Water stress: is a condition in which more water is lost by a plant through transpiration than water uptake by roots.

During water stress, the plant experiences the highest water potential gradient from soil to the roots and as such more water is taken up by the roots though it's not enough to meet the loss through transpiration.

During water stress, a plant hormone, abscisic acid is released which results into a number of responses aimed at reducing water loss; most notably the closure of stomata. This however has an adverse effect of reducing the rate of photosynthesis.

UPTAKE OF MINERAL IONS IN PLANTS

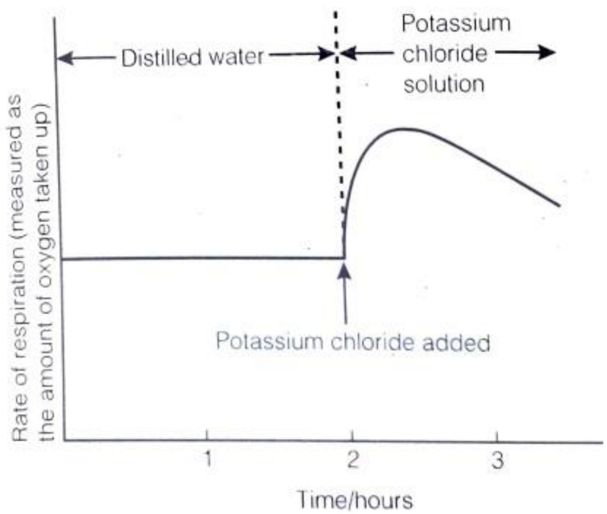
Plants require a variety of mineral ions which are important in the formation of plant structures, components of pigments such as chlorophyll and also facilitate physiological activity of enzymes.

The uptake of mineral ions by plants may occur either passively by diffusion or actively by active transport. The uptake of ions by plants is largely a selective process related to the plants need for particular ions.

a) Active uptake of mineral ions.

Most mineral ions required by the plant are selectively absorbed by active transport in which the ions are moved from the soil solution where their concentration is low to the root epidermal cells by transport proteins. The transport proteins reversibly change their shape using energy from ATP during this process.

The figure below shows the relationship between the rate of respiration and mineral uptake.



From the figure, when potassium chloride is added, the rate of respiration increases. This is to supply the required energy for mineral ion absorption by the plant

The control is of distilled water in which its presence has no effect on rate of respiration. It's absorbed passively

The energy from respiration is also used to prevent outward diffusion of the accumulated ions, using the cell membrane as a barrier.

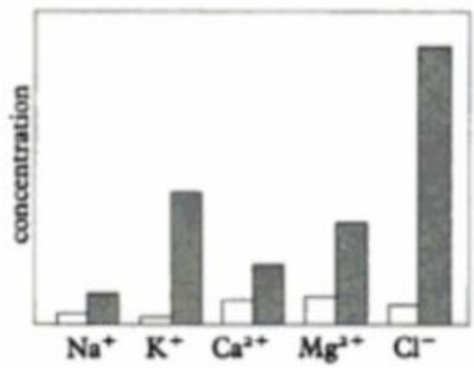
As a result, mineral ions tend to be in higher concentrations in the root cells as compared to the soil solution.

NOTE: (i) As a result of active transport, mineral ions tend to be more concentrated in root cells than soil solution.

(ii) Some ions tend to be in higher concentration with in root cells than others due to selective active uptake.

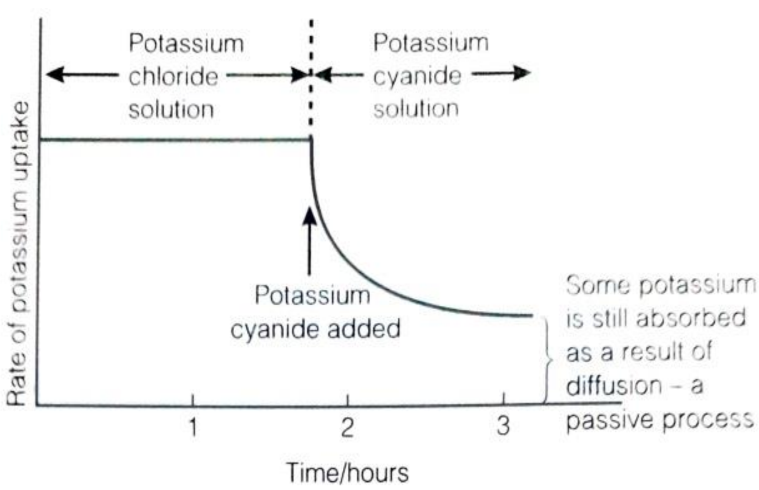
Evidence to show that mineral ion uptake is an active process

i. Certain ions are more concentrated in root cells than in the surrounding soil solution.
ii. Certain ions are more concentrated than others with in root cells.
   The figure below shows concentrations of different ions in pond water and in cell sap of green alga Nitella



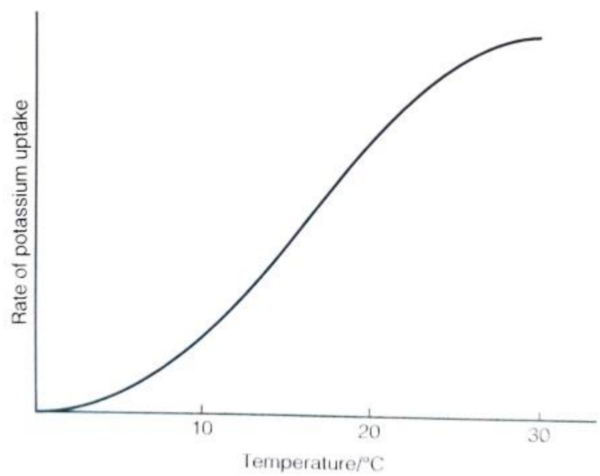
iii. Presence of respiratory inhibitor results into a reduction in the rate of mineral ion uptake. In this case, mineral ion uptake is only passive.

   The figure below shows the effect of potassium cyanide, a respiratory inhibitor on mineral ion uptake



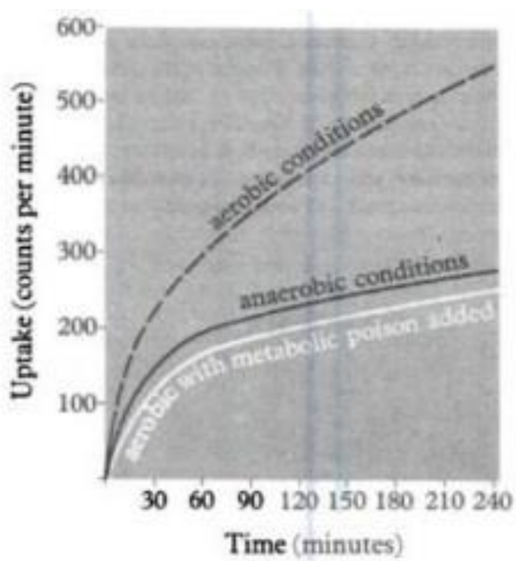
iv. The rate of mineral ion uptake is affected by temperature such that an increase in temperature results into an increase in mineral ion uptake.

The figure below shows the effect of temperature on rate of potassium ion uptake in plants



v. Cutting off oxygen supply from root results into a reduction in mineral ion uptake

A graph to show effect of oxygen deprivation and metabolic poison on uptake of sulphate ions in intact barley plants



The curves show that in aerobic conditions, the sulphate ion uptake is highest with increasing time. This is because a lot of energy from ATP hydrolysis is generated to power active uptake.

In anaerobic conditions, little energy is generated and the uptake of sulphur ions is lower than in aerobic conditions.

In presence of metabolic poison, uptake of sulphur ions is lowest and is only due to passive absorption

b) <u>Passive uptake</u>

This is mainly a result of diffusion and is non selective uptake. When mineral ions are higher in concentration within the soil solution as compared to the cytoplasm of epidermal root cells, ions tend to move down a concentration gradient into the cells of the roots. Fewer ions are however taken up by this process.

Once inside the root hair cells, ions dissolved in water move from cells of epidermis to cortex and into the epidermis through similar pathways as water. The ions tend to be actively transported by symplast from epidermis to the xylem tissue. This results into flow of water into the root xylem and results into root pressure.

The mineral ions thus move up the xylem of roots to stem by mass flow resulting from transpiration pull. The ions are absorbed by the cells in the stem and leaves.

Evidence to show that mineral ions are transported in the xylem

- ✓ Mineral ions are present in xylem sap
- ✓ There is a similarity between rate of mineral ion transport and rate of transpiration
- ✓ When a plant is grown in a solution containing a dye such as eosin, the dye is present in the xylem.
- ✓ Removal of living tissue including phloem does not prevent transportation of mineral ions.

<u>TRANSLOCATION OF ORGANIC FOOD MATERIALS</u>

Translocation refers to the movement of organic food materials from the structures where photosynthesis occurs to other parts of the plant.

Translocation of organic food materials occurs in the phloem tissue with in the sieve tubes. Organic food materials are transported from the source structures such as leaves and some photosynthetic stems where photosynthesis takes place to the sink structures i.e. **growing points** such as meristems and **perennating organs** such as fruits, roots and stems for;

- ✓ Respiration to provide energy required for growth and development
- ✓ Utilization by forming structures for growth, development and repair
- ✓ Storage.

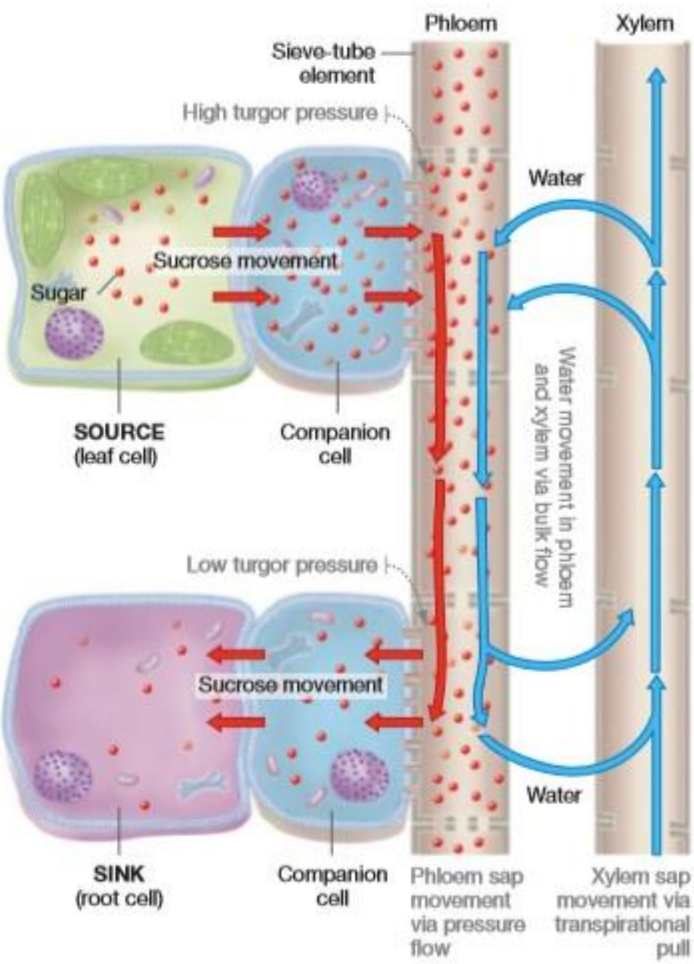
MECHANISM OF TRANSLOCATION

There are three hypotheses which explain the transport of organic food molecules from source organs to the sink organs with in the phloem. .i.e

- Mass flow hypothesis (pressure flow hypothesis
- Cytoplasmic streaming
- Electro osmosis

1. MASS FLOW HYPOTHESIS

The mass flow hypothesis is based on the principle of pressure flow of solution down a hydrostatic pressure gradient as described below. (Illustration to enable you understand. Don't draw)



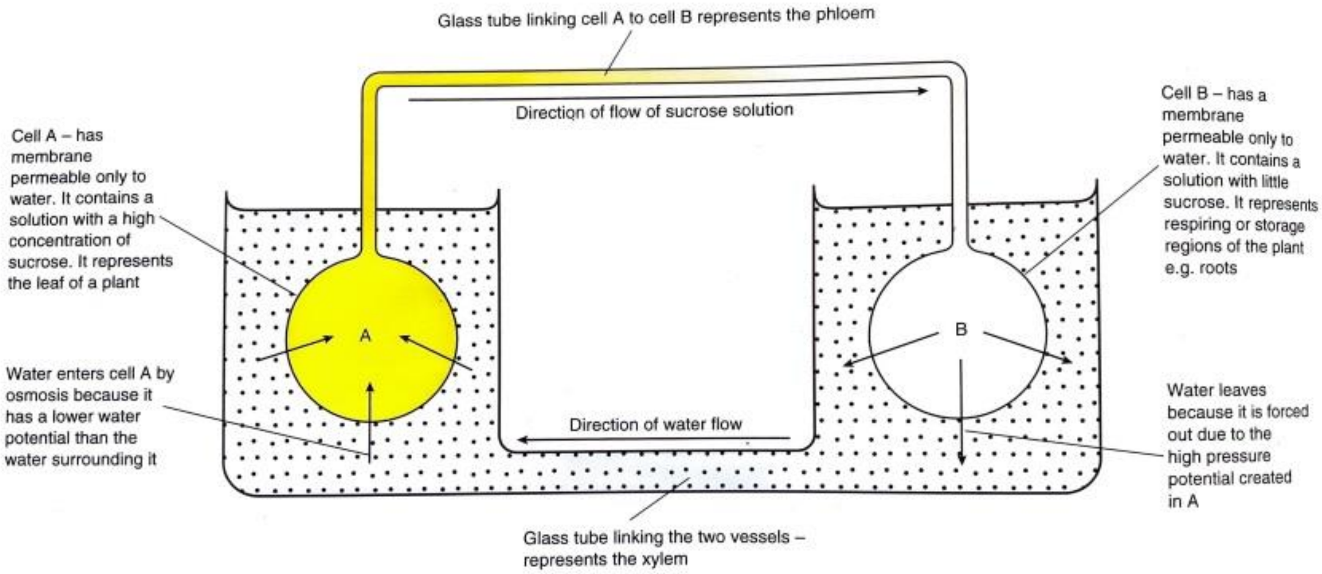
During photosynthesis, sucrose is manufactured by mesophyll cells and is actively transported into phloem sieve tubes. This results into a low water potential such that water transported up the stem through the xylem now moves by osmosis into the sieve tubes. This results into an increase in the hydrostatic pressure such that the phloem sieve tubes in the leaf region are now the source region for pressure flow.

Meanwhile, in other plant parts such as the roots, the sucrose is utilized during respiration while some is converted into starch for storage. This appears to bring about a high water potential in these cells such that water moves out of these cells to surrounding cells by osmosis. Consequently there is a low hydrostatic pressure in these regions, which sets up a pressure gradients between sink regions of roots with source regions.

This results into mass flow of sucrose solution from the source regions, through sieve tubes to the sink regions along a hydrostatic pressure gradient.

If sucrose continues to be formed in the source regions while sucrose is transpired and converted into starch for storage in the sink, a gradient is maintained for continuous translocation.

The physical model below illustrates the mass flow hypothesis.



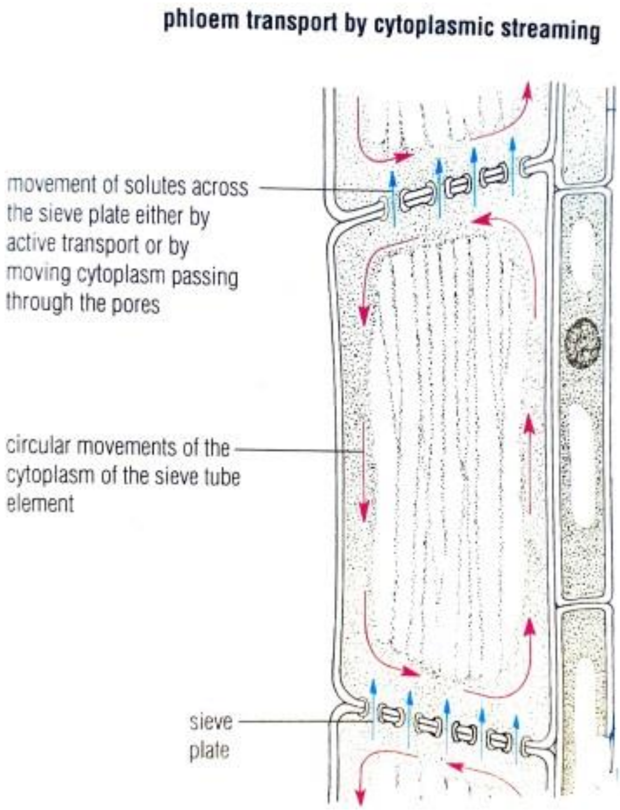
Evidence supporting mass flow hypothesis is derived from the fact that sucrose concentration is higher in photosynthetic regions and lower in growth and storage regions. This supports pressure build up to bring about mass flow of organic food substances

<u>Limitations of mass flow hypothesis</u>

- Does not explain difference in speed of movement of sugars and amino acids in phloem
- Does not explain movement of sugars and amino acids moving in opposite directions within the same group of sieve tubes.
- Does not explain why phloem consists of metabolically active cells along its length
- Does not explain presence of sieve plates which would offer resistance to flow of organic materials.

The figures included for cytoplasmic streaming and electro-osmosis are intended to help you understand the mechanisms here in described. You may not draw them

2. CYTOPLASMIC STREAMING (trans-cellular strand hypothesis)



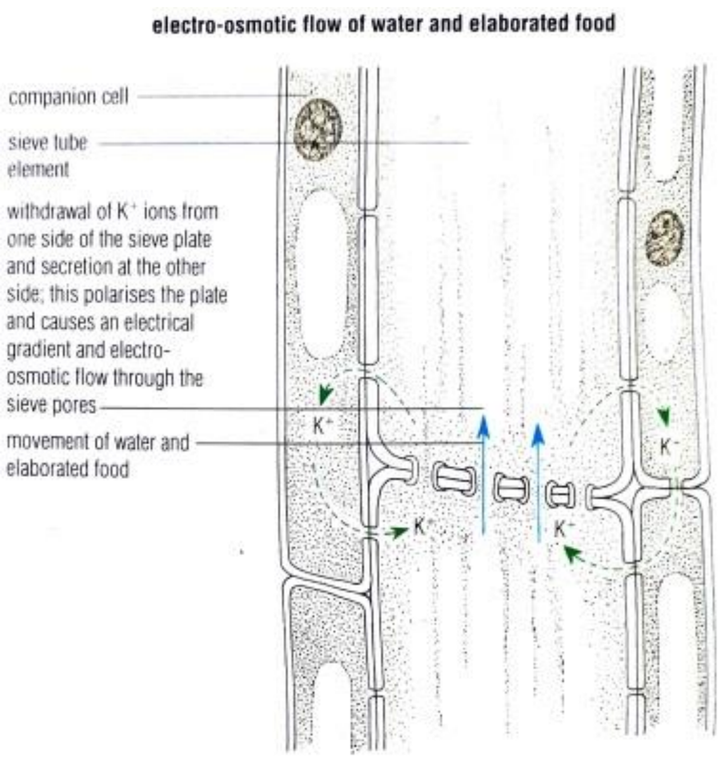
Phloem sieve tubes contain cytoplasmic strands which are believed to bring about movement of organic food material between them or through them since they are tubular.

Using energy from the few mitochondria in the sieve tubes and the majority in the companion cells, it is believed that organic food material are moved by streaming from one cell to the next. It is also assumed that movement of materials can occur in opposite directions by aid of the cytoplasmic strands.

The limitation of this hypothesis is

- The slow speed of streaming as compared to the higher speed with which organic food materials move.
- There is no conclusive evidence for the streaming action of cytoplasm.

3. ELECTRO-OSMOSIS



In this hypothesis, water molecules move across charged sieve plates in the sieve tube. This is a result of active transport of potassium ions which are pumped from one end of the sieve plate i.e. lower end to the opposite end i.e. upper end using energy from mitochondria in companion cells.

The stream of water flows towards the negative end such that solutes are carried with it in a mass flow.

The hypothesis is important because;

- ✓ It explains the importance of sieve plates as potential difference can be created across them to cause stream of water flow along with solutes.
- ✓ it explains the relevance of metabolically active phloem tissue
- ✓ explains speed at which substances are moved in the phloem, impossible by cytoplasmic streaming

LOADING AND UNLOADING OF SUGARS.

Loading of sucrose manufactured by mesophyll cells into sieve tubes for translocation is mainly an active process carried out by transfer cells and companion cells. Transfer cells are special parenchyma cells with intuckings of their primary cell walls and plasma membranes.

The intuckings increase surface area for ATP synthesis to provide energy for movement of sucrose.

During the process of loading of sucrose, symport cotransporter proteins are involved in which sucrose from mesophyll cells is moved against its concentration gradient, coupled with the flow of hydrogen ions along their electrochemical gradient. The energy required for this active transport is obtained from both the transfer cells and the companion cells. The sucrose from mesophyll cells is thus moved into sieve tube cells.

However, when the sucrose concentration in the mesophyll cells is higher than in the phloem, sucrose may be transported passively by facilitated diffusion into the sieve tubes.

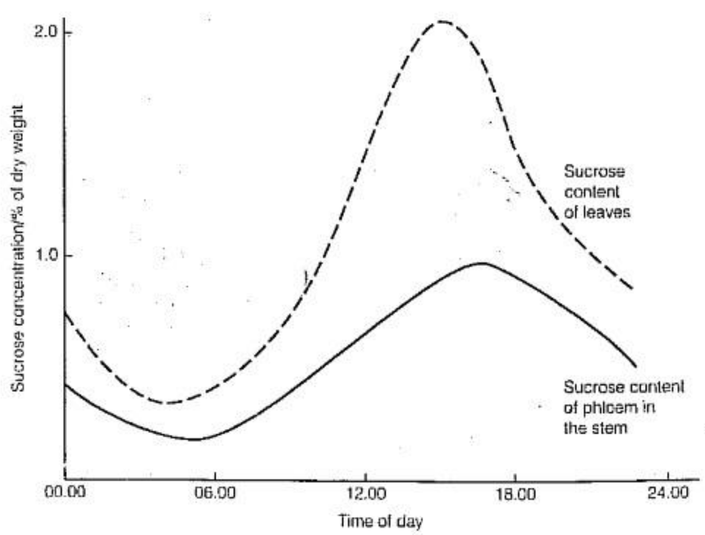
Once in the sieve tubes, the high sucrose concentration results into osmotic flow of water into the sieve tubes such that sucrose may be translocated to other regions.

The process of unloading sucrose in the sink regions is mainly passive since in the sink regions, the sucrose is metabolized to give energy, for growth, development and repair of structures. Passive movement of sucrose from the sieve tubes to the cells in roots is also due to conversion of sucrose to starch in some plants such that a concentration gradient of sucrose from sieve tubes to root cells is maintained.

However, unloading may also be an active process in cases where a concentration gradient does not exist. In this case, transfer cells and companion cells provide energy required which results into an antiport cotransporter unloading sucrose into cells in the sink regions.

Evidence to show that translocation of organic food materials occurs in the phloem.

i. Phloem sap exudes from the cut end of an aphid proboscis. This sap when analysed qualitatively, its chemical composition is similar to the contents of phloem
ii. Most organic substances are at higher concentration in leaves and lower concentration in roots.
iii. When carbon dioxide labelled with radioactive carbon (^{14}C) is provided to green leaves illuminated well with light, the resulting sugar formed obtained by sectioning plant tissues is found to be in the phloem tissue.
iv. Bark ringing experiment. Here, a ring of bark with all tissue external to the xylem is removed from the stem and the plant left to stand for several months. The section of the stem above the ring swells while the section below the ring remains almost same size or reduces slightly in size. The swelling is due to accumulated sugars possible because translocation tissue was removed, this can only be phloem since xylem were kept intact.
v. There is a diurnal variation in the sugar contents of the phloem with the diurnal rate of photosynthesis in relation to light intensity and favourable temperature.
In the figure below a peak in sucrose concentration in leaves results into a peak in the sucrose concentration in the phloem of the stem.



Since photosynthesis does not occur in the phloem, the photosynthesized food from mesophyll cells are passed on to the phloem sieve tubes where translocation occurs resulting into increased sucrose content.

The data below was obtained from experiments using plant materials treated as shown below. **Figure I** shows the uptake of potassium ions in an aerated solution by young cereal roots which had previously been thoroughly washed in pure water. After 90 minutes potassium cyanide was added to the solutions.

Figure I:

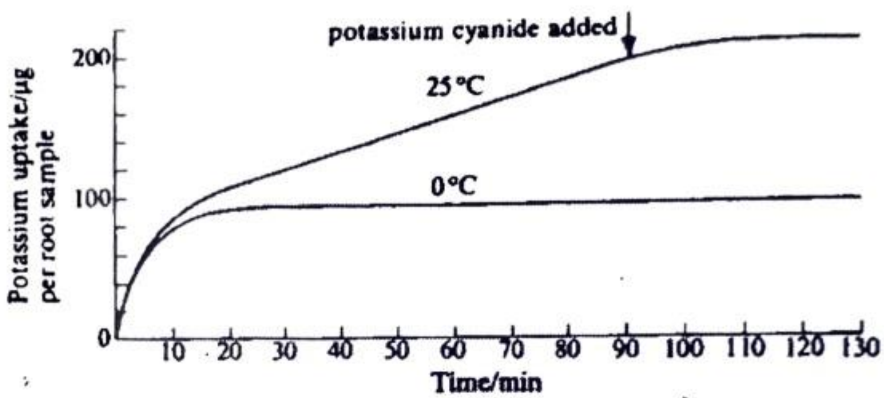
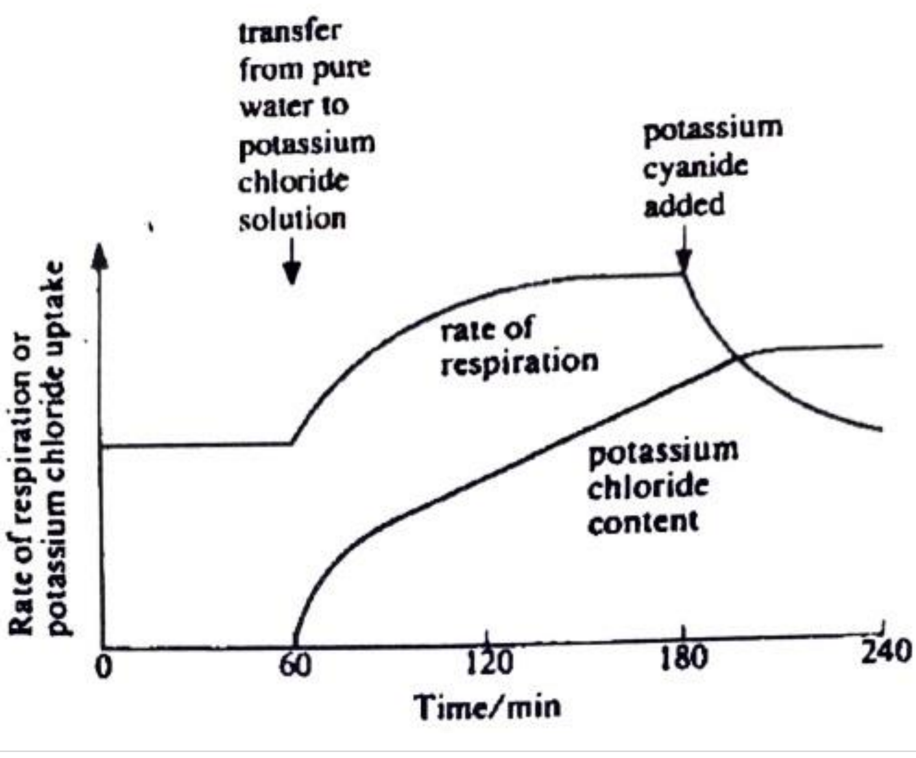


Figure II shows the rate of respiration and uptake of potassium chloride by young carrot discs. The carrot discs had previously been thoroughly washed in pure water and transferred to potassium chloride solution after 60 minutes. Potassium cyanide was added to the solution after 180 minutes.

Figure II:



With reference to figure I:
(a)(i) Compare the change in uptake of potassium ions at 0^0C and 25^0C. (05 marks)
(ii) Explain fully the trend of uptake of potassium ions at 0^0C. (06marks)

(b) Explain why:
(i) The same rapid uptake of potassium ions occurred in the first few minutes of the experiment at both temperatures. (02 marks)
(ii) The uptake of potassium ions at the two temperatures greatly differs for much of the experiment (06 marks)
(iii) Potassium cyanide has the effect it does at each temperature. (03 marks)
(iv) The cereal roots were washed before placing them in a solution containing potassium ions. (01 mark)
(v) In a similar experiment, but involving phosphate uptake, 16% of the phosphate taken up by barley roots over a short period could be washed out after transferring to pure water again. (02 marks)
(vi) Ions cannot reach the xylem entirely by means of the apoplast pathway. (03 marks)

With reference to Figure II:
(c) Explain the trend in rate of respiration:
(i) Before addition of potassium cyanide. (09 marks)
(ii) After addition of potassium cyanide. (03 marks)