

Transport in Plants

Why do plants need transport systems?

Some small or primitive plants, such as mosses, absorb all the nutrients they need directly from their environment. Larger plants do not have a large enough surface area to take in what they need. Like most multicellular animals, they have developed specialized tissues for transporting water and nutrients to all their cells. Plants that have specialized transport systems are known as vascular plants.

What materials do plants exchange & transport?

- Carbon dioxide
- Oxygen
- Water
- Organic nutrients
- Inorganic ions

Plant Processes:

- Photosynthesis: plants producing glucose, through sunlight.
- Respiration: plants supplying energy.
- Active Transport: energy required to move and transport substances.

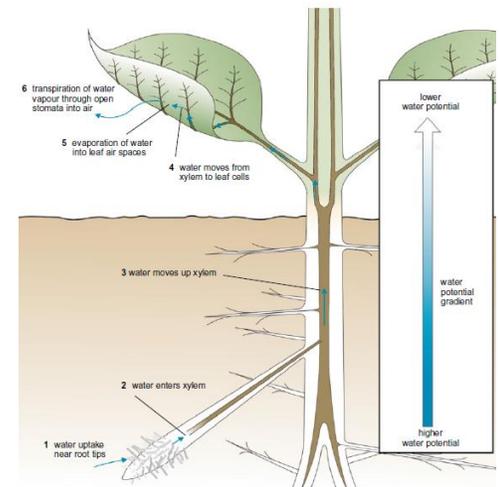
Two Transport Systems:

Transpiration System

Translocation System

Water transports in plants:

Water moves down a water potential gradient from the soil to the air.



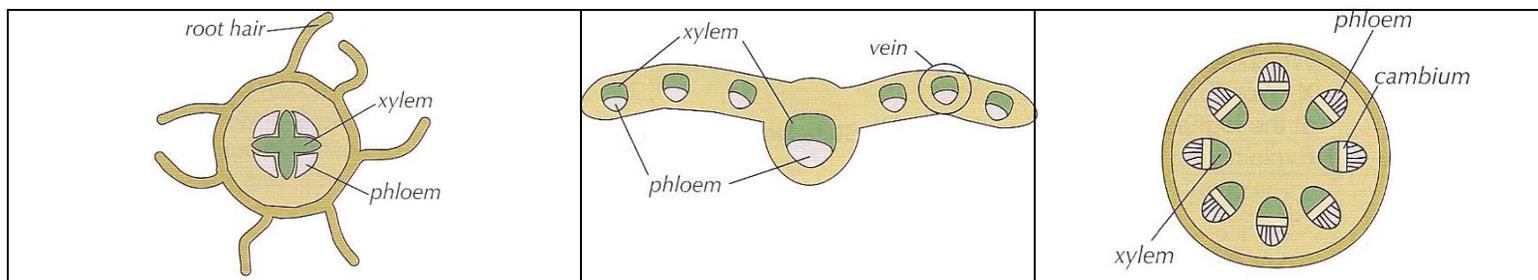
<p>Epidermis</p>	<p>This is the outermost protective layer of the stem, roots and leaves and is one cell thick.</p> <p>It is the leaves and stem it is covered with a waterproof layer called the waxy cuticle.</p> <p>The leaves have two epidermis (upper and lower). The lower epidermis contains pores called stomata (stomata - singular) which allows gaseous exchange.</p> <p>The roots have many extensions that increase the surface area for absorption of water and mineral ions. These are called root hairs.</p>
<p>Parenchyma</p>	<p>These are the unspecialized packing tissue of the stem, roots and leaves.</p>

	<p>The cells making up the tissue are thin-walled, are metabolically active and carry out many functions e.g. photosynthesis, storing starch, providing support (when turgid) and the air spaces within the cells aid diffusion of gases.</p> <p>In the roots, the tissue forms the cortex; in the stems, it forms the cortex and pith; in the leaves, it forms the mesophyll layer.</p>
Mesophyll	<p>This is made of specialized parenchyma cells. They are specialized for photosynthesis and therefore contain chlorophyll within chloroplasts.</p> <p>There are two types, palisade mesophyll and spongy mesophyll.</p>
Endodermis	<p>This is one cell thick and surrounds the vascular tissue in roots (and can be found in stems).</p> <p>In roots, the endodermis cells contain a structure called the casparian strip, which help regulate the movement of water and ions into the vascular tissue.</p>
Pericycle	<p>This is located between the endodermis and vascular tissue in the roots.</p> <p>It can be one to several layers of cells thick.</p> <p>In roots, new roots can grow from this layer.</p> <p>In stems, this tissue is specialized sclerenchyma (which has dead, lignified cells for strength)</p>

The Vascular Bundle

- Vascular tissue is distributed throughout the plant.
- Vascular tissue is made up of xylem and phloem tissue.
- As well as the transport of substances the vascular bundle has structural support purposes.

<u>In Roots</u>	<u>In Leaves</u>	<u>In Stem</u>
<p>This provides a 'drill' like structure. This enables the plant to push down into the root.</p> <p>Xylem tissues is the strongest so is in the center - X structure.</p> <p>Phloem in four separate sections.</p> <p>In the endodermis around the vascular bundle of the root, there is a layer of meristem cells that form the pericyclic.</p>	<p>Xylem is located on top of the phloem.</p> <p>This only applies to dicotyledonous plants, other plants types have a different structure.</p>	<p>Xylem is located on the inside - in non-wooded plants.</p> <p>This provides additional support to the stem.</p> <p>The cambium layer contains meristem cells.</p>



Xylem and Phloem: The design of a plant's transport system is quite different from that of a mammal. In fact, plants have two transport systems, xylem and phloem. Xylem carries mainly water and inorganic ions (mineral salts) from roots to the parts above ground. The xylem sap contained in the xylem can move in only one direction, from roots to the rest of the plant. The second system is phloem. This carries substances made by photosynthesis from the leaves to other areas of the plant. At any time, phloem sap can be moving in different directions in different parts of the phloem.

Xylem: Xylem tissue has 2 functions, namely support and transport. It contains several different types of cells. In flowering plants, xylem tissue contains vessel elements, tracheids, fibers and parenchyma cells. Xylem is a tissue that transports water & mineral ions in the stems & leaves of plants. These substances move against the gravity in a plant from the roots to the leaves.

Movement of water up the xylem

- Cohesion and adhesion help to keep the water in a xylem vessel moving as a continuous column.
- The vessels are full of water.
- Dead cells ensure no protoplasm to get in the way of transport.
- Since the xylem vessels are dead, open tubes, no osmosis can occur within them. This causes low pressure in the leaves, so water is sucked up the stem to replace the lost water. The column of water in the xylem vessels is therefore under tension (a stretching force).

<u>Structure:</u>	<u>Functions:</u>
Uni-directional	Quick upward movement of water by the transpiration pull (roots to leaves)
Dead Cells	Free movement of water without being used up. Doesn't impede the mass flow of water and dissolved solutes (transpiration stream)
Lignification	Strength & impermeability to water, helping it withstand hydrostatic pressure without collapsing.
Middle of the Stem	For support and strength.
Quick	Allows fast movement of water, up the stem defying gravity.
No Cross Walls	To form a long continuous tube of water & mineral ions.

No End Plates	Allows the mass flow of water and dissolved solutes as cohesive (between water molecules) and adhesive (between water and the walls) forces are not impeded.
Continuous Lumen	Free passage of water.
Joined end-to-end	Uninterrupted flow of water occurs.
Pits in Wall (non-lignified sections)	Lateral movement of water, allows continual flow in case of air bubbles forming in the vessels.
Small diameter of vessels (although they are longer than tracheids)	Helps prevent the water column from breaking and assists with capillary action.
Vessel elements & tracheids	Are the cells that are involved with the transport of water.
Sclerenchyma Fibers	Are dead, elongated cells with lignified walls that help to support the plant.
Parenchyma Cells	Are made of thin-walled cells used as packing tissue.

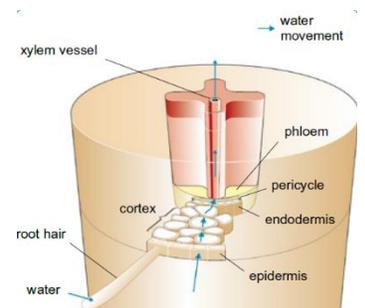
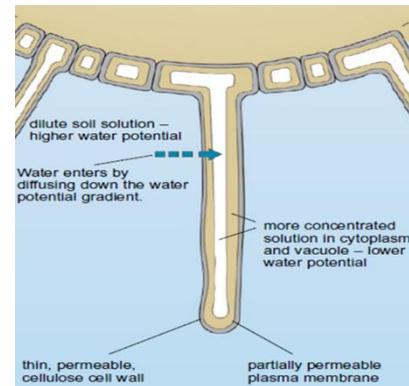
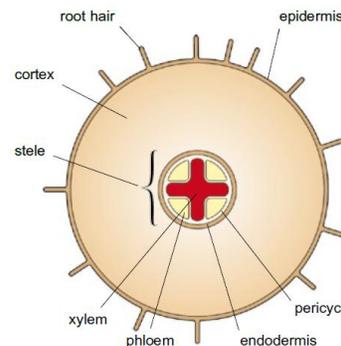
Phloem: Phloem contains unique tube-like structures called sieve tubes. They are made of living cells. A sieve tube is made up of many elongated sieve elements (sieve tube elements), joined end to end vertically to form a continuous tube. Each sieve element is living cell. Perhaps the most striking feature of sieve elements is their end walls. Where the end walls of two sieve elements meet, a sieve plate is formed. Each sieve element has at least one companion cell lying close beside it. Phloem is the tissue that transports organic substances in plant. Phloem transports solutes, mainly sugars like sucrose starch etc., all around the plants.

<u>Structure:</u>	<u>Functions:</u>
Bi-directional	To allow the transfer of sucrose & amino acids synthesized in leaves to all other parts of a plant. Transports soluble materials where they are needed. Phloem can carry nutrients to sites that are unable to photosynthesize, and areas of storage or tissues with a high energy demand so bidirectional movement is necessary. The phloem transports the food from the source to the sink in autumn and sinks to the source in spring because the sink is mobilised towards the growing but of the plant. (source to sink)
Living Cells (ER and Mitochondria)	They require energy which can only be provided by the respiration of living cells. Sieve tube elements are living cells without nucleus that form the tube like structures for transport of solutes.
No Nucleus, Vacuole, or ribosomes in mature cells.	Maximizes the space for the translocation of assimilates.

Outer Side of Stem	Differential action of hormones.
Sieve Tubes	Elongated cells arranged end to end forming long continuous tubes of cellulose. It contains few organelles to make room for a flow of materials through the cells
Sieve Plates with Pores	Are perforated and allow strands of cytoplasm to connect with sieve tube cells. Allows for the continuous movement of the organic compounds.
Companion Cells	They support sieve plates by carrying out metabolism and regulation. Companion cells carry out all the metabolic activities for sieve cells.
Cellulose Cell Wall	Strengthens the wall to withstand the hydrostatic pressures that move assimilates.
Thin Cytoplasm	Reduces friction to facilitate the movement of assimilates.

Root hair cells:

These are specialised exchange surfaces for the uptake of water and mineral ions. Root hair cells are about 200 - 250µm, this makes them visible to the naked eye. Root hairs just grow behind the growing tips of the roots. These specialized cells with a large S.A allow greater uptake of water by the roots. These cells are single-celled extensions of the epidermis cells in the root. They grow because soil particles absorb water and minerals such as magnesium, nitrogen and phosphorus from the soil. Water enters root hair cells by osmosis. This happens because soil water has a higher water potential than the cytoplasm of the root hair cells. The root hair increases the S.A of the cell significantly. This large S.A is important as it increases the rate of absorption of water by osmosis and mineral ions. With thousands on each root, they maximise surface area in contact with the soil.



Absorbing water: Water and mineral ions are contained within small air spaces in soil. When the roots are in contact with soil, water moves into the roots via osmosis. The osmosis occurs because there is a higher concentration of solutes in the plant than inside the soil.

Water movement pathways: Water moves through the roots cells and into the xylem tube by three pathways:

- Apoplast Pathway

- Symplast Pathway
- Vacuolar Pathway

These allow the plant to get water in as fast as possible.

The Apoplast pathway:

This is the movement of water through the cell wall and intracellular spaces.

- Cohesive and tension forces acting on the cell walls pull the water up the plant.
- This is the fastest movement of water.
- Assimilates diffuse through the cell wall and intermembrane spaces (the apoplast).
- When they reach the companion cells they are actively transported across the membrane into sieve cell cytoplasm.
- Hydrogen ions act as co-transporters and actively move assimilates across the membrane.

Symplast pathway:

This is the movement of water through the living spaces of the cell - cytoplasm.

Changing cells through the plasmodesmata.

- Each cell further away from the roots has a lower water potential so water is drawn up the plant.
- Assimilates are stored in the vacuoles of cells.
- The assimilates are moved through the cytoplasm of mesophyll cells into the sieve tubes across connecting plasmodesmata.
- This is a largely passive process.
- The assimilates are moved by changes in water potential of cells.

The Casparian Strip:

The endodermis is home to the Casparian strip.

The Casparian strip is an impermeable layer of suberin - a waxy material.

As a result all water in the apoplast pathway is forced into symplast pathways.

Transpiration:

The loss of water vapor from the surface of a plant shoot is known as transpiration.

The main organ which participates in the transpiration is leaf. Most of this occurs from the underside of a leaf, where there are many stomata in the epidermis. Most plants control their water intake by opening and closing their stomata. This happens when water levels change in the guard cells around each stoma. This occurs either passively by osmosis, or by active transport of solutes.

Transpiration rates also vary naturally in response to environmental factors such as temperature and humidity.

Water is required in the stem to make to maintain turgor pressure. Water osmosis into the roots where there is lower w.p. than the soil. Water moves up the transpiration stream into the stem because there is a suction-like pull from the top called transpiration which allows water to move up by cohesion and adhesion.

To maintain turgor pressure and supply sufficient water in the leaves for photosynthesis, water travels up the Xylem from the roots to the leaves to replace the water lost due to evapotranspiration.

Transpiration is the loss of water vapor from the plant leaves by evaporation of water from the surfaces of the mesophyll cells into the air spaces and then diffuses out of the leaves through the stomata as water vapor.

Regulating Stem:

- Stomal movement is the result of changes in the turgor of the guard cells.
- If water flows into the guard cells by osmosis, their turgor increases and they expand. The relatively inelastic inner wall makes them bend and draw away from each other. This opens the pore.

Stomata:

Flaccid - Closed

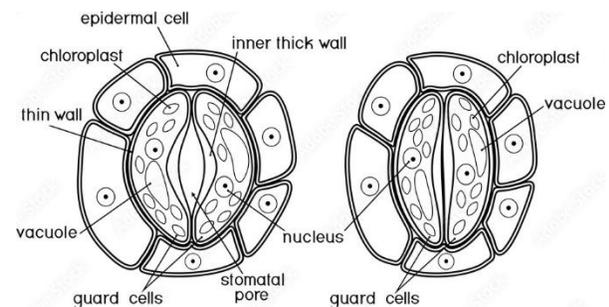
- Water moves out of the vacuoles by osmosis.
- Outer wall is more flexible than the inner wall, so to cell bends back and closes the stoma.

Turgid - Open

- Water moves into the vacuoles by osmosis.
- Outer wall is more flexible than the inner wall, so to cell bends and opens the stoma.

How does water move up the stem?

- Three processes caused by changes in concentration and attractions pull water up the xylem:
 - Transpiration Pull (Cohesion - tension theory):
 - Capillary Action (Adhesion): Adhesion of water is when water sticks to other molecules. Water adheres to the xylem walls. The narrower the xylem the bigger the impact of capillarity.
 - Root Pressure (Active Process): Water is usually drawn up a plant by the tension resulting from transpiration and cohesion between water



molecules. In some situations, such as 100% humidity, a plant is unable to transpire. Instead, water can be transported by positive pressure from below. This is known as root pressure. Solutes are actively transported into the roots of the plant, causing water to enter by osmosis. This increases the hydrostatic pressure in the root, forcing water up the stem.

Hydrogen bonds: Many of the properties of water are due to its ability to form hydrogen bonds. The slight negative charge on the oxygen atom makes it attract the slightly positive hydrogen atom of another water molecule. The numerous hydrogen bonds in water make it a very stable structure.

Transpiration Stream: Water evaporated from the leaves decreases the water potential of the air space inside the mesophyll. Water moves into the air spaces from the adjacent cells. Water moves out of the xylem into the cells in the leaves. Water hydrogen bonds to itself (Cohesion) and bond to the walls of the xylem vessel (Tension) resulting in capillary action. Passive. Water molecules attach by cohesive forces of attraction between the water molecules which helps create tension, enabling water to be pulled upward by a continuous column of water.

- Water moves up the Xylem vessels in a continuous transpiration stream from the roots to the leaves through the stem.
- Transpiration produces tension or pull on the water in the xylem vessels by the leaves.
- As water molecules are held together by cohesive forces, so water is pulled up.
- If the rate of transpiration from the leaves increases, water molecules that are pulled up through the suction-like pull in the Xylem vessels are quicker.

The cohesion-tension theory:

- The removal of water from xylem vessels in the leaf reduces the hydrostatic pressure in the xylem vessels. The hydrostatic pressure at the top of the xylem vessel becomes lower than the pressure at the bottom. This pressure difference causes water to move up the xylem vessels in continuous columns. It is just like sucking water up a straw.
- The water in the xylem vessels, like the liquid in a sucked straw, is under tension. The movement of water up through xylem vessels is by mass flow. This means that all the water molecules (and any dissolved solutes) move together, as a body of liquid, like water in a river.

- This is helped by the fact that water molecules are attracted to each other by hydrogen bonding; this attraction is called cohesion. They are also attracted to the cellulose and lignin in the walls of the xylem vessels, and this attraction is called adhesion.

Vertical transport of xylem sap:

- During daytime stomata are opened.
- When the water content in the atmosphere is low, it builds up a water potential gradient in between substomatal space and the atmosphere.
- Then water leaves through stomata by transpiration.
- This reduces the water potential of mesophylls creating a water potential gradient between xylem and mesophylls. Hence water moves from xylem to mesophylls.
- This builds up a suction pressure or a tension within xylem vessels causing a negative pressure potential.
- Suction pressure thrives down up to the xylem vessels of the root.
- Then water moves upwards through xylem vessels as a continuous flow.
- The continuity of water column is kept by cohesion and adhesion of water molecules and the power generated by capillary action.
- Due to this, a continuous gradient of water potential is maintained from soil, through the plant to the atmosphere.
- This results in the pulling of water continuously upward (cohesion, adhesion and tension theory).

Factors that affect Transpiration:

<u>Humidity</u>	<u>Temperature</u>	<u>Wind</u>	<u>Light</u>
H ↑ R ↓	T ↑ R ↑	W ↑ R ↑	L ↑ R ↑
H ↓ R ↑	T ↓ R ↓	W ↓ R ↓	L ↓ R ↓

CO₂ comes from the outside for photosynthesis to occur, so stomata need to open for CO₂ to diffuse in. When this pore opens, H₂O vapor evaporates.

<u>Factor</u>	<u>Condition</u>	<u>Effect on Transpiration Rate</u>
Wind Speed	High ↑	More - Good airflow removes H ₂ O vapor from air which sets a concentration gradient. (+ve correlation)
Humidity	High ↑	Less - Humidity is a measure of moisture in the air. When air is saturated with H ₂ O vapor, the concentration gradient is weaker so less H ₂ O is lost. (-ve correlation)

Temperature	High ↑	More - At higher temperatures particles have more, Kinetic Energy, and vibrate vigorously so transpiration occurs at a faster rate as H ₂ O molecules evaporate from the mesophyll & diffuse away faster. (+ve correlation)
Light Intensity	High ↑	More - At higher light intensity, the rate of photosynthesis is faster and for that, CO ₂ needs to diffuse into the leaf through the open stomata pore increasing S.A. As CO ₂ diffuses in, H ₂ O vapor diffuses out. (+ve correlation) Though transpiration doesn't stop regardless of light.

Translocation: is the movement of sucrose and amino acids in the phloem from parts of plants that produce or release them (sources) to parts of plants that use or store them (sinks). The term includes the movement of minerals, which can be dissolved in water and transported in the xylem, but usually refers to the transport of sugars, amino acids, and other organic molecules in the phloem. Active. Translocation can occur in either direction in the phloem - it is bidirectional. It is an active process, requiring energy, unlike water transport in the xylem.

- The term translocation can be applied to transport in both xylem and phloem - it means literally moving from one place to another.
- It tends to be used more commonly to describe the transport of soluble organic substances within a plant.
- The soluble products of photosynthesis are sucrose and amino acids.
- These are transported around the plant in the phloem tubes made of living cells.
- These cells are joined end to end and contain holes in the end cell walls called sieve plates which allow easy flow of substances from 1 cell to another.
- The transport of sucrose and amino acids in the flume from regional production to storage or usage is called translocation.
- Transporting the phloem goes in various directions depending on the development stage or the time of the year.
- Inventive and many plants have no leaves the phloem tubes may transport dissolved sugars and amino acids from the storage organs to other parts of the plants respiration can continue.
- During the growth period storage organs would be the source and growing areas the sink.
- After the plant has grown, the leaves are photosynthesizing and producing larger amounts of sugar, so they become the growing organs that is the source,

and storage organs become the sink again, storing sucrose as starch until needed.

- These are substances which the plant itself has made- for example, sugars which are made by photosynthesis in the leaves.
- These substances are sometimes called assimilates.
- Transportation of starch actively as sucrose through sieve tubes of phloem tissue from source end up to the sink end is known as phloem translocation. This occurs in both directions. The two ends of phloem translocation are as follows.

Source	<p>A location in a plant where sugar is being produced either by photosynthesis or breaking down of storage starch. These provide assimilates to the plant from reactions or storage for transport.</p> <ul style="list-style-type: none"> • Green leaves & stems • Storage organs. E.g tubers and root taps • Food stores in seeds. • Sucrose makes up 20-30% of phloem sap.
Sink	<p>A location in a plant where sugar is being stored or consumed is called a sugar sink. These use assimilates from the plant in various processes.</p> <ul style="list-style-type: none"> • Growing roots. • Active processes in the roots and stem. • Meristem cells activity dividing. • Developing stores, e.g seeds, fruits or storage organs.

Phloem loading:

- Translocation is vital process in plants.
- A large tree can move up to 250kg of sucrose around it trunk a year.
- Assimilates are moved into the phloem by active processes.

The mechanism of phloem sap translocation:

- Starch, the main photosynthetic product is transported in the form of sucrose as an aqueous solution (because sucrose is soluble and moderately inactive than glucose).
- This takes place through sieve tubes. At the source end, sucrose is actively loaded into sieve tubes through transfer cells. This is called phloem loading.
- This increases the Ψ_s of sieve tubes and decreases the Ψ_w of sieve tubes. Then water enters the sieve tubes by endosmosis from the xylem vessels. This builds up a high hydrostatic pressure in the sieve tube at the source end.
- At the storage organ, sucrose is actively unloaded into storage tissues through transfer cells. This is called phloem unloading.

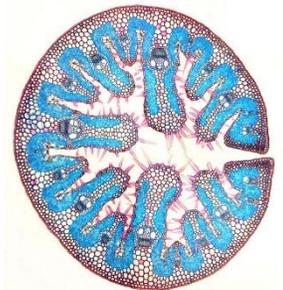
- This lowers the Ψ_s of sieve tube and increases the Ψ_w of sieve tube at the sink end. Then the water leaves the sieve tube by exosmosis into the xylem tissue. This builds up a low hydrostatic pressure in the sieve tube at the sink end.
- Due to this, a hydrostatic pressure gradient from source end to the sink end along the sieve tubes is created.
- Then the phloem sap is transported to the sink end upto the source end by mass flow. This mechanism is known as the pressure flow hypothesis.

The mass flow hypothesis for the mechanism of translocation in plants:

- In mass flow hypothesis, there are two ends, source from where solutes start moving and sink where solutes will be stored.
 - Loading of solutes from companion cells to sieve cells at the source.
 - Lowering of water potential inside sieve tube.
 - Water enters from xylem through osmosis.
 - Movement of solution up to the sink.
 - Unloading of solutes from sieve cells to companion cells at sink.
 - Gain of water potential leads to diffusion of water back to xylem.

Plants & Water:

- **Mesophytes:** able to take up sufficient water to replace transpiration (most plants).
- **Hydrophytes:** live either partially or completely submerged in water - problems with O_2 uptake.
- **Xerophytes:** live in areas where water lost via transpiration is greater than taken up by roots. When water is abundant, their rate of transpiration is about the same as other plants. However, in prolonged drought, they have several adaptations, which make them successful.



What are the adaptations shown by this photo microgram of a marram grass leaf and how it reduces water loss?

Stomata in pits	to trap air with moisture close to the openings. Stomata sunken in pits creates local humidity/ decreases exposure to air currents and decreases water loss. It reduces air movement, creating a layer of moist air, reducing transpiration.
Few Stomata	Reduces transpiration and gas exchange capabilities.
Outer epidermis	small, thick-walled cells (thick cuticle; no stomata).
Hinge (bulliform)	cells lose their turgidity and collapse in dry conditions, causing the leaf to roll up.
Hair	Trap water vapor reducing the water potential gradient between the leaf and the air. This traps a layer of still air between the hairs which increases the thickness

	of the uppermost layer (diffusion shell). This reduces the water vapor potential gradient and prevents the loss of vapor.
Loss of Leaves	Deciduous plants lose leaves in winters. Conifer leaves are thin needles. Losing leaves in long dry seasons allows for less water loss through transpiration.
Curled Leaves	Confines stomata in an environment of humid air, reducing transpiration and water loss greatly.
Reduced S.A	The plants will have thick leaves rather than thin, broad leaves. Some will have modified leaves which are spines. They also protect the plant from small mammals which would otherwise remove water from the plant.
Thick, Waxy Cuticle	The waxy layer that covers the epidermis may be thick to ensure that virtually no water can escape through it. A thick cuticle minimizes water loss. Common in evergreen trees and holly. Some plants also have a thicker epidermis.
Water Storage	Parts of the plant may be able to store water, such as the swollen stem of the cactus or the thick fleshy leaves of succulents. Succulent plants store water in specialized parenchyma tissue when water is in plentiful supply, for when it is not. Cacti and aloes are examples of succulents.