Lecture No: 5

Transpiration- Definition, types, structure of stomata, physiology of stomata, WUE and factors affecting WUE

Transpiration is the evaporation of water from cell surfaces and its loss through the anatomical structures of the plant (stomata, lenticels and cuticles). The total water loss by transpiration may be very great. The daily water loss of large, well watered tropical trees may run as high as 500 liters. A corn plant may lose 3 to 4 liters of water per day. Whereas a tree sized desert cactus may lose water less than 25 ml per day. In general about 99 per cent of water absorbed by a plant during the growth is lost in transpiration. Transpiration is the evaporation of water from plants. It occurs chiefly at the leaves while their stomata are open for the passage of CO_2 and O_2 during photosynthesis. Although large quantities of water are absorbed by plant from the soil, only a small amount is utilized. The excess of water is lost from the aerial parts of plants in the form of water vapour and this process is called as transpiration. Nearly >95 per cent of water absorbed by the plants is lost through transpiration and only <5 per cent is utilized by the plant. In general, there are 3 types of transpiration i.e. stomatal, cuticular and lenticular transpirations.

Types of transpiration:

1. Stomatal transpiration:

- Most of the transpiration takes place through stomata. Stomata are minute pores confined to epidermis of green shoot and leaves. Stomata are usually confined in more numbers on the lower sides of the leaves. In most of the monocots, they are equally distributed on both sides of leaves. While in aquatic plants, stomata are present on the upper surface of the floating leaves. Stomatal transpiration accounts for 80-90 per cent of the total water loss from the plants.

2. Cuticular transpiration:

Cuticle is impervious to water, even though, some water may be lost through it. The loss of water through the cuticle is called as cuticular transpiration. It may contribute a maximum of about 10% of the total transpiration.

3. Lenticular transpiration:

Some water may be lost by woody stems through lenticels which is called as lenticular transpiration. Loss of water in the form of water vapour taking place through the lenticels present in woody stem and fruits is called as lenticular transpiration. It accounts for about 0.1 per cent of the total transpirational loss of water.

Distribution of stomata:

The position and distribution of stomata on the two surfaces of the leaf are variable in plants and there are five types.

Kidney shaped are found in the most of the plants including mosses, gymnosperms, dicots and many monocots. Dumbbell shaped or bone shaped guard cells are characteristic of grasses and hence it is also refereed as "*grass type*". Lantern types of stomata are present mostly in the CAM plants

Different Types of Stomata:

A. Types of Stomata based on Distribution:

1. Apple or mulberry type: Stomata are found distributed only on the lower surface of the leaves. eg., apple, peach, mulberry, walnut etc. Such leaves are called as hypostomatic type.

2. Water lily type: Stomata are distributed only on the upper epidermis of the leaves. eg., water lily, Nymphaea and many aquatic plants. These plants are epistomatic type.

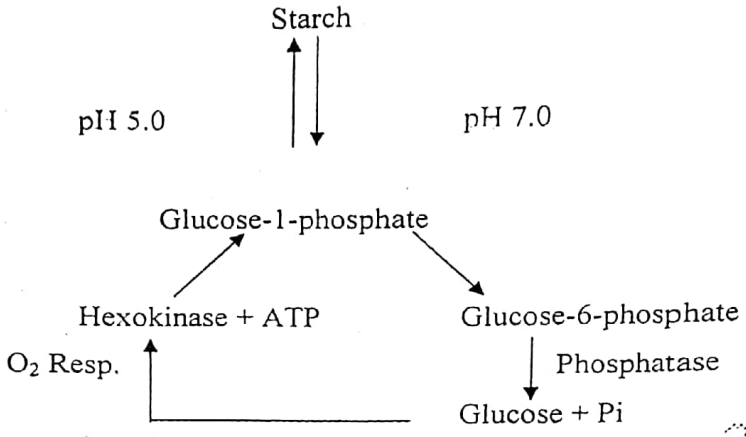
3. Potato type: In this type, the stomata are found more on the lower surface (multistomatic) and less on the upper leaf surface (paucistomatic type). eg., Potato, cabbage, bean, tomata, pea etc. Such leaves are called as amphistomatic and anisostomatic type.

4. Oat type: Stomata are equally distributed on the both lower and upper surface of the leaves. These leaves are referred as isostomatic type.

5. Potamogeton type: In this case, stomata are altogether absent or if present, they are vestigial. eg., Potamogeton and other submerged aquatics. Such leaves are called as astomatic type.

Glucose-1-phosphate should be further converted into glucose and inorganic phosphate for the opening of stomata.

Metabolic energy in the form of ATP would be required for the closing of stomata which probably comes through respiration.



2. Synthesis of sugars or organic acids in Guard cells:

During day light photosynthesis occurs in guard cells as they contain chloroplast. The soluble sugars formed in this process may contribute in increasing the osmotic potential of guard cells and hence resulting in stomatal opening. However, very small amounts of soluble sugars (osmotically active) have been extracted from the guard cells which are insufficient to affect water potential.

As a result of photosynthesis CO_2 concentration in guard cells decreases which leads to increased pH of organic acids, chiefly malic acid during this period in guard cells. The formation of malic acid would produce proton that could operate in an ATP-driven proton K^+ exchange pump moving protons into the adjacent epidermal cells and K ions into guard cells and thus may contribute in increasing the osmotic pressure of the guard cells and leading to stomatal opening.

Reverse process would occur in darkness.

3. ATP –Driven proton (H^+) – K^+ exchange pump mechanism in Guard cells:

According to this mechanism, there is accumulation of K^+ ions in the guard cells during day light period. The protons (H^+) are 'pumped out' from the guard cells into the adjacent epidermal cells and in exchange K^+ ions are mediated through ATP and thus are an active process. ATP is generated in non-cyclic photophosphorylation in photosynthesis in the guard cells. The ATP required in ion exchange process may also come through respiration.

The accumulation of K^+ ion is sufficient enough to significantly decrease the water potential of guard cells during day light. Consequently, water enters into them from the adjacent epidermal and mesophyll cells thereby increasing their turgor pressure and opening the stomatal pore.

Reverse situation prevails during dark when stomata are closed. There is no accumulation of 'K^+' in guard cells in dark.

(iii) The last step in the mechanism of transpiration is the simple diffusion of water vapours from the intercellular spaces to the atmosphere through open stomata. This is because the intercellular spaces are more saturated with moisture is comparison to the outer atmosphere in the vicinity of stomata.

Significance of Transpiration:

Plants waste much of their energy in absorbing large quantities of water and most of which is ultimately lost through transpiration. Transpiration is a unique feature in the plant system and referred as *necessary evil* as it is advantageous to plant under certain circumstances and harmful in some other situations.

I. Transpiration is necessary:

1. Role in the movement of water or ascent of sap

Water plays an important role in the upward movement of water i.e. Ascent of sap in plants, transpiration exerts a tension or pull on water column in the xylem which is responsible for ascent of sap. But, it does not mean that the translocation of water will be stopped without it.

2. Role in the absorption and translocation of mineral salts

Absorption of water and mineral salts are entirely independent process. Therefore transpiration has nothing to do with the absorption of mineral salts. However, once mineral salts have been absorbed by the plants, their further translocation and distribution may be facilitated by transpiration through translocation of water in the xylem elements.

3. Role of regulation of temperature

Some of the light energy absorbed by the leaves is utilized in photosynthesis, rest is converted into heat energy which raise the leaf temperature. Transpiration plays an important role in controlling the temperature of the plants.

Rapid evaporation of water from the aerial parts of the plant through transpiration brings down the temperature and thus prevents them from excessive heating.

Transpiration is one of the chief ways for the dissipation of excess energy, which the plant receives from the sun. Shull (1930) estimated that approximately 0.8 cal of energy is received upon each square cm of leaf surface per minute, of which about 10% is reflected and 25% is transmitted. The remaining 65% (0.52 cal) will increase the temperature of the leaves very rapidly. If the weight of the leaf tissue is $0.02 g/cm^2$ with the specific heat of 0.879, then the rise in temperature would be at 32°C per minute. With this rate of increase in temperature, the plant will be killed in less than two minutes, if there is no dissipation of energy. Transpiration plays a significant role here. It helps in dissipating this excess energy which will otherwise raise the temperature.

4. Role 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. Plants showing high rate of transpiration exhibit adequate development of mechanical tissues. Transpiration also shows that plants showing high rate of transpiration exhibit extensive root system.

5. Involves in improvement in the quality of fruits: Increased sugar and mineral contents of fruits follows high rate of transpiration.

6. Transpiration help in hardening process: Transpiration induces hardening which imparts resistance of plant to drought.

7. Transpiration help in removal of excess water: It has been held that plants absorb far more amount of water than is actually used by the plant. Transpiration removes excess of water.

II. Transpiration as a necessary evil:

1. It is a vital and unavoidable phenomenon of plants.
2. The loss of water does not serve any good purpose in plant life. Besides, the transpiration also consumes energy and causes unnecessary absorption of excess water by roots. Nevertheless, the internal structure is basically meant for the exchange of gases during photosynthesis and respiration.
3. When the rate of transpiration is high and soil is deficient in water, internal water deficit is created in the plants which may affect metabolic processes.
4. Many xerophytes have developed structural modification and adaptation to check transpiration.
5. Deciduous trees have to shed their leaves during autumn to check loss of water.

But, in spite of the various disadvantages, the plants cannot avoid transpiration due to their peculiar internal structure, particularly those of leaves. Their internal structure although basically mean for gaseous exchange for respiration, photosynthesis etc., it cannot check the evaporation of water. Therefore, many workers like Curtis (1926) have called *transpiration as necessary evil.*

Plants waste much of their energy in absorbing large quantities of water and most of which is ultimately lost through transpiration.

Some people think that – Transpiration is advantageous to plant.

Others regard it as an unavoidable process which is rather harmful.

Advantages of transpiration:

1. Role of movement of water

Plays an important role in upward movement of water i.e Ascent of sap in plants.

2. Role in absorption and translocation of mineral salts

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However, once mineral salts have been absorbed by the plants, their further translocation and distribution may be facilitated by transpiration through translocation of water in the xylem elements.

3. Role of regulation of temperature

Some light energy absorbed by the leaves is utilized in photosynthesis; rest is converted into heat energy which raises their temperature. Transpiration plays an important role in controlling the temperature of the plants. Rapid evaporation of water from the aerial parts of the plant through transpiration brings down their temperature and thus prevents them from excessive heating.

B. Transpiration as a necessary evil:

1. When the rate of transpiration is high and soil is deficient in water, an internal water deficit is created in the plants which may affect metabolic processes
2. Many xerophytes have to develop structural modification and adaptation to check transpiration.
3. Deciduous trees have to shed their leaves during autumn to check loss of water.

But, in spite of the various disadvantages, the plants cannot avoid transpiration due to their peculiar internal structure particularly those of leaves. Their internal structure although basically mean for gaseous exchange for respiration, photosynthesis etc. is such that it cannot check the evaporation of water. Therefore, many workers like Curtis (1926) have called transpiration as necessary evil.

Factors affecting transpiration rate:

A. External factors:

1. Atmospheric humidity:

In humid atmosphere, (when relative humidity is high), the rate of transpiration decreases. It is because atmosphere is more saturated with moisture and retards the diffusion of water vapour from the intercellular spaces of the leaves to the outer atmosphere through stomata.

In dry atmosphere, the RH is low and the air is not saturated with moisture and hence, the rate of transpiration increases.

2. Temperature:

An increase in temperature brings about an increase in the rate of transpiration by

1. lowering the relative humidity
2. Opening of stomata widely

3. Wind:

i. When wind is stagnant (not blowing), the rate of transpiration remains normal

ii. When the wind is blowing gently, the rate of transpiration increases because it removes moisture from the vicinity of the transpiring parts of the plant thus facilitating the diffusion of wastor vapour from the intercellular spaces of the leaves to the outer atmosphere though stomata.

iii. When the wind is blowing violently, the rate of transpiration decreased because it creates hindrance in the outward diffusion of water vapours from the transpiring part and it may also close the stomata.

4. Light:

Light increases the rate of transpiration because

In light stomata open

It increases the temperature

In dark, due to closure of stomata, the stomatal transpiration is almost stopped.

5. Available soil water:

Rate of transpiration will decrease if there is not enough water in the soil in such form which can be easily absorbed by the roots.

6. CO_2:

An increase in CO_2 concentration in the atmosphere (Over the usual concentration) more so inside the leaf, leads towards stomatal closure and hence it retards transpiration.

B. Internal factors:

1. Internal water conditions:

It is very essential for transpiration. Deficiency of water in the plants will result in decrease of transpiration rate. Increase rate of transpiration containing for longer periods often create internal water deficit in plants because absorption of water does not keep pace with it.

2. Structural features:

The number, size, position and the movement of stomata affect rate of transpiration. In dark stomata are closed and stomatal transpiration is checked. Sunken stomata help in reducing the rate of stomatal transpiration. In xerophytes the leaves are reduced in size or may even fall to check transpiration. Thick cuticle or presence of wax coating on exposed parts reduces cuticular transpiration.

Antitranspirants:

A number of substances are known which when applied to the plants retard their transpiration. Such substances are called as antitranspirants. Some examples of antitranspirants are colourless plastics, silicone, oils, low viscosity waxes, phenyl mercuric acetate, abscisic acid, CO_2, etc. Colourless plastic, silicone oils and low viscosity waxes belong to one group as these are sprayed on the leaves, form after film which is permeable to O_2 and CO_2 but not to water.

Fungicide phenyl mercuric acetate, when applied in low concentration (10^{-4} M), it exercised a very little toxic effect on leaves and resulted in partial closure of stomatal pores for a period of two weeks. Similarly ABA a plant hormone also induces stomatal closure. CO_2 is an effective antitranspirants. A little rise in CO_2 concentration from the natural 0.03% to 0.05% induces partial closure of stomata. Its higher concentration cannot be used which results in complete closure of stomata affecting adversely the photosynthesis and respiration.

The chemicals or substances applied to the transpiring surface with the aim to reduce transpiration are called antitranspirants.Antitranspirants will reduce transpiration without reducing the assimilation rate

Examples: ABA (5 to 10 ppm), CCC (1000 ppm), Alar (200 ppm), Simazine (50 ppm), Silicon (100 ppm), etc

There are three types of antitranspirants.

- **i) Stomatal closing type**
- **ii) Film forming type**
- **iii) Reflective type**

i) Stomatal closing type: These antitranspirants reduce the rate of transpiration by closure of stomata. Since the stomata are made to close, the rate of CO_2 diffusion into the leaf is also reduced leading to low photosynthetic rates. eg. Phenyl Mercuric Acetate (PMA), Abscisic Acid (ABA) and high CO_2 concentration. Fungicide phenyl mercuric acetate, when applied in low concentration (10^{-4} M), it exercised a very little toxic effect on leaves and resulted in partial closure of stomatal pores for a period of two weeks. Similarly ABA a plant hormone also induces stomatal closure. CO_2 is an effective antitranspirants. A little rise in CO_2 concentration from the natural 0.03% to 0.05% induces partial closure of stomata.

ii) Film forming type: This type forms a thin film coating on the surface of leaf and inhibits the loss of water vapour from the leaf. But they allow CO_2 to pass into the leaf through lower epidermis. E.g. Waxes, Plastic films, Silicone oils

Disadvantages:

1. Affects only at low temperature but not at high temperature
2. Comes in the way of gas exchange.
3. Form the mechanical barrier for stomatal movement

iii) Reflective type:

The principle of using this type of chemicals is to increase the light reflection by the leaves, thus decreasing the leaf temperature or heat load on the leaf. The water loss is reduced without affecting the CO_2 assimilation. E.g. Kaolinite (Kaolin), Lime water (Lime wash). Kaoline when applied it forms white thin film. Usually it is sprayed at 2-5 per cent and forms thin coating on the leaf.

Features of ideal antitranspirent:

1) Non toxic to plants, 2) Non permanent damages to stomatal mechanism, 3) Specific effect should be on guard cells and not to the other cells, 4) Chemical should be cheaply and readily available.

Use of antitraspirants:

1. To reduce transpiration of high value fruits and vegetable plants.
2. Helps in ornamental horticulture
3. Usage in water curing for lawns

GUTTATION:

In some plants such as garden nasturtium, tomato, colocasia etc, water drops ooze out from the uninjured margins of the leaves where a main vein ends. This is called as

guttation and takes place usually early in the morning when the rate of absorption and root pressure are high while the transpiration is very low.

The phenomenon of guttation is associated with the presence of special types of stomata at the margins of the leaves which are called as water stomata or hydathodes. Each hydathode consists of a water pore which remains permanently open.

Below this there is a small cavity followed by a loose tissue called as epithem. This epithem is in close association with the ends of the vascular elements of veins. Under high root pressure the water is given to the epithem by the xylem of the veins. From epithem water is released into the cavity. When this cavity is completely filled with watery solution, the later begins to ooze out in the form of watery drops through the water pore.

Difference between Transpiration and Guttation:

Transpiration	Guttation
1. Water is lost from aerial parts of plants in the form of invisible water vapours	Watery solution oozes out from uninjured margins of aerial leaves only
2. Transpiration occurs mostly through stomata. It may also takes place through cuticle and lenticels	It occurs only through hydathodes (water stomata)
3. It takes place throughout the day, its rate being maximum at noon.	It takes place only early in the morning when root pressure and the rate of water absorption are higher
4. It does not depend on root pressure	Depends on root pressure
5. Transpired water is pure	Guttation fluid contains salts and sugars as aqueous solution.
6.The leaf temperature is reduced	There is no such effect