Plant water relations
Unit I B.Sc III Year

Theory of proton transport or Levitt hypothesis or Malate or K^+ ion pump hypothesis.

Since stomata opens because guard cells take up water and water uptake is caused by more solute and hence a more negative osmotic potential. What is the solute and where does it come from? Experimental evidence has made it clear that K^+ ions move from the surrounding cells into the guard cells when stomata open. Increase of upto 0.5 M ion K^+ concentration is observed enough to decrease the osmotic potential by about 2.0 Mpascals. Light causes a built of K^+ in guard cells. When leaves are transferred to dark K^+ ions move out of the guard cells into surrounding cells and stomata close. This has been observed in numerous species from all leaves of the plant kingdoms (eg. From Mosses to higher plant leaves stems and sepals) exception is *Paphiopedlium leearum* seems to be exception. Their guard cells do not contain chlorophyll and do not take up sufficient K^+ when stomata are open. In some species Cl^- ions or other anions accompanying into and out of guard cells, But Claus Rashke and G. D. Humble 1973 observed that no anion accompanies the movement of K^+ ion into guard cells of *Viccia faba* leaves. Instead as K^+ ion move into guard cells, an equal number of H^+ ions come out .Where does the H+ come from? Organic acids are synthesized in the guard cells which are the sources of H^+. The organic acids are made largely from starch and sugars stored in the guard cells. Starch is apparently broken down to produce a 3 carbon compound phosphoenol pyruvate (PEP). The PEP combines with Co_2 to produce Oxaloacetic acid and then 4 carbon mallic acid. Finally H^+ ions from the mallic acid (which dissociates into malate and H^+ ions) leaves the cell to balance the K^+ ions that are entering.

Thus the increasing negative osmotic potential is caused by an uptake of K^+ and some times Cl^- or a build up of potassium salts of organic acids mostly malate. Which of the two possesses predominates apparently depends on the species and perhaps on the availability of Cl^-. It has been observed that ATP which may be generated by degradation of starch through metabolism and photophophorylation in guard cells is utilized to pump out protons out of the guard cells by the membrane bound ATPase due to development of electro chemical gradient K^+ moves by passive transport. It is said that guard cells are not able to synthesize the sugar because of lack of Rubisco enzyme. Starch in the guard cells stored is supplied from the mesophyll cells of the leaf. Reverse events would bring about closure

Factors affecting stomatal movement:- Many Changes in environmental factors influence stomatal opening and closing. These are.

1. Light:- Generally the stomata of a leaf are open when exposed to light and remain open under continuous light unless other factors become limiting allowing entry of Co_2 needed for photosynthesis during the day time. Opening generally requires about an hour and closing is gradual through out the afternoon. Stomata close faster if plants are suddenly placed in darkness. Certain succulents that are native to hot, dry conditions eg. *Cacti, Bryophylum* act in an opposite manner. They open their stomata at night fix Co_2 into organic acids in the dark and close their stomata during the day. This is an appropriate way to absorb Co_2 through open stomata at night when transpiration stress is low and conserve water during the heat of the day. The minimum light level for the opening of stomata in plants is about 1/1000 to 1/30 of full sunlight, which reduces the Co_2 concentration of the leaf.

2. <u>Co_2:-</u> Low concentration of Co_2 in the leaves causes stomata to open and removal of Co_2 by mesophyll cells during photosynthesis is the main reason that stomates of most species open in light, Succulents fix Co_2 during night diminishing Co_2 and causing stomatal opening. When the stomatas are completely closed which is unusual external Co_2 free air has no effect. The environmental factors that influence photosynthesis and respiration probably affect stomata opening and closing by acting directly on the internal Co_2 concentration.

3. <u>Water potential:-</u> Water potential within a leaf also has a powerful effect on stomatal opening and closing. As water potential decreases the stomata close. This effect can override low Co_2 levels and bright light. Its protective value during drought is obvious.

4. <u>Temperature:-</u> High temperature 30^0C to 35^0C usually causes stomata closing. This might be an indirect response to water stress or else a rise in respiration rate might cause an increase in Co_2 within the leaf. In some plants, however high temperature causes opening instead of closing as a result increasing transpiration removes heat from the leaf.

5. <u>Wind:-</u> Sometimes stomates partially close when the leaf is exposed to gentle breeze. Probably more Co_2 is brought close to stomates increasing its diffusion into the leaf. Wind can also increase transpiration leading to water stress and stomatal closing.

6. <u>Abscisic acid:-</u> When leaves are subjected to water stress the abscisic acid in their tissues built up before stomates close, suggesting that stomatal closure in response to water stress is mediated through abscisic acid.

7. <u>Cytokinins</u>:- Cytokinins are essential for the opening of stomata. They help the guard cells in the intake of $K^{+.}$

8. <u>Light quality:-</u> Blue and red light are effective in both photosynthesis and stomatal opening. Blue light is more effective in causing stomatal opening than it is in photosynthesis. The blue light causes movement of $K^{+.}$ It also promotes the breakdown of starch into PEP that can accept Co_2 producing mallic acid which is the source of H^+

9. <u>PH</u>:- Rise in PH causes opening of stomata while a fall in PH brings about aclosure of stomata.

<u>Mechanism of Transpiration:-</u> In order to form vapours water requires a source of heat energy. There can be three sources of energy which can be used by plant organs for evaporation **(i).** Radiant energy **(ii).** heat energy from air **(iii).**heat energy from the transpiring surfaces. During day time the principal source of energy for transpiring leaves and other sunlit organs is the radiant energy. However in its absence the heat energy of the air and the transpiring organs is taken up. The atmosphere is seldom saturated with water vapour except soon after rains. The dry air of the atmosphere has a high DPD or low water potential After water has evaporated from the cell surface into the intercellular air space diffusion is the primary means of any further movement of water out of the leaf . The waxy cuticle which covers the leaf surface is a very effective barrier to water movement. It has been estimated that only about 5 % of water lost from leaves escapes through the cuticle which receives water from the epidermal cells by the process of imbibition. Almost all of the water lost from typical leaves is lost by diffusion of water vapor through the tiny pores of stomatal apparatus from low DPD of the air space of the leaf to high DPD of the atmosphere when the stomata are open.

On its way from the leaf to the atmosphere, water is pulled from the xylem into the cell walls of the mesophyll where it evaporates into the air spaces of the leaf. The water vapour then exists the leaf through the stomatal pore. Water moves along this path way predominantly by diffusion. So this water movement is controlled by the concentration gradient of water vapour.

The mechanism of lenticular transpiration is similar to stomatal transpiration with the exception that the pore size of the of the lenticels is larger and they always remain open, however their number is small so that lenticular transpiration forms only a fraction of 1% of the total transpiration

Factors affecting rate of transpiration:-These can be studied under two headings. External and internal

1.External factors:- include

(a). Humidity :- Less humidity in the atmosphere increases the rate of transpiration. More the humidity in the atmosphere less is the rate of transpiration.

(b). Temperature:- Temperature influences the rate of transpiration in four ways. **(i).** Change in vapour pressure deficit of air. **(ii).** Alternating the relative humidity of the atmosphere (it decrease by about 50% for every 10^0 rise in the temperature so increasing rate of transpiration. **(ii).** Change in the vapour pressure of the saturated air inside the leaf. (it almost doubles after every 10^0 rise in temperature. **(iv).** Changing the rate of diffusion of water vapours from the plant. A rise in the leaf temperature increases the vapour deficit of the atmosphere and allows the vapours to pass put quickly from leaf interior.

(c). Light:- In majority of plants stomata open in the presence of light and close in darkness. Therefore rate of transpiration is quite high in light. It falls down appreciably in darkness. Light has also heating effect which is largely dependent upon light intensity. High light intensity enhances permeability of the protoplasm. 250 foot candles light intensity is necessary to achieve maximum stomatal opening in Tobacoo. In bright moon light some stomata open eg. Onion, Pumpkin etc. In far red and ultraviolet light stomata close, while they open in red and blue light.

(d). Wind velocity:- Several investigations have shown that when plants are suddenly exposed to the wind there is a sharp increase in the rate of transpiration by quickly removing partly saturated air and bringing in new unsaturated air. This increase in the rate of transpiration is followed by the gradual decrease because increase in transpiration may lead to water stress or the surface of the leaf may become cool when the temperature of air blown over the leaf surface is cooler than leaf surface.

(e). <u>Water content in the soil:-</u> The availability of the water in the soil to the roots of the plant and the efficiency of its absorption have a profound influence on the rate of transpiration.

(f). <u>Atmospheric pressure:-</u> Low atmospheric pressure is accompanied by air currents so transpiration is increased. High atmospheric pressure decreases the rate of transpiration.

2. <u>Internal factors</u>: - include.

(a). <u>Leaf area:-</u> Greater the leaf area greater will be the magnitude of transpiration. On the per unit basis smaller plants often transpire at a greater rate than do larger plants. Larger plants loose more but on per unit area basis smaller plants loose more.

(b). <u>Leaf structure:-</u> Leaf structure determines the rate of transpiration in three ways.**(1)** thickness of cuticle **(2).** Number, density and thickening of the epidermal hairs. **(3).**The ratio of internal exposed surface area to the external exposed surface area of the leaf. Cuticular transpiration depends on the degree of its thickness. The epidermal hairs increase the thickness of the adherent stationary air. They reduce the rate of transpiration. If more of the leaf cells are exposed to the intercellular spaces the internal air of the leaf will tend to become saturated rapidly losing more water in transpiration.

(c). <u>Stomata:-</u> The Rte of transpiration is influenced by the number, spacing, distribution structural peculiarities, size of the stomatal aperture and the periodicity of the stomatal opening. The rate of transpiration in is little in xerophytes because their stomata remain open during the night and closed during the day. Sunken stomata reduce the rate of transpiration.

(d). <u>Leaf orientation</u>:- Solar radiations cause more heating when the flat surface of the leaf lies perpendicular to the incident light. The effect is minimum when it lies parallel to it as found in compass palnts *Lactuca.* Leaves of *Eucalyptus* hang downwardly to avoid overheating during the hot periods of the day.

(e). <u>Leaf size and shape</u>:- With the decrease in the leaf size the rate of transpiration decreases. It is very little in needle shaped leaves

(f). <u>Leaf modifications</u>:- Like spines, thorns and scales show reduced rate of transpiration.

(g). <u>Root shoot ratio:-</u> Parker found that transpiration increases with increase in root shoot ratio. Sorghum typically transpires at higher rate than corn plant per unit of leaf surface. Muller has pointed out that the secondary root development is much more advanced in Sorghum than that in corn.

(h). <u>Mucilage and solutes:-</u> They decrease the rate of transpiration by holding water tenaciously.

(i). <u>Water content of the leaves</u>:- Optimum transpiration continues only when the leaves have sufficient moisture. Low water content of the leaf generally brings down the rate of transpiration by decreasing water vapor pressure inside the leaf and closure of the stomata.

(j). <u>Diseases</u>:- The rate of transpiration is generally higher in the diseased plants as compared to healthy ones.

Significance of transpiration:- Transpiration is both advantageous and disadvantageous to plant.

Advantages of Transpiration.

1. **Mineral salt absorption:-** Numerous studies in 1930's clearly established that the salt absorption is predominantly an active process, and that only a small portion of salt is absorbed passively as a result of water uptake. Once the absorbed salts have been dumped into the xylem ducts of the root transpiration definitely influences their translocation.

In one of the experiments with *Tomato* plant, in which the transpiration rate was reduced considerably, the plant exhibited some calcium deficiency in their leaves. So calcium transport requires a faster transpiration stream.

2. **Effet on growth and development:-** Winneberger 1958 has observed that the buds of hardy pear cease to grow under conditions of high humidity and that under the same conditions growth of the sunflower plant is reduced to about half of the normal. So it is clear that transpiration is necessary factor in the normal growth of these two plants. Most important point is that cell growth depends on absorption of water which is passively absorbed by the roots of plants due to transpiration pull.
3. **Cooling effect:-** Evaporation of water is a powerful cooling process. Plants evaporate tremendous amount of water into their environment and each gram of water transpired uses 2.4 to 2.5 K joules of energy from the leaf and its environment.
4. **Water absorption:-** In a rapidly transpiring plant the xylem cells are generally in a state of negative tension or reduced pressure with the result water is pulled into the root from the soil . The process is termed passive absorption of water.
5. **Ascent of sap:-** Transpiration exerts a tension or pull on water column in the xylem which is responsible for ascent of sap.
6. **Mechanical tissue:-** Plants showing high rates of transpiration exhibit adequate development of mechanical tissues.
7. **Extensive root system:-** High transpiring plants generally show extensive root system.
8. **Improvement in the quality of fruits:-** Increased sugar and mineral contents of fruits follows high rates of transpiration.
9. **Hardening:-** Transpiration induces hardening which imparts resistance of plant to drought.
10. **Removal of excess water:-** It has been held that plants absorb far more amount of water than is actually used by the plant by the plant . Transpiration removes excess of water.
11. **Drainage of soil water:-** Rains increase the water content of the soil, reduce aeration and mineral content, and raise the water table. Transpiration reduces the water content of the soil, lowers the water table and increases soil aeration so that it functions as drainage system.

Disadvantages of transpiration.

1. **Wilting:-** If the amount of water lost through transpiration exceeds the amount of water absorbed through roots the cells of the plant become flaccid. (Wilting injury). Metabolic process including photosynthesis are retarded, checking growth, yield of crop is greatly reduced. Permanent wilting if not recovered may lead to death of the plant.
2. **Stunted growth:-** Excessive rates of transpiration lead to stunted growth of plant.

3. Expendiure of energy:- Energy is utilized in absorption of water and transpiration. This is a loss to plant because 98 to 99 % of the total water absorbed is lost in the process of transpiration.

4. Formation of abscisic acid:- Under conditions of water stress which can be due to high rates of transpiration the plant organs are stimulated to synthesize abscisic acid. Abscisic acid is known to inhibit several plant processes.

5. Modifications:-The plants have to adopt themselves for reducing transpiration during critical periods. e.g. the xerophytes have hypodermis, reduced leaf size, modification of leaves in thorns and spines, reduced number of stomata, sunken stomata etc. Deciduous trees shed their leaves to check their transpiration.

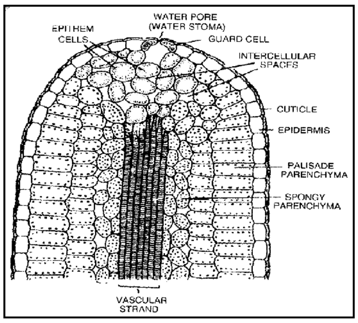
6. Reduced photosynthesis:- Under conditions of water deficiency which can be due to high transpiration rate, rate of photosynthesis declines.

7. Fall in metabolism:- Protoplasm requires a certain hydrature for maximum efficiency. When the water content of the protoplasm falls bellow this level, due to its loss in transpiration, all metabolic activities are retarded.

8. Formation of proline:- It has been found that under conditions of water stress there is an accumulation of free proline. The amino acid is believed to increase osmotic potential in order to retain water and prevent desiccation.

9. Accumulation of Betaine (Betacyanin):- In some plants the amount of betaine increases under water stress conditions. The product is believed to reduce toxicity of ions as found in halophytes.

Process of transpiration is one of the physiological processes of the plant which is unavoidable because of anatomy of the leaves. The loss of water occurs through stomata, which are necessary for the exchange of gases required for photosynthesis and respiration. So keeping in view both advantages and disadvantages Curtis 1926 truly called it as an essential necessary evil and Steward 1959 has called it as unavoidable evil.



Guttation:- The herbaceous flowering plants growing in moist places possess special structures at the vein endings of the leaf called **Hydathodes.** The water exudes through hydathodes in the form of small liquid droplets. This oozing of water in the form of small droplets through the hydathodes is called guttation. This liquid is not pure water but a solution containing a number of dissolved substances like P, K, Na, Mg, glucose, fructose, sucrose, thiamine, and riboflavin. Guttation was discovered by De Bary in 1869. The stomata closes on sunset and remains in closed condition during night. In Contrast the hydathodes remain open while day and night. Each hydathode opens to the exterior by means of pore called stoma. The stoma is surrounded by two guard cells. And opens internally into an air chamber. Just below the air chamber there is a group of parenchymatous cells with intercellular spaces called **epithem**. The xylem vessels and tracheids opens just behind the epithem. The liquid moves from xylem elements into cells of **epithem** and then exudes through stoma.

When soil conditions favour rapid absorption of water and there is high humidity in the atmosphere. The transpiration takes place slowly but the root pressure increases continously due to active absorption which results in gutation. It can be observed only in morning after a moist and warm night in the leaves of herbaceous plants like *Grasses, Tomato, Potato, Brinjal*. So guttation is the manifestation of root pressure.

Bleeding:- The exudation of water and cell sap through the cuts or wounds of plants is called bleeding. In certain plants the pressure is developed either in phloem elements or in the cells surrounding the cut or wound eg. the exudation of latex from Haevea (Rubber) stems is the example of bleeding.