Topic 3. Plant Nutrition

3.1 Soil

The vast majority of plants on Earth grow with their **roots in the soil** and are called **terrestrial plants**. The **exceptions** are **epiphytes**, such as many orchids and bromeliads, which live on tree branches and are adapted to the challenging conditions of life in the canopy. **Lithophytes** live on rocks and have similar adaptations as epiphytes. A very small number of plants are parasites that live on a host plant, such as mistletoe, and do not grow roots into soil.

Roots growing in soil experience a relatively stable environment free from rapid, stressful environmental changes. The soil temperature changes relatively slowly, moisture and oxygen levels are relatively buffered from extreme swings, nutrients are generally available and the pH tends to remain stable. However, soil properties vary depending on the type of soil and this influences the plants that will grow and compete best on particular soil types.

Note: RHS level 2 does not require candidates to understand how soils form, though it's important to appreciate that soil formation is a slow process taking millions of years, so soil losses due to human activity are incredibly detrimental to the environment, causing damage that can't be rectified quickly.

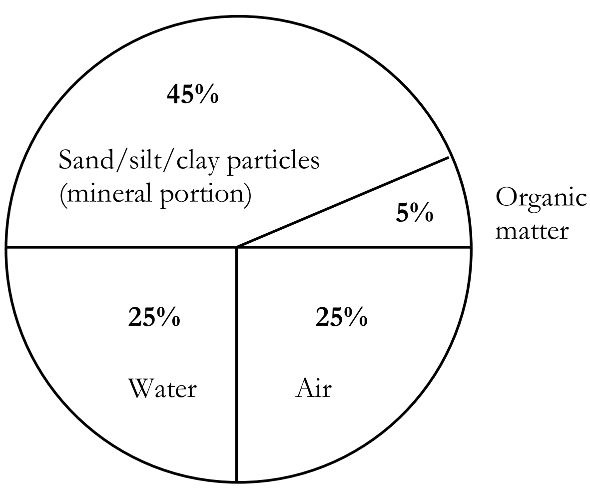
Properties of a particular soil are down to two major factors: **soil texture** and **soil structure**, with **pH** having a significant impact on nutrient availability.

Soil texture is the **relative proportions of sand, silt, clay** and **organic matter** (soil particles) that a soil is composed of:

- **Sand**, **silt** and **clay** particles are derived from **weathered bedrock** beneath the soil, and in some cases (like river flood plains) **deposited material** as a result of flood events, and/or wind-blown material. The three types of particles are **mineral**-based.
    - **Sand** particles are the biggest soil particle (other than stones), varying from 0.06 – 2mm in diameter. They are largely made of silicon and do not have the capacity to retain nutrients.
    - **Silt** particles are mid-sized, between 0.002 - 0.06mm diameter.
    - **Clay** particles are the smallest mineral particle, less than 0.002mm diameter. They have a great capacity to retain nutrients in the soil.
- **Organic matter** is derived from decomposing plant and animal matter that ultimately forms the **humus** component of soil. **Soil organisms** are largely **dependent** on **organic matter** content of the soil.
- **Humus** particles are significantly smaller than clay particles but have similar nutrient holding properties.

Soil structure is **how the soil particles fit together** in the soil, giving a balance between solid particles and varying sized pores (gaps) in the soil.

Ideally a soil would have the following properties:



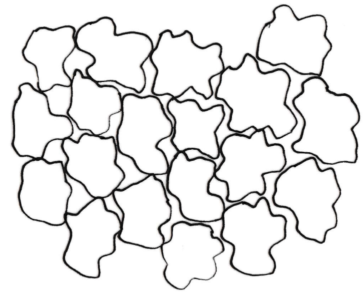
This ideal balance of water, air and solid particles is typical of a **loam** soil. John Innes no.3, a loam-based compost, is an example of an 'ideal' soil, where oxygen from the air and water are readily available to roots at field capacity due to the soil structure creating different pore sizes.

Loam soils are typically made of a balance of sand, silt and clay particles (in the mineral portion) where no one particle type dominates.

Field capacity is the amount of water a soil can hold once excess water (e.g. from rain) has drained away due to gravity.

Not all soils have an ideal balance of properties. If the mineral portion of soils is predominantly only one type of particle then the soil properties can be very different.

- **Clay soils should only be worked when they're moderately damp** (neither dry nor waterlogged) – this normally occurs in spring and autumn.
- **Slow to warm in spring and slow to cool in autumn**.
- Plants that do well on clay soils must be able to tolerate a cold, damp winter with low oxygen at the roots. Many plants thrive on clay soils, benefitting from its moisture and nutrient holding capacity in the growing season. Generally, plants that require freely draining soils will not do well, such as mediterranean climate plants and many wildflowers.



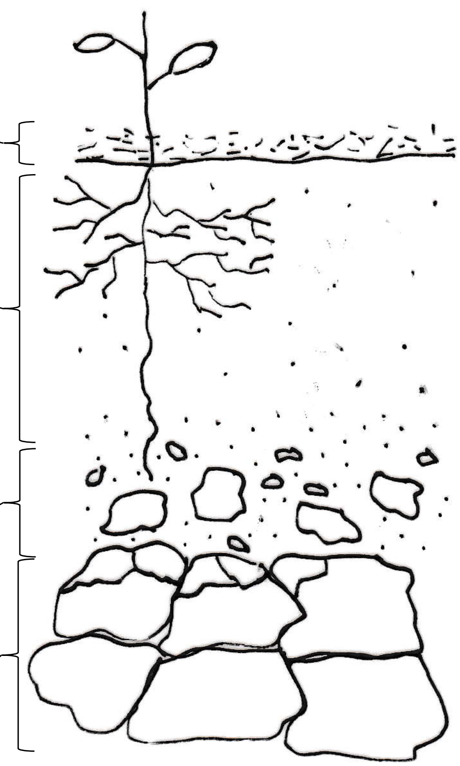
Loamy soils have a crumb structure, with each crumb made of sand, silt, clay and humus particles.

Loamy soils combine properties of the soil particles they're made from, typically having **good water retention and air availability, freely draining and nutrient retentive**. They're the most ideal soils for optimum growth of most plants. As mentioned, the addition of organic matter as a mulch can slowly alter the properties of any soil type toward a loam and is an important consideration for most gardens.

Healthy soils with a **loamy texture** are made of different **soil particles** (sand, silt, clay and organic matter) that **aggregate into crumbs/peds**. These crumbs each hold moisture, whilst the spaces between crumbs is freely draining, creating a healthy balance between moisture retention and drainage.

Soil profiles: whatever the **soil** type, soils exist as **horizons** (layers):

- **Organic horizon** (where leaf litter accumulates):
  - This is where decomposition of organic matter starts and humification (definition on next page) begins
- **Topsoil horizon**:
  - Top layer of soil, varying in depth from 10 – 50cm (likely to be very thin over chalky bedrock)
  - By far the majority of soil organisms and roots are found here
  - Usually has a balance of water and air
  - Usually darker in colour than subsoil due to the higher organic matter and humus content
- **Subsoil:**
  - Very varied in depth and structure with a lower organic matter and humus content, therefore lighter in colour
  - Lower oxygen availability than topsoil and less fertile
- **Bedrock/parent material:**
  - The rock layer beneath the soil, which is usually what the soil above is derived from



Soil profile illustrating the different horizons that are found in most soils.

Water table:

- The point at which soil below is completely saturated with water and holds little to no air, making it very challenging for healthy root growth.
- Moves up and down the soil profile depending on the volume of rain over time; usually it's higher in winter and lower in summer.

Waterlogged soils:

There are various situations where soil drainage is very limited and soil tends to remain **waterlogged**, **hampering root health and plant growth**. This can be where **gardens are located near to water bodies** (rivers, lakes, natural ponds), **at the bottom of slopes** where the water table sits high, or where there is a **perched water table**. **Clay soils are most prone to waterlogging**.

Persistently waterlogged soils do not benefit from organic matter mulches as the low-oxygen soil fosters a low rate of aerobic respiration in decomposers and therefore slow decomposition. Organic matter also improves water holding capacity of the soil, which is not needed.

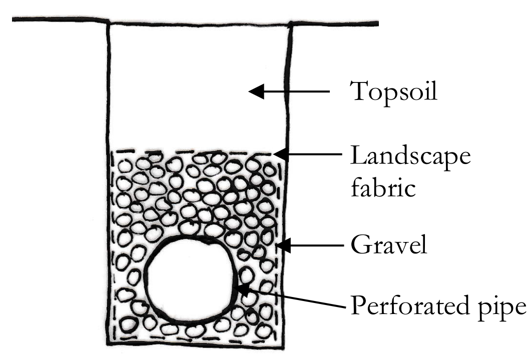
Additional drainage can be installed to speed up the loss of water from the soil. This improves soil aeration, increasing aerobic respiration rates of roots and soil organisms, resulting in improved root health and plant growth. It's highly advisable to direct drainage away from buildings, reducing the potential for rising damp.

Types of drainage systems:

All drainage systems rely on improving the loss of water from the soil. Other than soakaways, drainage systems rely on water moving through a pipe or channel in the soil which has a gradient toward the outflow point. The gradient of drains can be 1:40 to 1:100 (e.g. 1:40 = for every 40m length, there's a fall of 1m). Shallower than 1:110 may result in a faster rate of the pipe silting up.

- **Pipeless**:
  - **Mole drains:**
    These are created using a **mole plough**, which essentially pulls a torpedo-like cylinder through the ground at a set depth, **creating a mole-like tunnel through the soil**. Water can seep down and then drain rapidly along the tunnel, improving drainage.
    Mole drains are fast to install, but can only be undertaken where the machinery has access and the soil is suitable (e.g. not too stony, avoiding underground service pipes etc.)
  - **French drains:**
    A **trench is dug** 45 – 60cm deep and **part-filled with gravel** (e.g. 20cm gravel at the base); perforated landscape fabric can be used to line the trench and contain the gravel, reducing the rate at which it may silt up.
    The **upper layer is backfilled with some of the removed topsoil and plants may well grow above the drain**.
    French drains are relatively easy and cheap to install and resemble the diagram below, but without the pipe.
  - **Sand slitting:**
    A narrow slit is dug into the soil, **connecting to a drainage system below**, usually piped drainage. **The slit is filled with sand**, which aids surface drainage and reduces waterlogging and runoff. Sand slits run in parallel lines and may have additional drainage via sand slits running at 90° to the parallel lines, creating a grid.
    The distance between sand slits will determine how rapidly they can drain water – closer together means faster drainage.

- **Piped drainage**
  - This works much like French drains, but instead of just using gravel, perforated pipes are installed along the drain, surrounded by a gravel layer and perforated landscape fabric to filter out silt. Traditionally porous clay pipes were used – each unit around 30cm long and these are laid so one pipe meets the next, but the joints are not sealed so soil water can enter and drain. Today it's more likely that plastic, perforated pipes are used – these are quicker to install and can be curved easily.



Piped drainage

3.2 Nutrients

Plants require a number of essential nutrients to enable healthy growth and aid in resistance to pest and pathogen attack. Unlike many of the nutrients animals need, which include organic molecules like proteins, carbohydrates and lipids (fats), **plants require only inorganic nutrients**, most of which are **taken in by root hair cells** as **soluble** (dissolved) mineral salts.

Plants require some nutrients in higher quantities relative to others, much like humans need higher quantities of protein, carbohydrate and lipids each day than minerals and vitamins. The nutrients plants need more of are called **macronutrients** and those they require less of are called **micronutrients**.

All nutrients are naturally available in the soil. However, in some soils, particularly those with a high percentage sand during periods of high rainfall (resulting in leaching), **some nutrients may become absent or present in only trace amounts**, leading to a **deficiency**.

Nutrients are released from the breakdown of organic matter in soils **and** from the **weathering of rocks** within the soil. On cultivated land, **growers can also apply organically derived nutrient sources – organic fertilisers** – such as manure, bonemeal, seaweed fertiliser and many others to **boost nutrient availability**. These all require soil organisms to break them down, releasing plant nutrients; this benefits the soil biota and soil health. **Synthetic fertilisers** are **artificially produced** via industrial processes and contain plant nutrients in a form that's immediately available to plants. They are useful for containerised plants and for instant remedying of nutrient deficiencies, but they **do not benefit soil life**.

Macronutrients:

- **Three** of the most **important nutrients** that plants need come from the air and water: **carbon, oxygen, hydrogen**. These are called **non-mineral elements** because (in nature) they're not derived from minerals in the soil, unlike all the other nutrients. Photosynthesis requires the reactants **carbon dioxide**, CO_2, and **water**, H_2O. Whilst O_2 is given off as a byproduct of photosynthesis, the useful product, **glucose – $C_6H_{12}O_6$**, is made from **carbon** (from the air), **hydrogen** and **oxygen** (from water). Glucose is important because:
    - **Glucose** is a reactant in **respiration**, which is how **energy is released** in a plant to power all its processes, like growth and active transport.
    - **Glucose** is a type of carbohydrate that can be further **altered** by plants into different types of sugar, like **fructose**, and into **starches** that are used as an **energy store**, e.g. in potatoes, or to construct **cell walls** (**cellulose**).
    - Cell walls surround every plant cell and are an essential use of carbohydrates in a plant. Plants are around 90% water, but if a plant were to be dried out completely, **over 50% of the dry mass of a plant is carbohydrate**, all originating in photosynthesis.
    - Therefore, **carbon, oxygen and hydrogen** (from carbon dioxide and water) are **three of the most essential nutrients** for plants and, assuming the roots have sufficient water, plants have access to all three for healthy growth without horticulturalists doing anything.
    - However, **greenhouse growers can increase the rate of photosynthesis**, and therefore plant growth, by **artificially increasing the carbon dioxide levels**. This is not possible outdoors as carbon dioxide is a gas and would diffuse and dissipate into the atmosphere very quickly, so the concentration around plants' leaves outdoors can't be effectively increased.

- **Macronutrients** obtained from the **soil** include: **nitrogen**, **phosphorous**, **potassium**, **calcium**, **sulphur** and **magnesium**.

Nutrient	Role in the plant	Sources	Deficiency Symptoms
Nitrogen, N	- Commonly termed 'the leaf maker', but is important throughout the plant. - Key constituent of **proteins.**	Plants cannot take up nitrogen gas (N_2) from the atmosphere, though 78% of the atmosphere is nitrogen gas. Nitrogen is available from the **soil** as a result of **nitrogen-fixing bacteria**, which fix atmospheric nitrogen into compounds like NO_3 (**nitrate**) or NH_4 (**ammonia**).	- **Chlorosis** (yellowing) of the leaves, starting with older leaves as nitrogen can be translocated (moved) within the plant.

The practice of **no-dig** involves **minimal cultivation** (see topic 3.1) and **annual mulching**. The **selection of mulch should be matched to the soil fertility needs**. On lighter, sandier soils that are lower in fertility, well-rotted farmyard manure could be spread as this is rich in nutrients and will provide a nutrition boost where it's needed. Clay soils, on the other hand, are rich in nutrients and benefit more from the addition of low nutrient bulky organic matter such as compost, e.g. from home composting, council produced compost, spent mushroom compost, etc.

- By focusing on this as a part of **best practice, edible (and all) plant growers reduce their need for fertiliser inputs**.
- Some crops do not require especially nutrient-rich soil for optimum yields, such as onions, garlic, carrots, parsnips and other alliums and root crops; in these cases mulching and any fertiliser application should be modified.
- Higher application would be more appropriate for brassicas, leafy crops like lettuce and spinach, potatoes, and legumes (although legumes fix nitrogen in their root nodules, so high-nitrogen fertilisers such as chicken/poultry manure are not the optimum choice).

Bark mulch being applied to a garden bed of *Calluna* cv. (heather) plants. This will help to reduce drying of the sandy soil that can become very dry in summer.

The Rhizosphere:

The rhizosphere is extremely complicated and is the subject of ongoing research; much is yet to be discovered. For the purposes of level 2 horticulture, a simplified overview is detailed below:

The **rhizosphere** is the **narrow zone around roots** in which soil organisms, such as **fungi** and **bacteria**, **interact with roots** in order to **exchange substances** such as **mineral nutrients for carbohydrates** produced by the plant. **Roots** produce **exudates** that **contain carbohydrates** (such as sugars) and **proteins**, as well as **organic acids**. The exudates influence the soil environment immediately around the roots, the rhizosphere.

A portion of the energy captured in photosynthesis is transferred, via root exudates, to soil organisms in exchange for mineral nutrients. Many species of fungi form **symbiotic relationships with plant roots**, and through their vast mycelial networks they essentially extend capacity for nutrient uptake by the plant in exchange for photosynthesis-produced carbohydrates, benefitting both organisms.

Fungi and bacteria can mineralise rock fragments in the soil, ultimately **producing mineral nutrients** that can be **absorbed** by **plant roots**. These minerals become available in the rhizosphere in exchange for root exudates.

When synthetic fertilisers are applied to plants, which supply nutrients in immediately available forms, the health of the rhizosphere decreases as the symbiotic relationships between roots and soil organisms become less necessary. This makes plants less resilient, relying on synthetic fertiliser inputs. If the synthetic fertiliser is not complete (i.e. lacks one or more nutrients) there is a risk a plant may become nutrient deficient where it wouldn't otherwise be if synthetic fertilisers had not been used. **It is wholly irresponsible to solely rely on synthetic fertilisers for soil nutrition**; they should be used only where absolutely necessary in the soil.

Phosphorous Cycle:

Again, at level 2 this is simplified:

Phosphorous is found in rock minerals and becomes **available to plant roots due to natural weathering**, which releases phosphate ions into the soil.

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Phosphate is absorbed by roots and incorporated into **organic molecules** in plants. Some of these molecules are passed up the food chain.

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When plants and animals die, **decomposers release phosphate** back into the soil where it can be absorbed by plants.

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Some **phosphate** is **leached** and ends up in rivers and the ocean, eventually being **incorporated into** sedimentary **rocks** (and ultimately other rock types).

↓

Over millions of years of geological activity, including **uplift** of **rocks** containing phosphorous, **phosphorous** on land is **replenished**.

As with nitrogen, **phosphorous is also added to the soil via phosphate-rich fertilisers**. **Rocks rich in phosphorous are mined** and phosphorous is extracted, a process that **destroys habitats where the mine is located** and has a **high carbon footprint**. As with nitrogen (and all synthetic) fertilisers, **synthetic phosphorous fertilisers should be avoided because they are not sustainably produced**.

Phosphorous is traditionally called 'the root maker', but it has many different, essential roles in a plant.

Mineralisation of Organic Matter and Rocks by Soil Organisms:

Mineralisation of **organic matter** is the process by which **microbes**, such as **bacteria**, and **fungi convert organic molecules into inorganic** ones that are **available** to **plant roots**. Mineralisation happens most **quickly** in **warm**, **damp**, **aerated** soils. In colder climates, naturally waterlogged soils and in soils with damaged structure due to human activity (e.g. compaction), it's minimal, and organic matter often accumulates in the soil faster than it's mineralised, meaning the soil is not at optimum fertility.

Microbial weathering of **rocks**, such as rock fragments in the soil and bedrock, also **releases mineral nutrients** to **plants**. Microbes use a variety of means to weather rocks, including changing the soil chemistry (chemical weathering) and use of enzymes. Microbial weathering of rocks is an essential part of the phosphorous cycle.

Plants can be grown in **soil-less growing media**, such as clay granules, in a **hydroponic** system. In this circumstance, which takes place in completely controlled indoor environments, fertilisers are applied as soluble, synthetic feeds in the irrigation water which is constantly circulated through the root zone.

A common misconception is that summer rain will sufficiently irrigate containerised plants, which also relates to nutrition. Other than spectacularly heavy summer downpours and/or unusually prolonged rainy weather, summer rain will not water plants in containers. It may dampen the upper few cm's of growing media, fooling growers into believing watering is not needed, but the lower growing media remain dry. **Drought-stricken plants are not taking up water, and therefore they cannot absorb nutrients either**. Topic 1.3 details transpiration, which fully explains this. **Plant nutrients are all soluble (dissolved) in water and travel from the roots to the leaves, via the xylem vessels, in water** as part of the **transpiration stream**. Therefore **drought-stressed plants have reduced growth** not only due to **reduced photosynthesis**, but also **due to reduced nutrient availability in** the above ground **meristematic regions** (growing tips, developing flowers and fruits, etc.).

It's a part of **best practice to ensure there is sufficient water availability in containerised plants**, without overwatering (which would reduce oxygen availability for root respiration).

Fertilisers:

Fertilisers are **concentrated sources of nutrients** that are either derived from **organic** sources or are **synthetic** (industrially produced).

At the start of topic 3.2, organic and synthetic fertilisers were touched on:

'On cultivated land, **growers can also apply organically derived nutrient sources – fertilisers** – such as manure, bonemeal, seaweed fertiliser and many others to **boost nutrient availability**. These all require soil organisms to break them down, releasing plant nutrients; this benefits the soil biota and soil health. **Synthetic fertilisers** are **artificially produced** via industrial processes and contain plant nutrients in a form that's immediately available to plants. They are useful for containerised plants and for instant remedying of nutrient deficiencies, but they **do not benefit soil life**.'

Types of fertilisers have also been mentioned throughout topic 3.2 via their supply of nutrients to plants. These are recapped and further detailed below:

Nutrient content of fertilisers:

- **Nutrient ratios**:
  - It's common on synthetic fertiliser to see a ratio of three numbers. This is the ratio of macronutrients **nitrogen : phosphorous : potassium, or N:P:K**.
  - A summer lawn fertiliser might have a ratio of 2:1:1, meaning it's higher in nitrogen to boost leafy growth; a winter lawn fertiliser might have a ratio of 4:3:8 – the high potassium content will aid hardiness in response to winter cold.
  - A tomato fertiliser and a rose fertiliser might have ratios of 4:3:8, or similar. This is because the high potassium content boosts flowering and fruiting. A good quality tomato fertiliser should also contain calcium to prevent blossom end rot (see topic 3.2).

N:P:K ratio on a synthetic tomato fertiliser.

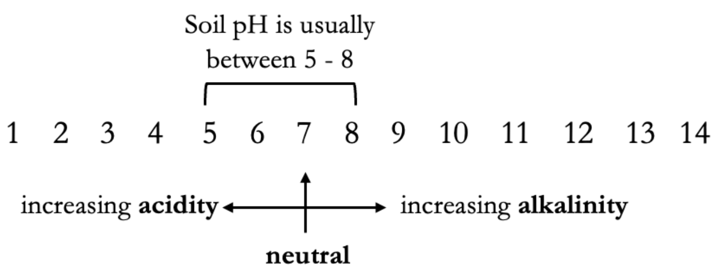
  - General purpose fertilisers usually have the ratio 1:1:1, meaning N, P & K are balanced. A good quality fertiliser will also contain other macronutrients and micronutrients.
  - Organic fertilisers vary in nutrient composition; they may or may not have indicative N:P:K ratios.
- **Straight fertilisers**: all straight fertilisers are synthetic; they contain only **one nutrient**, such as ammonium nitrate or superphosphate.
- **Compound fertilisers**: these contain **more than one type of nutrient**, such as sulphate of potash (contains potassium and sulphur), ammonium phosphate, as well as commercial brands with various formulations, such as Growmore, Miracle-Gro®, Tomorite®, and many others.

3.3 pH and Nutrient Availability

pH relates to the acidity or alkalinity of the soil. pH stands for 'potential of hydrogen' and, essentially, increasingly acidic soils have increasingly higher concentrations of hydrogen ions (H^+), whilst increasingly alkaline soils have an increasing concentration of hydroxide ions (OH^-); in neutral soils they are balanced (knowledge of H^+/OH^- is beyond level 2 and included for background information only).

The only concept that level 2 learners need to appreciate is that the availability of plant nutrients is affected by the pH. A detailed understanding of how this happens, in terms of soil chemistry, is not required.

The pH scale:



The **optimum soil pH is 6.5** because this is the pH at which **most plant nutrients are most available to plant roots**. pH 6.5 is lightly acidic. The vast majority of garden plants will grow well if the soil pH is around 6.5

As the soil becomes increasingly acidic or increasingly alkaline, various nutrients begin to become less available to plant roots. Some examples are given below:

- Below pH 6, nitrogen, potassium, phosphorous, sulphur, calcium, magnesium and molybdenum become increasingly less available.
  - However, iron becomes more available as pH decreases.
- Above pH 7.5, potassium, iron, manganese, boron, copper and zinc become less available.
  - However, molybdenum, calcium, magnesium, sulphur and nitrogen are very available at a higher pH.

Nutrient availability and soil pH is strongly linked to 'right plant, right place', especially in regard to ericaceous (acid-loving) plants. In the wild, plants have spent millions of years evolving to suit particular habitats. Some plants have very specific needs whilst others may be more generalist. Garden plants are often very tolerant of a range of soil pH and will grow well in most garden situations.

- **Calcicoles:** tolerant of alkaline soils. These include *Clematis, Viburnum, Fraxinus excelsior* (ash tree), *Taxus baccata* (yew) and others. Almost all garden plants that are classified as calcicoles will also tolerate lightly acidic soils.
- **Calcifuges:** prefer acidic soils. Within this group are the **ericaceous** plants that require acidic soils (ideally pH 5 – 6). If planted in alkaline soils, where iron is less available due to the soil chemistry, they soon suffer from iron deficiency (see topic 3.2). Ericaceous plants include *Rhododendron, Camellia japonica, Pieris japonica, Erica carnea* (heather), *Calluna vulgaris* (a different type of heather) and many others.

As soils become more acidic, their capacity to support diverse soil life diminishes. Many soil organisms, such as earthworms, and some fungi and bacteria, cannot tolerate highly acidic conditions. Their lower occurrence in highly acidic soils slows down the breakdown of organic matter. This reduces the build-up of soil humus and associated benefits of improved water and nutrient holding capacity, as well as improved structure. Neutral to slightly alkaline soils best suit soil organisms.

Testing soil pH:

- pH testing kits can be purchased. A small sample of soil, taken from at least 10cm deep, is mixed with universal indicator and the colour change can be compared with a chart, giving an indication of the soil pH in that area. Gloves must be worn, both to avoid universal indicator contacting skin and because skin has organic acids on its surface; contamination could lead to false pH readings.
- It's important to take samples from various locations. Often, a W formation is used to collect samples, essentially zig-zaging across the site to give a range of localities.

The table below details some of the bulk constituents used in peat-free composts:

Bulk Constituent	Properties	Sustainability
Bracken (composted)	• Crumbly texture that can improve aeration and water retention in composts. • Acidic pH suitable for ericaceous plants; also aids soil acidification if used as a mulch. • High in nitrogen and potassium.  Composted bracken used as a mulch.	Bracken grows naturally in the UK and, when dry, is relatively lightweight, lowering carbon footprint of transport. Bracken can be invasive in moorland areas used for grazing sheep and may be cut down anyway by farmers; utilising it for horticulture allows it to be used for other purposes. There is a limited supply of bracken and its removal destroys a natural habitat.
Coir	• High water holding capacity and good nutrient retention. • Lightly acidic, making it suitable for growing most plants.  Chunky coconut coir.	As a by-product of the coconut industry that would otherwise be burned; it's sustainable in that it would otherwise be wasted and it's renewable. Although it can be dried and compacted, it needs to be transported from tropical regions where coconuts are grown, meaning it has a higher transport carbon footprint than UK-sourced materials. Coconut plantations destroy natural habitats, reducing biodiversity. However they are primarily for culinary and beauty industry products; coir as a horticultural byproduct is not a primary driver of the plantations.
Composted organic matter (decomposed plant material)	• Very variable in properties, depending on what was composted. • Generally has high water and nutrient retention. • Air filled porosity/aeration varies. • If commercially produced with high temperatures it is free from viable seeds, weed roots/rhizomes, and pathogens. • If produced by home composting, it may contain viable weed seeds, weed rhizomes/roots, and pathogens – in this case it's better suited for mulching than use in containers.	Can be produced locally, reducing transport carbon footprint – especially if produced within the garden (in which case it contributes to cycling of nutrients and, if used as a mulch, enhances soil carbon store). Makes use of organic waste that might otherwise go to landfill or even be burned. Its production supports biodiversity, as many organisms live within compost heaps.  Commercially produced compost.