europe** http://www.europe-geology.eu/onshore-geology/geological-map/onegeologyeurope/
**National geological** maps https://www.usgs.gov/products/maps/geologic-maps
**National soil maps** https://esdac.jrc.ec.europa.eu/resource-type/national-soil-maps-eudasm

## What do you need to measure?

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As we refined our question in the last section, we started to give some thought to what we will measure. We are going to use the words “measure” and “measurement” here to cover everything we might record or observe, including true measurements like length, weight, or amount, as well as observations like soil texture, light or shade, or rainy or sunny.

There are two aspects to the measurements you will take:

- What you need to measure to help answer your question
- What other things might influence that result which you also need to account for

Some people start by thinking about what they want to measure and then need to work back to see what their question is. Others start with a question and then work out what they need to measure to answer it. It is a cyclical process, so it does not matter where you start.

**Example:** *which three food crops can I grow in 2 m2  (2 m x 2 m) to maximise my total harvest?*

*Approach* - try two different combinations of crops.
*How to answer* - measure the weight of each crop's harvest and add up to the total.

Now imagine you have your results. Try to think of some values that are reasonable, like this:

| Plot A | Plot B |
|---|---|
| Sweetcorn 5 kg | Lettuce 1 kg |
| Squash 10 kg | Rocket 1 kg |
| Beans 5 kg | Peas (shelled) 1 kg |
| **Total 20 kg** | **Total 3 kg** |

In this case the result would show that Plot A yields more. However, squash weighs much more than lettuce. If the aim was to get the greatest weight of food, then it would lead us to plant the heaviest crops like potatoes and squash, rather than lighter ones like lettuce and peas. Does that answer the question you meant to ask? If not, think about what you want to achieve and revisit your plan. You could use weight to work out economic value (how much it would cost to buy) or nutritional content (based on averages).

The next example question has some quite different considerations on measurements:

**Example:** *what plant species can I grow to maximise the number of bees and butterflies?*

*Approach* - grow several plants that are likely to attract pollinators like bees and butterflies

*How to answer* - the total number of bees and the total number of butterflies visiting each plant. Which gets the most?

**Some things to consider when answering this question:**

- Can you tell bees from wasps or hoverflies?
- Does it matter if they are bumblebees, honey bees, or other kinds of bees?
- Can you distinguish butterflies from moths, and do you need to?



If you are doing this with other people, can they tell them apart too? It is best not to get too technical if you are not sure about identification. You could look at all flying insects landing on your flowers, for example.

Are you going to spend the whole summer in your garden counting all of the pollinators that come and visit? If not you will need to take some samples. A sample is a set of data that we can use to represent the wider population of bees or butterflies without having to count them all.

## To determine what a sample might look like think about:

- What size area to look for bee or butterfly visits in? For example, you might look at your plot in a 50 cm x 50 cm square that is 1 m above the ground, or look at insects landing on ten flowers.
- How long to watch out for them in one go? For example, you might choose to watch for 10 minutes.
- How often to repeat this? For example, you might choose twice a day, every Monday, or once a month.

Do the same thing on each plot so that the results you get are fair and comparable. The best way to do this would be to have someone watching each plot at the same time. If that is not possible, do the measurements close together, for example, you might monitor Plot A at 10 am and Plot B at 10:15 am, then the next time do Plot B first.

Imagine that we decide to watch our plot at 10 am on the first day of each month. Let's take a look at our imaginary results:

| | Bees counted | |
|---|---|---|
| **Date** | **Plot A** | **Plot B** |
| 1 June | 2 | 5 |
| 1 July | 24 | 18 |
| 1 August | 10 | 20 |
| **Total** | **36** | **43** |

Plot A has fewer bee visits (36) than Plot B (43) which gives us an answer for part of our question. What if we do the same for butterflies?

| | Butterflies counted | |
|---|---|---|
| **Date** | **Plot A** | **Plot B** |
| 1 June | 5 | 2 |
| 1 July | 20 | 25 |
| 1 August | 20 | 15 |
| **Total** | **45** | **42** |

Plot A has more butterfly visits (45) than Plot B (42). What if you find more bees in one plot and more butterflies in another plot? Is that OK? Which would be "best"?

As you are thinking through your possible results, it is a good idea to imagine unexpected situations like this so you can think about how you can use the information you get to answer your question. If you cannot see a way to answer it, you might need to rethink it.

Look at the question again. We can see it is about total bees **and** butterflies. By adding up bees and butterflies we find Plot B is slightly better overall and can see that is because of the lower number of bee visits in Plot A. So, we can answer our question and see some interesting differences between the plots.

Think about what you would need to measure to answer the following question:

**Example question:** *does growing in a polyculture increase the amount of food I could get from my plot compared to growing the same crops in a monoculture?*

*Approach*: grow the same crops on their own and in combination.
*How to answer*: measure the total harvest of each crop and compare each grown alone with that crop in a mixture.

## Control and replication

Scientific studies can be observational or experimental. An experiment deliberately imposes a change on a system in the interest of observing a response.

This differs from an observational study, which involves collecting and analysing data without changing conditions. In general, in an observational study, we want to make an initial assessment to gain insights. In an experiment, we want to test a hypothesis to see if our insights are valid. Here are examples of observational and experiment questions:

### Observations

- What proportion of people in my town grow their own food? - this seeks to evaluate what already exists. We don't have any expectations in advance and there is no element of comparison.
- Which plant species maximise the number of bees and butterflies? - this explores bee and butterfly numbers on different plants (that are already in place) but we do not have an expectation of which plants will attract most insects.

### Experiments

- Does adding compost increase my yield? - our expectation, or hypothesis, is that more compost will result in a greater yield.
- Does growing in a polyculture increase the amount of food I could get from my plot compared to growing the same crops in a monoculture? - our expectations here might be that a polyculture will yield more food per land area.

Experiments can be used to test our questions (or hypotheses) by making manipulations or treatments, for example, adding compost or growing crops in a polyculture. However, it is not enough to make a manipulation and measure what happens; we need to **compare** it with an area which has not been changed – this is our control.

### Controls

A control should be kept the same as the manipulated plot, except for the variable we are testing. A control gives you something to compare you manipulated plot with, meaning that we can be more confident that there is a cause-and-effect between treatment and results. A control also helps rule out alternative explanations due to other variables and makes it easier to detect differences by reducing the variability between plots. In reality, it can be difficult to control for everything so we may also need to account for other factors by measuring them. If we want to consider the impacts of adding compost on yield, for example, then adding compost should be the only difference between our plots. Everything else should be the same (or as close as possible).

## Replication

### How do we know if the difference (or not) between the control and the treatment plot is 'real' and not just due to chance?

One way to do this is to repeat the experiment many times and compare the results. You could do this by having several plots of each type; for example, you might try five plots with compost and five plots without compost. However, this can take up quite a lot of space.

The more times an experiment is carried out, the less variability there is, and the more confident we can be in the results. This is known as the Law of Large numbers – if enough measurements are taken, the invalid ones balance out so that their average is close to the actual value. A striking demonstration of this is when you independently ask people to guess the number of small objects in a jar - if you ask enough people the average of their guesses will be close to the actual number.

However, the Law of Large numbers is not a substitute for good experimental design. The more care we take to control other factors the fewer replications we need to be confident in our results. We need to bear in mind the importance of control and replication as we design our experiment.

## Influencing factors

We now have a question, and we can see what kind of answer we are going to get. We have considered what resources and knowledge we need, and we know that what we plan to do is feasible.

We have chosen to do either an observational study or an experiment, and we know what the type of measurement – the result – will be. Next, we need to think about what other factors can influence our results.

Where possible, we will "control" these additional influences by keeping them the same in all of our plots. Sometimes, this is not possible, so in those cases, it is useful to measure these other factors. In scientific terms, we call these factors "variables." They are measurements that can vary, and we do not know in advance what the values of them will be. In a laboratory, researchers can control all of the conditions, such as light, temperature, humidity and nutrients. In the field – outside, in real growing conditions – we do not have this same level of control.

In both of our experiment examples (adding compost and growing in polycultures) we are going to measure and compare our harvest weight. Yield is a measure of plant growth so it will be influenced by everything that affects plant growth. These factors can influence, or "bias" our results. We can control for some and measure others, but we cannot measure everything, so we need to identify which variables have the greatest impact. These are likely to be:

- Location - distance from the equator, elevation, how far inland
- Climate - light, temperature, water availability
- Topography and microclimate - slope and aspect
- Soil properties - texture, structure, stone content and pH
- Nutrients - macronutrients, micronutrients
- Competition from weeds
- Pests and diseases

Taking the polyculture experiment as an example, in this experiment, each crop in a monoculture acts as the control, giving us a reference for the "normal" growing conditions. The polyculture mix is the treatment.

## Essential design requirements

For each condition, we need to think about what we can do to minimise or measure differences; essential design requirements are noted below to help avoid controllable bias. If these essentials are not met, we won't have "fair" results. Measurement suggestions are also given below to show how we would measure these conditions in ideal circumstances.

**Location**

Your location will determine climate, geology (rock type) and factors like day length. We would not plant a monoculture at the South Pole and polyculture in Greece and then be able to say that growing in a monoculture is less effective. The location would bias (influence) our results, we can reduce this by:

*Design* - plots should be as close as possible to one another without impacting the other conditions.
*Measure* - it is common to record coordinates and, if possible, elevation.

**Climate**

Climatic conditions like sunshine, rainfall, and temperature have a big impact on plant growth. We cannot control the weather, but we can ensure that our plots experience the same weather by locating them close to each other. This way, if it rains on one, it will rain on all of them.

*Design* - plots should be as close as possible to one another without impacting the other conditions.
*Measure* - light, temperature and rainfall can be measured in each plot

**Topography and microclimate**

Slope angle, aspect, and position can all influence how exposed a site is, how much light it gets and how water moves through it. Trees and buildings can shade plots and alter light, temperature and moisture levels at a small scale.

*Design* - plots should be on similar slopes (with the same steepness, facing the same way, and in the same place on the overall slope). Plots should experience the same amount of light and shade.
*Measure* - on each plot, we should measure slope angle, aspect, and position, and we should also record light, temperature, soil moisture.

**Soil properties**

Soil properties influence root development and access to water and nutrients. We cannot reasonably influence soil texture or stone content, but whether or not we dig the plot will influence the structure.

*Design* - plots should be close to one another and prepared in the same way, for example, either all dug over or all no-dig.
*Measure* - soil properties in each plot can be assessed

**Nutrients**

An adequate supply of each plant nutrient is required for good growth. If nutrient concentrations are too low or too high, plants won't grow well. We cannot easily know what the levels of all nutrients in the soil are, as these can vary over small scales, but, generally, plots close together are more likely to have similar conditions than plots further away. We can adjust nutrients by adding organic matter such as compost, manure, mulch, and adding fertiliser.

*Design* - plots should be close to one another. Plots should be prepared and managed in the same way, for example, with the same compost added at the same time before planting.
*Measure* - soil nutrients

**Weeds**

Weeds can inhibit the growth of our crops through competition for light, moisture and nutrients. They can also influence it through shading and attracting insects. Unless your question is specifically about the impact on weeds, such as "Do polycultures have fewer weeds?" then it is best to remove all weeds from all plots. However, it's also good to know if one plot has many more weeds than another.

*Design* - remove all weeds prior to planting. Remove all weeds that grow during the experiment.
*Measure* - total weight of weeds removed from each plot or time spent weeding each plot.

**Pest and diseases**

Like weeds, these can influence our harvest. In the context of this example experiment, pest and diseases are unpredictable variables that we cannot control for easily. The occurrence of pests or disease could be a random unlucky event, or they may be caused by the actual experiment. These can have a big impact on the results, so we need to be aware of and record any occurrence.

*Design* - none, but it is a good idea to consider what your response would be if this happened. Would you treat all plots to remove the problem, treat only the affected plot, or do nothing and measure what happens?
*Measure* - it is essential to note incidence of pest and disease in any and all plots. You could also record damage to each crop in each plot from pests and disease.

We have looked at specific factors that we can control for in our design and those that we can measure to assess how much impact they have on our results. Replication is a great way to account for some of the natural variability in soils, microclimates, nutrients and more. If we have multiple plots of each type across a range of conditions and we always get the same results, then we can be more confident that is because of our manipulation (treatment). If we get inconsistent results, then we might be able to look at these factors to explain our results.

## Taking measurements

By now you will probably have a good idea of the measurements you require so it is time to get into the details of the measurements. They will be the ones that directly help you to answer your question plus measurements of other variables that could influence your result.

There are thousands of possible measurements you could take, depending on your question. We cannot cover how to do them all here, but we can look at some fundamentals that apply to all measurements.

**Be careful**

For all your measurements, be as careful as possible in what you see and how you write it down and input it into a computer.

**Use the right equipment**

Make sure you have appropriate equipment and that you know how to use it. If you cannot get the equipment you need, consider other ways to do your measurements. If that is not possible, then you will need to refine your plan to account for this. For example, if I wanted to measure heavy metals in soils, I would ideally need a spectrophotometer (a really expensive piece of kit!), or I would need to send my sample to a laboratory where there is one. However, it might also be possible (and cheaper) to get a home testing kit to measure some key contaminants. I would not get quite such an accurate reading, but perhaps it will be good enough.

**Note any uncertainties**

If you are not sure about a measurement, make a note of that when you record it, for example, "I think this was a honey bee, but I did not see it for long enough to be sure." If you think that something you observe could influence your results, and then note it, for example, "this radish patch was completely water-logged". Things like the weather and how you feel can also influence your observations, so be sure to note them down too, for example "it is raining and I am really tired". These notes can be critical to helping you understand any odd results you might get later. If you made a note, you can see why it might be odd. If you did not make a note, you have no reason not to accept it as genuine, which can affect the quality of your data.

**Check your measurements**

Always check your measurements when you write them down and if you type them into a computer. Make sure they make sense, for example, were there really 66 eggs in the nest, or did you mean 6? To reduce errors, it is best to write down your readings immediately and then input them into the computer (if you are using one) within a day. This means you can remember the reading and anything that might have affected it.

## Measurement types

To understand how you will use your measurements, it is useful to consider measurement types. Much scientific study is based on measurements of things. The type of measurement determines what we can do with the information.

**Numerical measurements**

These measurements are numbers; there are two types – scale or interval and ratio. Scale or interval measurements have intervals (gaps) between numbers that are exact and consistent. There is no true starting point or zero that is unique and not arbitrary. For example:

- Temperature in degrees Celsius. This takes the difference between two known points (the melting point of ice and the boiling point of water) and divides them by 100. This scale was previously called "centigrade" meaning 100 grades or marks.

- Percentages
- Direction in degrees from north, for example, compass bearing or aspect
- Date from a selected point, for example, BCE (Before Current Epoch) or AD

Ratio is the most common type of numerical measurement. Ratios are like intervals except that they also have a meaningful starting point – a true zero. The zero in a ratio scale means that something does not exist. For example, the zero in the Kelvin temperature scale means that heat does not exist at zero. However, zero degrees Celsius does not represent the complete absence of temperature; it was just decided that the point at which ice melts was a convenient starting point. Ratio measurements include:

- Height
- Length
- Weight
- Mass
- Duration (time elapsed)
- Count (for example, a number of birds)

These have the broadest possibilities for quantitative and statistical analysis. There are lots of ways to use ratio measurements – you can compare differences, look for trends, look for relationships or look for patterns.

**Ordered categories**

This type of measurement has a clear order. These are also called 'ordinal' measurements. They include ranks and related categories. For example:

- First, second, third
- Small, medium, large
- Flat, shallow slope, steep slope
- Strongly agree, agree, disagree, strongly disagree

**Named categories**

These categories are names that do not have any order between them so it wouldn't matter which way around you put them. They are also called 'nominal'. For example:

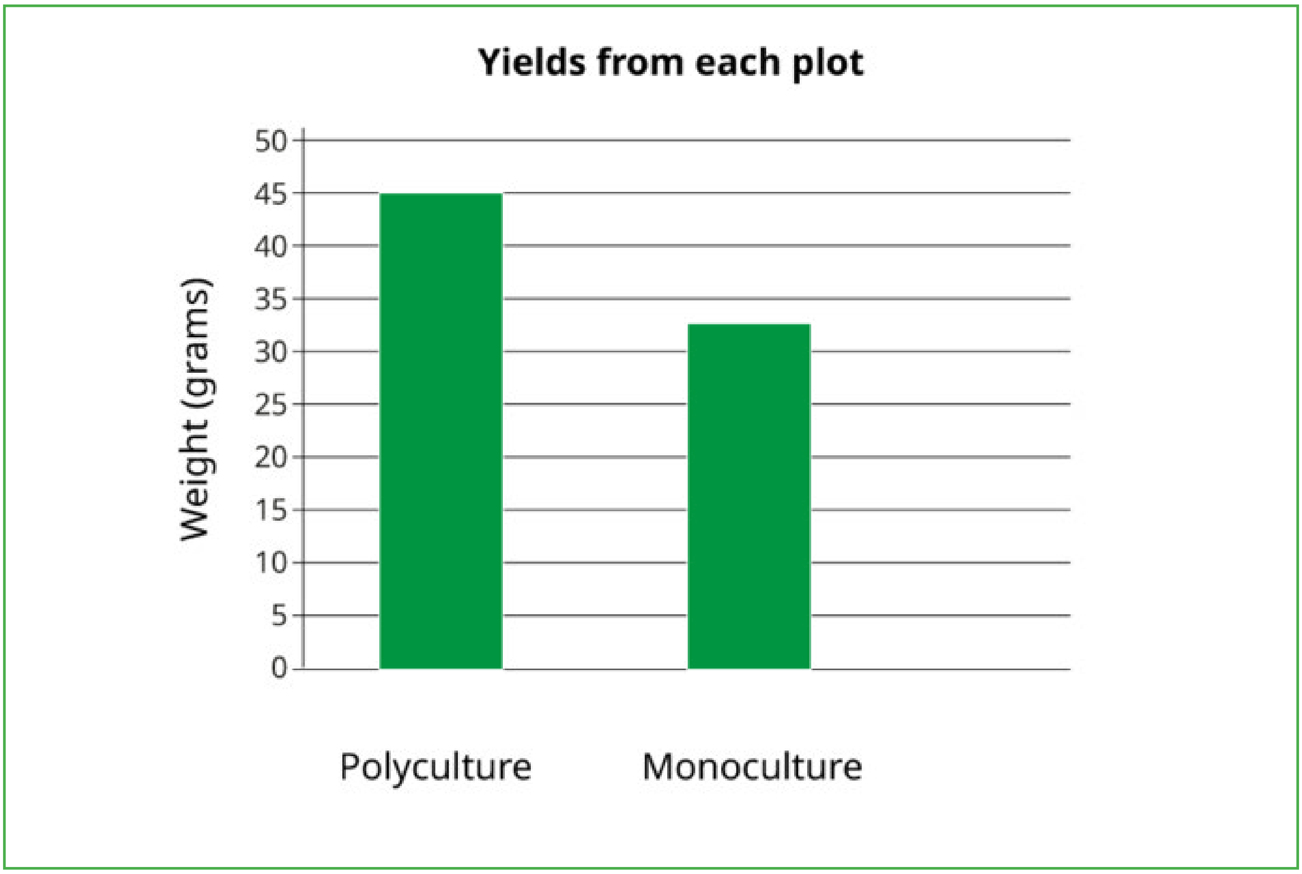
- Beans, carrots, cabbages
- North, south, east, west
- Male, female

## Using your data

You have decided your question, designed your experiment and collected your data. Now you need to use your data to answer your question. How you display and analyse your data will depend on the measurement types you have. It can be helpful to imagine what your results might look like visually when planning your investigation. There are a few common examples below.

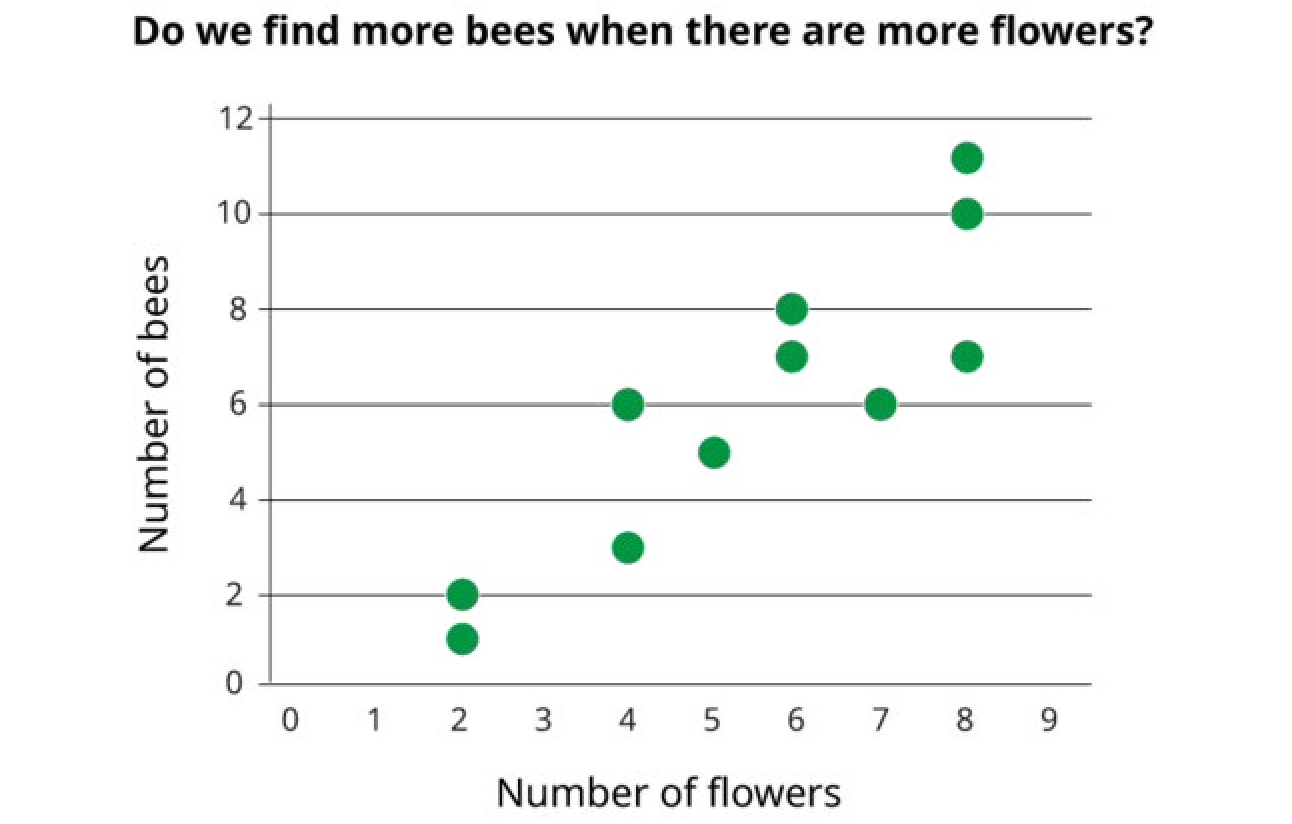
**Amounts in categories (ratio and nominal)**

Plot types were assigned, and weight of harvest was measured.



**A trend (ratio and ratio)**

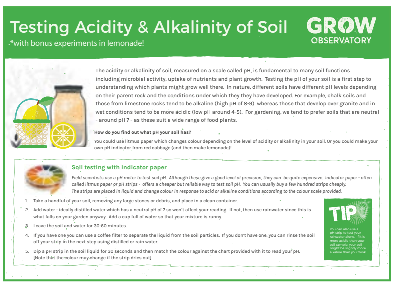
Bee visits to areas with different numbers of flowers were counted.






## Experiments to try

The GROW Observatory developed several experiments for you to try in your growing space, the instructions for these are linked below.

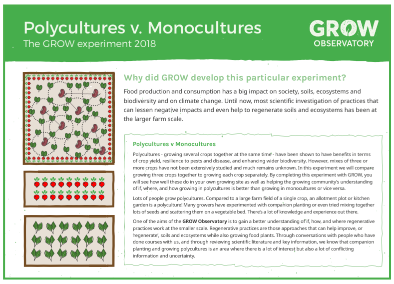



### Testing Acidity and Alkalinity of Soil

These experiments take an hour or less and explain how to test the acidity and alkalinity of your soil using litmus paper, and with your own homemade indicator. There is also an activity on making colour changing lemonade.


## Make an Earthworm Hotel

This experiment shows the effect earthworms have on soil structure; it takes up to an hour to set up and two weeks to complete._




## Polyculture Experiment

This longer experiment takes a whole growing season and tests how the yield of three crops grown in a polyculture compare to the same three crops grown as monocultures.

# Further information

The **Permaculture Research Handbook** goes into more detail in how to design a permaculture research project, collect and analyse data, and share your findings.