

1. Plant Science 2

Unit 2 content builds on Plant Science 1 knowledge by adding further detail of how leaves, roots, stems, etc. are adapted, and how this relates to their use in garden settings.

The adaptations are related to environmental pressures such as dry soils, waterlogging, climbing to compete for light, floating leaves and stems, surviving harsh winter weather, defence from herbivory, and more. The different adaptations are detailed under headings that cover different plant organs, comprising: leaves, stems, roots, flowers and seeds. Growth habit adaptations are also detailed.

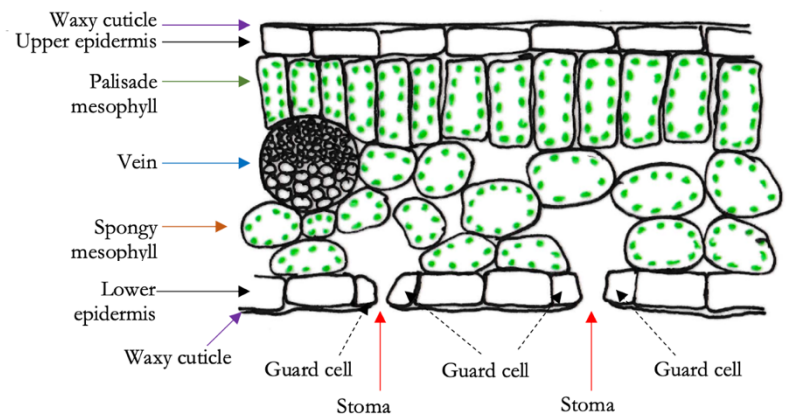
Where relevant, a brief recap of Unit 1 content is included. It is a good idea to review the relevant part of Plant Science 1 in Unit 1 if you need a more detailed reminder of the base knowledge.

1.1 Leaf adaptations

Leaf Function – Unit 1 Recap

Plants have evolved **leaves** as an organ that **has a high surface area** for light absorption as a way of maximising **photosynthesis**. This means more glucose for respiration, which releases energy for all plant functions such as:

- Growth,
- Reproduction,
- Storage of energy (starch and oils),
- Manufacture of proteins and other organic molecules.



Cross-section through a leaf

Leaves have specialised cells that perform different functions – these include:

- **Epidermal cells:**
 - **Transparent** cells that create a surface layer around the leaf (and other plant parts).
 - They are transparent to let light through to internal cells that contain chloroplasts for photosynthesis.
 - **Produce the waxy cuticle** that reduces water loss from plant surfaces, and prevents entry of pathogens like bacteria and fungi, as well as some pests.
- **Palisade mesophyll cells:**
 - Cells packed with **chloroplasts**.
 - Chloroplasts are small structures found in some plant cells; they're the site of **photosynthesis** and contain specialised pigments called **chlorophyll**.
 - Different types of chlorophyll absorb different wavelengths of light as part of photosynthesis.
- **Spongy mesophyll cells:**
 - **Loosely packed** cells with many **air spaces**.
 - Their primary function is **gas exchange**: carbon dioxide from the air diffuses into leaf cells for use in photosynthesis, and excess oxygen diffuses out.
 - Water is lost from leaf cells as it evaporates into the air spaces of the spongy mesophyll layer.
- **Guard cells:**
 - These exist in **pairs of kidney-shaped cells**, which change shape to **control opening and closing of the stomata**. (Stomata is plural, singular = stoma)

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- Stomata are tiny pores largely found on the undersides of leaves. When open they allow carbon dioxide into the leaf. Excess oxygen and water vapour exits the leaves via stomata.
- **Stomata usually close at night, and also close in response to drought conditions.**
- When closed, water vapour cannot exit the leaf, reducing water loss from the plant. However, carbon dioxide cannot enter the leaf, meaning photosynthesis will stop.
- **Xylem** in the leaf veins:
 - Bring **water and minerals from the roots into the leaf.**
 - Minerals are essential for plant function and growth, for example nitrogen is an essential component of protein, and magnesium is needed for chlorophyll production.
 - **Water is important for cell turgidity, as a medium in which dissolved substances (solutes) like minerals are transported around the plant, and for use in photosynthesis.**
 - It is important to remember that around **98% of water entering the plant is lost to the atmosphere as water vapour exiting leaves via the stomata (transpiration).** Water is drawn in from the roots to replace this lost water, creating the 'transpiration stream'.
 - The transpiration stream is essential not only to replace lost water, but to ensure a continuous supply of minerals reaches above ground plant parts.
- **Phloem** in the leaf veins:
 - **Transport sap** (sugars, proteins, minerals, hormones and other substances) from the leaves to other plant parts, such as flowers, fruits, growing tips and roots.

Leaf adaptations. Unit 2 content:

Unit 2 content builds on the general understanding of leaf functions through knowledge of how leaves are adapted for dry conditions, to reduce pest or pathogen attack, to float on water, to enable asexual reproduction, and more.

This section starts with a focus on leaf adaptations for dry conditions:



Acer palmatum (Japanese maple) has broad, thin leaves that are not adapted for dry conditions

In habitats that don't (or rarely) experience dry weather, plant leaves do not have to be adapted to reduce water loss. These leaves tend to be **broad** and **thin** to maximise light absorption, with **many stomata** to facilitate entry of carbon dioxide into the leaves. Plants in these habitats, assuming other abiotic factors aren't too limiting to growth, have generally evolved to grow tall as they compete with each other for light, e.g. trees in tropical and temperate rainforests.

However, not all habitats have sufficient water for this type of leaf structure and growth habit. **Some habitats experience constant dry conditions**, such as deserts, or seasonal dryness such as mediterranean or monsoonal climates.

Plants growing in these climates have evolved a range of leaf (and other) adaptations to maximise their survival during dry weather.

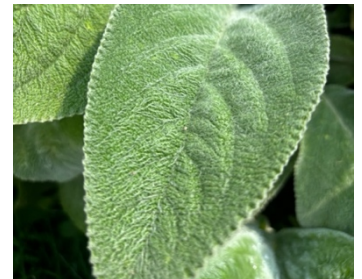
It is important to note the difference between dry (arid) conditions and drought. A habitat that routinely experiences dry conditions is not the same as a habitat experiencing drought. Drought is when there's a prolonged period of time with less rainfall than usual in a particular area. This causes unusually dry soil and a water shortage for plants that naturally grow there. Drought conditions are occurring more frequently, and are more severe, due to climate change. This is one impact of climate change that is influencing plant selection by gardeners, favouring those which are more tolerant of dry weather.

The following leaf adaptations enable plants to better survive in their native habitats.

Hairy Leaves:

The scientific term is: **hirsute leaves** (leaves without hairs/smooth leaves are called 'glabrous'). You can use the terms 'hairy leaves' and 'hirsute leaves' interchangeably. 'Hirsute leaves' is a more technical term.

The scientific name for a single leaf hair is a **trichome**; plural trichomes.



Stachys byzantina (lamb's ear), a herbaceous perennial with densely hirsute leaves that are soft to the touch

Topic 1: Plant Science 2. 1.1 Leaf Adaptations

Many plants have evolved hirsute leaves to reduce water loss from their leaves.

The following table details the advantages and disadvantages of hirsute leaves:

Advantages	Disadvantages
Hairs trap a layer of air around the leaf. This air becomes humid, reducing transpiration and therefore water loss from the plant. For a detailed explanation, see Unit 1, topic 1.3: Transpiration.	Producing hirsute leaves requires more energy than glabrous leaves. This is a competitive disadvantage where hirsute leaved plants are grown in damper climates than they evolved in (such as growing <i>Stachys byzantina</i> - lamb's ear - in a UK herbaceous border in damp soil).
A dense covering of leaf hairs reflects some of the light hitting the leaf, meaning the leaf doesn't heat up as much as it would without them. Cooler leaves means a slower rate of transpiration, further reducing water loss. This is an advantage in hot, dry weather which is more likely to occur in the UK due to climate change.	Plants with densely hirsute leaves can't absorb as much light as glabrous leaves. This reduces their potential rate of photosynthesis and therefore growth rate. This is a disadvantage in the cool, damp UK climate where hirsute leaved plants may be outcompeted by nearby glabrous leaved plants.
Other than a drought adaptation, a dense covering of leaf hairs can help to prevent entry of pathogens by trapping fungal spores and bacteria.	Hirsute leaves can filter particles from the air, such as dust, pollen and pollutants. Whilst this is an advantage to people, it lowers light penetration into the leaf, reducing photosynthesis. This limits potential plant growth.
Highly hirsute leaves hold beads of water after rain. This can offer a water source for garden wildlife such as invertebrates.	As hirsute leaves trap water, in rainy climates like the UK these plants remain damp for longer, increasing likelihood of fungal infections developing.



Most plants with a dense covering of leaf hairs come from seasonally or permanently arid climates. If a plant is sparsely hirsute this may indicate leaf hairs serve a different purpose – this is detailed below.

Hardy plants with densely hirsute leaves include *Stachys byzantina* (lamb's ear), *Alchemilla mollis* (lady's mantle) and *Verbascum bombyciferum* (broussa mullein).

Verbascum bombyciferum is a biennial (occasionally short lived perennial) with highly hirsute leaves and a deep tap root, both adaptations to dry conditions.

For most plants, **densely hirsute leaves are an adaptation for dry, sunny conditions**. Many mediterranean and desert climate plants have hirsute leaves, though typically only **mediterranean climate plants can successfully be grown in the UK**. They are well adapted to the hotter, drier summers that are likely to occur due to climate change.

Not all plants with hirsute leaves are adapted for dry conditions – plants have leaf hairs for other reasons:

Urtica dioica (stinging nettle) has hirsute leaves (and stems) as a **defence against herbivory**. Each **stinging hair** is hollow and **contains chemicals that irritate skin**. If these hairs are broken, for example if a deer or rabbit starts grazing the leaves, the chemicals are released, resulting in a painful reaction that deters a herbivore from further eating. Stinging nettles are avoided by most animal herbivores, however their leaves are important fodder for peacock and red admiral butterfly caterpillars.



Urtica dioica (stinging nettle) has a covering of hollow, chemical-filled hairs

Bulbs:

Some **monocotyledonous plants** produce **underground** structures called **bulbs**. These consist of many **succulent leaves** **attached to a basal plate**, which is a condensed stem. The fleshy leaves are much like the succulent leaves detailed above but they do not contain chloroplasts. They **store water and energy** in the form of starch, which allows bulbs to produce new leaves and flowers when they come into growth. Onions, shallots and garlic are common bulbs with a culinary use.

Structure of a bulb:

Succulent leaves:

The outer leaves are older, with new succulent leaves produced from the bulb's centre.
The papery outer layers are dried out older succulent leaves. They help to protect the bulb from pests and pathogens.

Basal plate, which is a condensed stem. The basal plate produces:

- New roots
- New succulent leaves to increase the bulb's size
- Photosynthetic leaves
- Inflorescences (flowering structures)



An onion bulb showing layers of succulent leaves attached to the basal plate.

Bulbs all have the same cycle of growth from seed to maturity, though the cycle's annual growing phase and dormancy phase varies between bulb species:

1. **The seed of a bulbous plant species germinates**, growing roots and leaves. **A small bulb develops in its first growing season** before the foliage dies down and the bulb goes dormant. The young bulb stores water and energy in the form of starch.
2. **In the second year** (and all subsequent years) **the bulb uses stored energy to produce leaves at the start of its growing season**. Once the leaves have grown, sugars produced in photosynthesis are transported, via sap in the phloem, to the bulb. This grows larger and stores more energy (in the form of starch) for the following growing season.
3. **After a few years the bulb reaches flowering size**; an incipient inflorescence is produced at the end of the bulb's growth cycle and lies dormant until the bulb commences growth the following year. Flowering size bulbs are sold in garden centres and by wholesale suppliers. Sometimes cheaper, smaller grade bulbs are supplied but they may not yet be of flowering size.
4. **Once bulbs are flowering size, they can use some of the energy supplied by photosynthesis to produce small bulbils**, which emerge from the basal plate adjacent to the main bulb. These eventually grow to flowering size bulbs – this is how plants such as *Narcissus psuedonarcissus* (wild daffodil) form a larger clump. Established clumps can eventually be divided.

Flowering size bulbs will flower in the first growing season after planting. If they're planted in the wrong location they may not be able to store enough energy in their bulb during their growth phase to initiate flowering the year after. Unsuitable locations include too much shade in a north-facing location, or under evergreen shrubs. Removing foliage before it has naturally died down can also inhibit next year's flowering. This is due to the reduced period of photosynthesis that supplies the energy needed to replenish the bulb's reserves.

Cultivars of bulbs, e.g. *Tulipa* 'Ballerina' (tulip 'Ballerina') are **propagated via tissue culture**. This is an expensive process undertaken in a laboratory, requiring specialist



Tulipa 'Ballerina' (Tulip 'Ballerina')

Plant Leaves and Growing Conditions:

The **different adaptations of plant leaves can indicate the plant's preferred growing conditions. These can be related to changing conditions in gardens due to climate change.** In the UK, summers are expected to become hotter with more prolonged dry periods. Autumn and winter are expected to experience increased intensity of storms. Knowledge of how climate change will affect a particular site needs to be considered with its existing microclimates and soil conditions.

With this understanding of a site, and expected changes due to climate change, suitable plant choices can be made for the growing conditions. This includes consideration of how a plant's leaves are adapted:

- As noted above, plants with **densely hairy (hirsute) leaves** are usually **adapted for dry conditions**, as are **grey-green leaved** plants, those with **succulent leaves, reduced leaves, rolled leaves**, and those with a **thick waxy cuticle**. These are all xerophytic adaptations.
- Plants that have **large, glabrous** leaves with a **thin lamina** are usually **only suitable for consistently damp conditions** as these leaves are not xerophytic. These plants may benefit from siting in sheltered areas where their leaves are less vulnerable to wind damage.
- Plants with **reduced leaves**, or **rolled leaves**, have a lower surface area and are **better suited to windy locations** than those with a broad, thin lamina.
- Plants with **hirsute leaves** can **trap pollutant particles** from the air, which is helpful in combatting pollution in urban areas.
- Plants that produce **bulbs**, especially those that undertake their **growing cycle in winter and/or spring**, are generally **tolerant of dry summer soil** when they're dormant. They are therefore suitable for areas that are becoming increasingly dry in summer due to climate change.
- Plants with **aerenchyma cells** are suited to **aquatic habitats** as their aerenchyma tissue improves gas exchange in submerged plant parts.



Darmera peltata (umbrella plant) has broad, thin leaves which require constant soil moisture

Benefits of Leaf Adaptations to Green Spaces:

In **fostering garden biodiversity**, inclusion of **different leaf adaptations inherently increases garden diversity** through a **wider range of plant species**. If plants are selected with consideration to their leaf adaptations and 'right plant, right place', successful establishment and long term plant health will improve. This means plants can produce more flowers and fruits, which provide forage for wildlife such as pollinators and birds. Their **foliage, stem and root growth provide shelter and food for wildlife**. Herbivores attract natural predators that may have their own predators, meaning green spaces can support complex food webs. **This is an essential part of fostering biodiversity in the UK, and reversing the decline of certain species such as west European hedgehogs and house sparrows – both are listed as UK BAP priority species (see topic 4.5).**



Hyacinthoides non-scripta (bluebell) is a native bulb that flowers in early spring, offering nectar for early pollinators

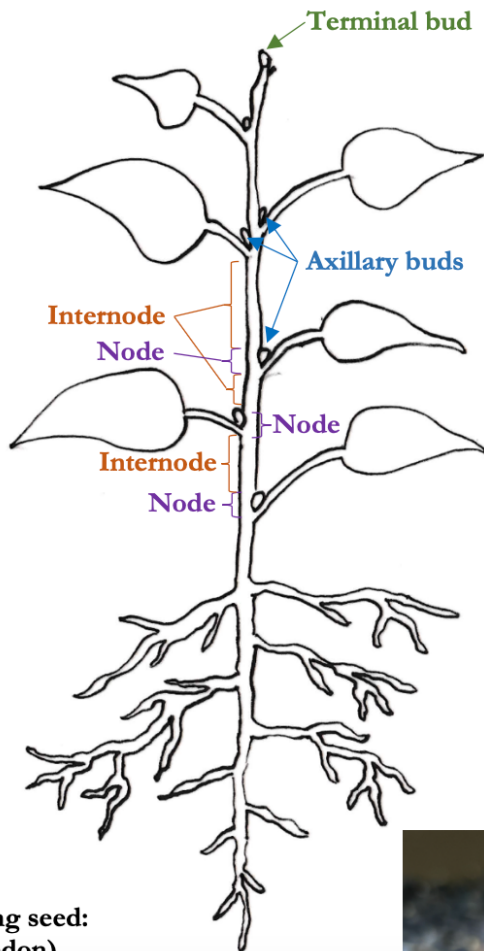
Planting **winter and spring flowering bulbs** amongst herbaceous perennials or under deciduous shrubs and trees **increases plant biodiversity, the forage offering to pollinators, and shelter for wildlife**. Biodiversity can be increased in gardens by taking advantage of the growing season of winter and spring flowering bulbs, which complete their growth cycle just as most garden plants are coming into growth. They also offer **colour through late winter and early spring** when little else is flowering, **which can improve people's mood, benefitting wider society**.

1.2 Stem adaptations

Stem Function – Unit 1 Recap

The role of most plant stems is to hold the plant upright to give them a **competitive advantage for sunlight**, and to **transport water and minerals** from roots to shoots in **xylem or tracheid** vessels, and **transport sap** (water, sugar, hormones, minerals, etc.) around the plant in the **phloem**.

External Stem Structure:



1. Nodes and internodes.

A **node** is where a leaf attaches to a stem, or used to attach. Sometimes there are two or more leaf attachment points at each node. Immediately above the point of each leaf attachment is an **axillary bud**. This can develop into a new shoot.

An **internode** is the section of stem between nodes. It can be long or short depending on the plant species and growing conditions.

2. Buds:

At the tip of the stem is a **terminal bud**. This is typically larger than the axillary buds along the stem and develops into the primary growth point for the stem when a plant starts growing in spring.

Axillary buds are almost always arranged along the stem in either **opposite** pairs, e.g. in *Cornus alba*, or **alternately** arranged along the stem, e.g. in *Salix caprea*. When a plant is in leaf you can tell the axillary bud arrangement by observing the leaf arrangement along the stems.

3. Bark:

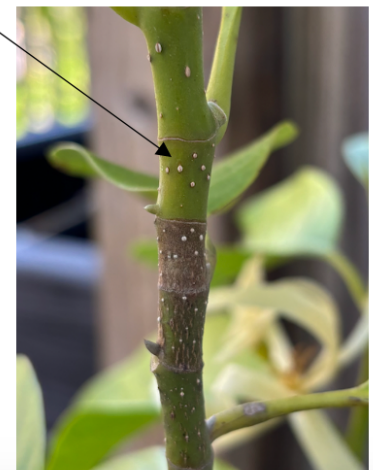
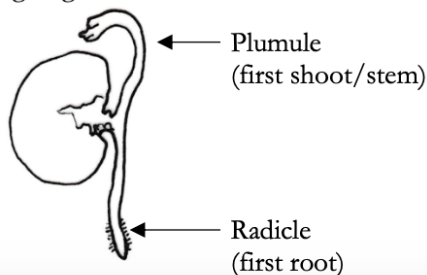
Woody eudicotyledons produce bark on their stems to **protect** the active growth tissue beneath (meristem) from pests, diseases and extremes of weather.

4. Lenticels:

Lenticels are corky regions along plant stems that allow **gas exchange** between the living cells in the stem and the air outside

Germinating seed: (eudicotyledon)

Hypogeal germination



Stem adaptations. Unit 2 content:

Internal stem structure relates to Plant Science 2 primarily in **secondary thickening**, detailed below, and the **role of parenchyma cells** in stems that are adapted to **store energy**, detailed in stem tubers, below. An in-depth understanding of internal stem structures is not required in Plant Science 2.

Secondary Thickening:

Only woody plants undergo secondary thickening, which is the process by which **xylem vessels** in angiosperms (flowering plants) **and tracheid's** in gymnosperms (conifers) **become lignified**, producing wood.

- **All gymnosperms undergo secondary thickening** (there are no herbaceous gymnosperms).
- Within **angiosperms** there are two groups: monocotyledons and eudicotyledons
 - **Monocotyledons do not undergo secondary thickening.** Even bamboo and palm trees, both monocots, do not have secondary thickening in their stems – these strengthen through different processes that are beyond the RHS level 2 syllabus.
 - Eudicotyledons can be split into two groups: herbaceous and woody. Herbaceous plants, including ephemerals, annuals, biennials and herbaceous perennials, do not undergo secondary thickening. **Only eudicotyledon shrubs and trees undergo secondary thickening.**

[Note: at level 2 you only need to state that gymnosperms have tracheid's and angiosperms have xylem, and that both tracheid's and xylem transport water and minerals from the roots to above ground parts. Further study will reveal that angiosperms xylem consists of tracheid's and vessels, but this is beyond level 2].

Xylem and tracheid cells become lignified as they mature: cell walls of developing xylem and tracheid's become enriched with lignin, which is what wood is made from. Lignin makes cell walls very strong, and waterproof (which is why water is contained within xylem and tracheid's in a similar way to water within a straw).

Once xylem or tracheid's reach maturity, the cells they're made from die, losing their contents. Only the lignified cell walls remain. This results in a very strong, lignified, hollow structure made of many cells joined end to end, essentially forming a tube (further study – beyond level 2 – will reveal the differences between xylem vessels and more primitive tracheid's).

As woody plants grow, new xylem or tracheid's are produced beneath the bark, in the cambium layer of actively dividing cells. This means, over time, woody stems increase in girth, with **layers of xylem or tracheid's building up year after year. This makes woody plants stronger** and is why tree trunks can withstand the immense physical stress of bearing heavy branches, especially in high winds, rain and snow. In trees from temperate climates, the rings of wood seen in cut trunks or branches each contain one growing season's xylem vessels.

The advantage of secondary thickening is that it allows woody plants to grow larger each year, enabling trees and shrubs to compete for light and position their leaves in the optimum position for photosynthesis.

Other organisms take advantage of woody plants:

- Epiphytes growing on high branches to gain access to higher light levels (this includes lichen and moss growing on woody plants).
- Birds nesting out of reach of predators – including woodpeckers excavating holes to nest in.



Secondary thickening allows conifers to grow tall to compete for light. In this cut trunk you can see the central heartwood, made of non-conductive tracheid's. The outer ring is sapwood, where tracheid's conduct water and minerals up the trunk, and other tissues enable the trunk to grow and thicken

Rhizomes:

These are **underground stems** that spread horizontally through the soil away from the parent plant. They are very common in herbaceous perennials. **Plants that produce rhizomes are called rhizomatous.** Most rhizomes develop in the upper 30cm of soil, though some species send rhizomes much deeper.

One function of a rhizome is to **store energy (starch)**. This allows deciduous herbaceous perennials to survive the winter and regrow in spring. Rhizomes can be called an ‘organ of perennation’ because they allow plants that produce them to survive year after year, making them perennial (the same is true of bulbs, stem tubers and root tubers).

Like above ground stems, **rhizomes have nodes and internodes. Nodal areas produce new shoots**, and are often where new roots arise from. **If a section of rhizome is severed, as long as it has a nodal area it can survive independently of the parent plant** – producing its own roots and shoots – therefore **enabling colonisation of new areas**.

This is **useful in the vegetative propagation of rhizomatous perennials** by gardeners. When a gardener **‘lifts and divides’** a herbaceous perennial, it is almost always a rhizomatous perennial where the multitude of **rhizomes are split into several sections and replanted** as individual clumps. This is an almost carbon neutral way of propagating within a garden, and as long as each section is planted within the garden, or very close by (e.g. a neighbour’s garden), there is no biosecurity risk.



Tightly clustered rhizomatous perennial stems

Most garden ornamentals have been selected, in part, due to the short lateral growth of their rhizomes, meaning they form a tight clump that only slowly increases in diameter year-on-year. It is easy to tell plants that are tightly clumping herbaceous perennials because their stems are tightly clustered, and new stems do not arise at a distance from the main plant.

Some rhizomatous perennials, e.g. *Mentha spicata* (spearmint), send out long, spreading rhizomes and can quickly colonise large areas. These are **typically considered weeds in gardens**, and are difficult to eradicate once established. To remove them, every section of rhizome must be dug out, which is time consuming and disturbs the soil. Herbaceous plants may need to be dug up and the weed’s rhizome picked out, however this is not practical with trees

and shrubs. Even a small severed section of a weed’s rhizome can sprout into a new plant. Garden plants like mint should always be containerised in large pots to prevent them colonising areas where they are not desired.

Common rhizomatous weeds include *Aegopodium podagraria* (ground elder), *Cahystegia sepium* (bindweed), *Elymus repens* (couch grass), *Equisetum arvense* (field mare’s tail), and *Urtica dioica* (stinging nettle).



Melissa officinalis (lemon balm) rhizomes have been uncovered. These extend a reasonable distance from the parent plant each year, needing regular maintenance to control its spread



Rhizomes (purple tipped) emerging from the base of *Eupatorium cannabinum* (hemp-agrimony). Note they are distinct from the narrower, white roots



Elymus repens (couch grass) rhizome with new shoots visible



A *Geranium* ‘Orion’ rhizome has been lifted, showing new roots forming along its length. If separated from the main plant, this will grow into a new, clonal plant

Root adaptations. Unit 2 content:

Fibrous Roots:

Only monocotyledonous plants produce a fibrous root system, unlike eudicotyledons which have a tap root system. Note that Eudicotyledons never produce fibrous roots (only tap roots) and monocots never produce tap roots (only fibrous roots).

Fibrous roots have a fixed diameter in each species of plant, meaning at maturity they do not get any thicker, unlike tap roots. Fibrous roots are **predominantly found in the topsoil layer** (they rarely grow deeper, into lower soil layers), with many spreading out from the base of a plant. They form a relatively **dense network in the soil**. This gives them an overall **high surface area over which they can absorb moisture and nutrients**, as well as firmly anchoring plants into the soil.

Their density in the soil also makes them excellent for **binding soils to prevent erosion**, especially on slopes, and with consideration of the heavier rainfall events expected due to climate change that increase likelihood of soil erosion. Plants such as *Miscanthus sinensis* (eulalia), *Stipa tenuissima* (Mexican feather grass) and *Agapanthus africanus* (African lily) are all monocotyledonous plants that can be used to bind soil and reduce soil erosion.

An established monocotyledonous plant with a dense fibrous root network can be challenging to remove, transplant or plant near to. Large, established monocotyledonous plants such as *Cortaderia selloana* (Pampas grass) can take an enormous effort to lift and divide if they outgrow their space, which should be taken into consideration if planting large monocotyledonous grass species.



Stipa tenuissima (Mexican feather grass) has a dense fibrous root network that binds the soil around the plant, reducing soil erosion

Tap Roots:

Only eudicotyledon plants and gymnosperms (conifers) have a tap root system. A tap root system is **derived from the radicle** – the first root that grows from a eudicotyledon seed. The **radicle develops into the primary root, which has lateral roots arising from it**, forming a branched root system.

Unlike fibrous roots, **tap roots can continue to thicken as they age.** **Roots of woody plants** can gain significant diameter as they **undergo secondary thickening**, helping to anchor the above ground parts. They can have wide reaching root systems that absorb water and minerals from far beyond the canopy edge.

Herbaceous eudicotyledon plants have a tap root system that does not undergo secondary thickening, meaning the roots (like their stems) do not become woody.

Some woody plants, like pine trees (e.g. *Pinus sylvestris*, Scots pine), or *Quercus robur* (English oak) can **develop a deep tap root that can help the trees resist drought conditions**, as well as firmly anchor them in the ground.

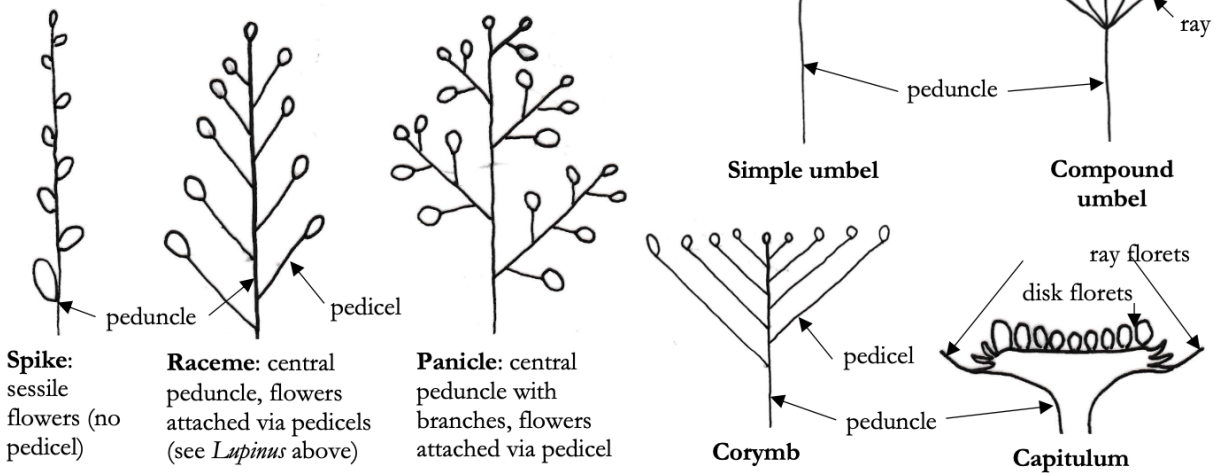
Tap root systems can store starch (which is rich in energy), **enabling the perennial plants to survive the winter** and regrow using energy stored in the roots. **In some species**, like *Daucus carota* (wild carrot) and *Taraxacum officinale* (dandelion), the **primary root is swollen and stores starch** (a form of energy storage) – this is called a **swollen tap root**.



This *Vicia faba* (broad bean) has a primary root descending into the compost, with many lateral roots arising from it

Species that grow in damp soils, such as near rivers and lakes; **in naturally shallow soils**, e.g. chalk soil; or **in compacted soils**, such as in urban areas where street trees are planted; **do not develop a deep tap root.**

Inflorescence structures:



Flower adaptations. Unit 2 content:

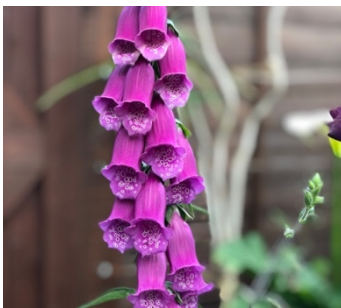
Flowers are always arranged to maximise chance of pollination:

- **Winter flowering shrubs and trees tend to be deciduous and often have wind pollinated flowers.** These can hang freely in the breeze with wind-blown pollen unimpeded by foliage, allowing it to travel long distances and cross-pollinate other plants of the same species. They are produced high on the plant to maximise exposure to wind. Likewise, when fruits/seeds are dispersed in the autumn, they are located high on the plants. Wind pollinated seeds have an increased likelihood of catching stronger breezes and travelling further from the parent plant, improving colonisation potential. Examples include:
 - *Betula pendula* (silver birch), which has wind pollinated flowers and wind dispersed seeds.
 - *Quercus robur* (English oak), which has wind pollinated flowers and animal dispersed seeds, usually by squirrels' hoarding (see topic 1.5).



Corylus avellana (hazel) produces wind pollinated catkins, which dangle from the branches in winter when the shrubs are leafless

- **Spring, summer and autumn flowering plants typically hold their flowers above their foliage to maximise access to insect pollinators.** This also positions fruits/seeds in a better location for dispersal. Examples include:
 - *Papaver orientale* (oriental poppy) produces a **single** flower atop a tall pedicel, above the foliage. It has colourful petals to attract pollinators and increase likelihood of successful cross-pollination.
 - *Digitalis purpurea* (common foxglove), has a one-sided **raceme** of large flowers that are held well above the foliage. Their flowers, collectively, are more visible from a distance by being arranged on side of the peduncle. The flowers open sequentially up the spike, meaning only a few flowers at a time are accessible to bees. This reduces the risk of bees moving between many flowers on the same plant and self-pollinating it.
 - The same effect occurs with plants that produce a **spike** of flowers, such as *Agastache foeniculum* (anise hyssop) – though with this species the flowers are arranged around the entire peduncle, rather than on just one side.
 - *Syringa vulgaris* (lilac) produces large **panicles** of flowers in spring, just as it is coming into leaf. These are produced at the tips of branches, maximising their visibility to pollinators.



Digitalis purpurea (common foxglove) has an upright raceme with large purple flowers arranged on one side

1.5 Seed adaptations

Function of Seeds:

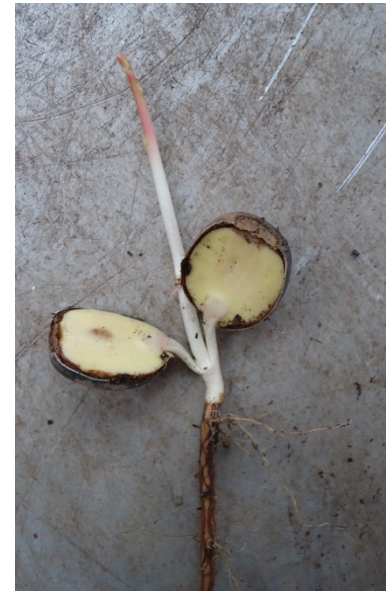
Seeds contain an embryo plant, which developed as a result of successful fertilisation of an ovule in the ovary of a flower. **The embryo in a seed is in a quiescent state, meaning it is inactive, until germination is triggered.**

The **embryo is made of a plumule**, which becomes the first shoot, **a radicle**, which becomes the first root (although in monocotyledons its role is brief and it doesn't persist to become a primary root), **and a hypocotyl** that joins the plumule and radicle.

For **the embryo to develop** (if conditions are right), **it needs an energy source** to enable it to develop its first root(s) and send up the plumule. Once the first leaf/leaves open, the young plant can support itself via photosynthesis. Until this point, it relies on stored energy within the seed, in the form of starch and oils.

In **eudicotyledons the energy store is in its cotyledons** (the seed leaves), whereas in **monocotyledons it is stored in a structure called the endosperm.**

The **embryo and energy store is encased in a seed coat, called the testa**; this can be relatively thin, or hard and durable. The testa has a small hole called a **micropyle** through which water can enter. This is an important part of triggering germination.



The germinating seed of *Quercus robur* (English oak), with the outer testa, inner cotyledon food store, plumule, hypocotyl and radicle visible. This is undergoing hypogeal germination

- **Seeds have evolved as a way for plants to sexually reproduce, enabling continuation of the species.** Due to cross-pollination, seeds are genetically varied. This means the offspring that develop are all a little different and some may happen to have generic advantages – for example, in a changing climate those which are genetically predisposed to tolerate higher temperatures, or drier growing conditions, may survive better. This is important for ensuring a species can evolve and change to maximise its survival; the process of evolution is gradual and happens over thousands of years.
- **Seeds can be dispersed some distance from the parent plant, enabling plants to colonise new areas.** This also enhances survival of the species (discussed in more detail below).
- **The seed itself can impose dormancy on the embryo**, preventing germination when conditions are not suitable (discussed in more detail below).
- **The seed structure protects the internal embryo from damage**, meaning it is in a healthy state to develop during germination, which only occurs when conditions are suitable.

Quantity of Seed:

Each species of plant has evolved a trade-off in the quantity and size of seed produced. An example that's representative of all seed bearing plants (gymnosperms and angiosperms) is given below:

A tree like *Quercus robur* (English oak) produces large seeds, but far fewer than an equally sized specimen of *Betula pendula* (silver birch), which has much smaller seeds:

- ***Quercus robur* seeds, being larger, have a much greater energy store.** This means there's **more energy for the radicle to grow deep into the soil to firmly anchor the plant, and for the plumule to push up through the soil**, even if the seed is relatively deep (which can happen if a squirrel buries the seed as a winter cache – see 'seed dispersal', below). Their large energy store also means the plumule can grow taller and better compete with surrounding plants to reach the light, improving chance of survival.
- **However, the tree doesn't produce as many seeds, so there's a higher risk none will survive and make it to adulthood.** Their large size also makes them more vulnerable to herbivory, as each seed has a large energy store, making it worth cracking open and eating.

Topic 1: Plant Science 2. 1.5 Seed Adaptations

- **Large seeds are also more difficult to disperse away from the parent plant.** A falling acorn will land beneath the parent tree's canopy. If it were to germinate there it won't survive in the shade of the parent tree above. Typically, trees with large seeds have evolved to be dispersed by animals (see 'seed dispersal', below).
- ***Betula pendula* seeds are small, light and plentiful.** They have a papery outer casing that catches the wind, meaning they can be blown a distance from the parent tree, dispersing them far and wide.
- **As so many are produced, it is not a huge loss if a proportion land in a position that's not suitable for the survival of the seedling.** Many others will land in suitable locations.
- **Small seeds are also less likely to be found and eaten by herbivores,** increasing their likelihood of survival.
- **However, small seeds have small energy stores.** This means the seed has only enough energy to send down a young radicle and develop a short plumule and first leaves. **In areas of high competition for resources, the more vulnerable, smaller seedling is less likely to survive.** The sheer number of seeds germinating can offset this, which is why it is an effective strategy.



Different species of plant have different sized seed, with a general correlation between smaller size and larger quantity produced.

To maximise biodiversity potential, having plants that produce a range of seed sizes is ideal, as different herbivores have evolved to seek and eat different sized seed.

Seeds of different sizes sown in pots, before being covered. Larger seeds have more energy to push their plumule up through growing media. In the wild, this improves their chance of successful germination

Seed Dispersal:

It is essential that a seed germinates at a distance from the parent plant. Germinating in the shade of the parent canopy, along with root competition for water and nutrients, is not conducive to seedling survival. By being dispersed away from the parent plant, the likelihood of a seed ending up in an optimum position for survival is higher.

There are several different vectors to disperse seeds: wind, animals, explosive (self-dispersed) and water:

Wind dispersal:

- Wind dispersed seeds are **usually small/light and attached to a structure with a high surface area** – this can be wing-like or parachute-like, and is **able to 'catch' the wind to transport the seed** some distance from the parent plant. A small number of plant species produce such tiny seed that it can be carried some distance on the wind without an additional structure, for example orchid seeds.
- **Three common types of wind dispersal structures:**
 - **Parachute.** This is perhaps best known on *Taraxacum officinale* (dandelion), where an elongated stalk with an umbrella like end is attached to the seed. This catches the wind, dispersing the seed. Other plants produce parachute-like structures, e.g. *Clematis vitalba* (traveller's joy).
 - **Winged seeds**, which are commonly seen on trees of the *Acer* genus, such as *Acer japonica* (Japanese maple) and *Acer griseum* (paperbark maple). The winged structure of *Acer spp.* is called a **samara**. These seeds tend to be a little larger than those attached to parachute structures. When the wind dislodges a winged seed, the weight of the seed orients the wing upward. As it falls a helicopter-like spinning motion happens, slowing the seed's fall so it can be blown away from the parent plant.



The feathery seed appendages of *Clematis vitalba* (traveller's joy) enable wind dispersal

1.6 Growth Habit Adaptations

All plants have adaptations that enable them to survive and compete in their climatic and geographic region. The term ‘climatic climax vegetation’ is given to the plants that naturally exist in an area, forming a stable community within the region’s climatic limitations. In the UK this is temperate deciduous forest. Within the UK climate there are sub-climax communities that are limited by environmental factors, such as bog vegetation in permanently wet soils, calcareous meadows on shallow chalk soils (chalk downlands), and others.

Plants from other regions of the world that are grown in UK gardens have adaptations that suit their native environment. This includes plants from mediterranean regions, alpine plants, prairie plants, and others.

This section overviews different growth habit adaptations, the understanding of which is essential in making suitable plant selections for each microclimate within a garden – ‘right plant, right place’.

Woody Plants:

In climates that have sufficient rainfall and mild to warm temperatures for at least part of the year, plant growth is abundant enough that there’s competition for light between plants. Over millions of years this has led plants to evolve ways of growing taller – for example the ability of some eudicotyledon plants to lignify (become woody) and have permanent above ground stems. The tallest plants have better access to light for photosynthesis, improving their survival.

In the UK, woody plants from temperate climates that are tolerant of mild summer temperatures tend to perform well as garden plants. These create a myriad of microclimates, with varying degrees of shade and dryness beneath depending on the woody plant species. For example, *Betula utilis* var. *jacquemontii* (West Himalayan Birch) casts dappled shade and allows more rain through to the understory, allowing a wide plant selection to be grown beneath. *Fagus sylvatica* (beech) casts heavy shade that few plants can tolerate.

Careful selection of woody plants will bring the following benefits to a garden:

- **Height and structure**, e.g. through the use of focal point specimen trees – such as *Acer griseum* (paperbark maple) in a lawn, or use of shrubs within borders, e.g. repeated spheres of *Ilex crenata* (Japanese holly) in a formal setting. These offer permanent above ground structure, unlike herbaceous plants.
- **Privacy**. Woody plants height means they can be used to create boundaries, such as hedges, around and within gardens. Boundary hedges block views into a garden, creating privacy and an increased sense of safety and seclusion in gardens.
- **Compartmentalising gardens**. Hedges within gardens can separate different parts of a garden, creating mystery and intrigue, and allow for different themes/purposes in different areas. This is often used in garden design such as Arts and Craft gardens.
- **Screening**. Trees, tall shrubs, hedges or (taller) pleached hedges can be sited to provide screening to block unsightly views, or prevent unwanted views into a garden to improve the sense of privacy.
- **Shelterbelts**. Hedges and trees filter winds, slowing them down for some distance downwind. If sited correctly, this can reduce the intensity of winds blowing through a garden, reducing wind-chill to create a milder microclimate. It can also reduce wind damage to herbaceous plants, e.g. during summer storms. In the UK, shelterbelts are often sited to the south west of a garden to buffer the prevailing winds. Shelterbelts to the north and east can buffer cold winter winds.
- **Habitat for wildlife**. Woody plants permanent above ground parts create space for wildlife to shelter and nest in; many overwintering invertebrates hide in cracks and crevices in bark. Woody plants physical structure and microclimate creation results in a greater range of ecological niches in a garden, increasing biodiversity. Many woody plants also have animal (insect) pollinated flowers and foliage that’s fodder for garden wildlife – these further their biodiversity benefits. A number of woody plants flower in spring on bare branches. This is both ornamentally beneficial and ecologically vital to pollinators that are emerging from winter.



Taxus baccata ‘Fastigiata’ (Irish yew)
provides structure and focal points in
this formal arrangement