

Factors Affecting CO₂ Reduction

Factor # 1. Temperature:

When CO₂, light and other factors are not limiting, the rate of photosynthesis increases with a rise in temperature, over a range from 6°C to about 37°C. Above this temperature, there is an abrupt fall in the rate and the tissue dies at 43°C. High temperatures cause the inactivation of enzymes and therefore affect the enzymatically controlled 'dark' reactions of photosynthesis.

The optimum temperature for the maximum falls between 20-30°C. Above 25-30°C the maximum rate is not maintained as the time factor begins to operate and the optimum temperature is reduced from 37°C to 30°C.

Given other factors are limiting, the rate of photosynthesis follows Vant Hoffs rule between 6°C-30°C to 35°C i.e., it doubles with each increase of 10°C. The reason being that all the reactions of the Calvin cycle are temperature dependent and the rate of diffusion of CO₂ to the chloroplasts is accelerated by high temperature.

Temperature range at which optimum photosynthesis can occur, varies with the plant species. For instance some lichens can photosynthesize at 20°C while conifers can assimilate at 35°C. On the other side certain blue green algae and bacteria inhabit hot springs and can perform photosynthesis at 70°C. Similarly, cacti can also carry on photosynthesis at 55°C.

In nature the maximum rate of photosynthesis due to temperature is not realized, because light or CO₂ or both are limiting. The response curve of net photosynthesis to temperature is different from those for light and CO₂.

It shows minimum, optimum and maximum temperatures. Between the C₃ and C₄ plants, while the former species have optimal rates from 20-26°C, the latter species may show optimal rates from 35-40°C. Similarly, temperature also influences the light (optimum, 30-35°C) and dark respiration (optimum 40-45°C).

Factor # 2. Carbon Dioxide Concentrations:

Nearly 0.032% by volume of carbon dioxide is present in the atmosphere and at this low level it acts as a limiting factor. Under laboratory conditions when light and temperature are not limiting factors, increase in CO₂ concentration in the atmosphere from 0.03% to 0.3-1% raises rate of photosynthesis.

With the further increase in the concentration of CO₂ progressively the rate of carbon assimilation increases slightly and then it becomes independent of CO₂ concentration.

Thereafter, it remains constant over a wide range of CO₂ concentrations. Plants vary in their ability to utilize high concentrations of CO₂. In tomatoes, high concentration of CO₂, above the physiological range, exerts harmful influence causing leaf senescence. During the early period of the earth, the concentration of CO₂ in the atmosphere was as high as 20%.

Factor # 3. Light:

The photosynthetically active region of the spectrum of light is at wavelengths from 400-700 nm. Green light (550 nm) plays an important role in photosynthesis. Light supplies energy for the process.

Light varies in intensity, quality and duration. A brief account on these three aspects is given as follows:

Factor # 4. Intensity:

When CO₂ and temperature are not limiting and light intensities are low, the rate of photosynthesis increases with an increase in its intensity. At a point saturation may be reached, when further increase in light intensity fails to induce increase in photosynthesis.

Optimum or saturation intensities may vary with different plant species e.g., C₄ and C₃. C₃ plants become saturated at levels considerably lower than full sunlight but C₄ plants are usually not saturated at full sunlight.

When the intensity of light falling on a photosynthesizing organ is increased beyond a certain point, the cells of that organ become vulnerable to chlorophyll catalyzed photo-oxidations. Consequently, these organs begin to consume O₂ instead of CO₂ and CO₂ is released. Photo-oxidation is maximal when O₂ is present or carotenoids are absent or CO₂ concentration is low.

Factor # 5. Quality:

The action spectrum for photosynthesis in leaves shows two major peaks, one in the red and the other one in the blue (Fig. 14-1). In these regions, chlorophylls absorb maximal light. Most effective wavelengths differ with different plants.

It is of interest to note that plants show high photosynthesis in the blue and red light while red algae do so in green light and brown algae in blue light. The blue-green algae have action spectrum peak in yellow or orange light.

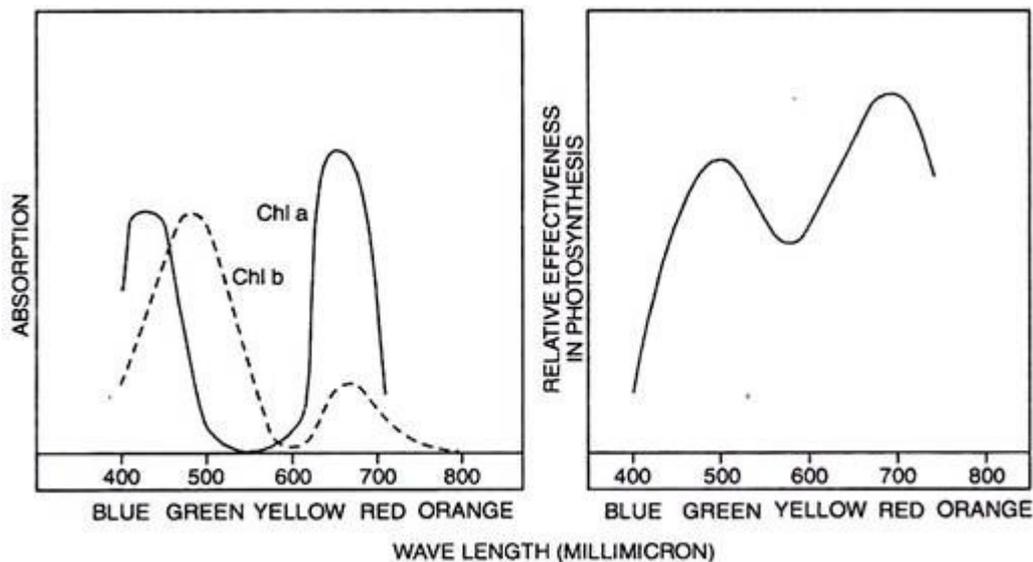


Fig. 14-1. Left, absorption spectra for chlorophyll a and b. Right, action spectrum for photosynthesis.

Factor # 6. Duration:

In general, a plant will accomplish more photosynthesis when exposed to long periods of light. It has also been found that uninterrupted and continuous photosynthesis for relatively long periods of time, may be sustained without any visible damage to the plant. We would also do well to bear in mind that if we remove the source of light, the rate of CO₂ fixation falls to zero immediately.

Clearly, no species has evolved and/or has developed a storage battery in its leaves whereby the immediate products of the photochemical reactions can be retained in significant amounts to be utilized for the fixation of CO₂ later on.

Factor # 7. Oxygen:

Oxygen has been shown to inhibit photosynthesis in C_3 plants while C_4 plants show little effect. It is suggested that C_4 plants have photorespiration and high O_2 stimulates it. The rate of photosynthesis increases by 30-50% when the concentration of oxygen in air is reduced from 20% to 0.5% and CO_2 , light and temperature are not the limiting factors.

Oxygen is inhibitory to photosynthesis because it would favour a more rapid respiratory rate utilizing common intermediates, thus reducing photosynthesis. Secondly, oxygen may compete with CO_2 and hydrogen becomes reduced in place of CO_2 . Thirdly, O_2 destroys the excited (triplet) state of chlorophyll and thus inhibits photosynthesis.

It may be stated that direct effect of O_2 on photosynthesis remains to be understood.

Factor # 8. Water:

Water is an essential raw material in carbon assimilation. Less than 1% of the water absorbed by a plant is used in photosynthesis. The decrease in water contents of the soil from field capacity to the permanent wilting point results in the decreased photosynthesis.

The inhibitory effect is primarily attributed to increased dehydration of protoplasm and also stomatal closure. The removal of water from the protoplasm also affects its colloidal state, impairs enzymatic efficiency, inhibits vital processes like respiration, photosynthesis etc. Dehydration may even damage the micromolecular structure of the chloroplasts.

It is also assumed that primary factor of dehydration in retarding photosynthesis is due to stomatal closure which reduces CO_2 absorption. Water deficiency may cause drying of the cell walls of mesophyll cells, reducing their permeability to CO_2 . Water deficiency may accumulate sugars and thus increase respiration and decrease photosynthesis.

Factor # 9. Mineral Elements:

As discussed earlier, several minerals are essential for plant growth. These include Mg, Fe, Cu, Cl, Mn, P and are closely associated with reactions of photosynthesis.

Factor # 10. Air Pollutants:

Gaseous and metallic pollutants decrease photosynthetic activity. These include ozone, SO_2 , oxidants, hydrogen fluorides, etc.

Factor # 11. Chemical Compounds:

Compounds like HCN, H_2S , etc. when present even in small quantities, depress the rate of photosynthesis by inhibiting enzymes. In addition chloroform, ether etc., also stop photosynthesis and the effect is reversible at low concentrations. However, at high concentrations the cells die.

Factor # 12. Chlorophyll Contents:

The rate of photosynthesis in two varieties of barley having normal green leaves and yellow leaves was studied. CO_2 , light and temperature were not limiting factors. The rate of assimilation per unit area of leaf surface in the two varieties was the same even though the green-leaved variety contained ten times more

chlorophyll than the yellow one. Clearly, the chlorophyll in the green leaves is surplus. Leaves having high chlorophyll content do not photosynthesize rapidly since they lack the enzymes or co-enzymes to use the products of the light reactions to reduce available CO_2 .

Factor # 13. Protoplasmic Factor:

Besides chlorophyll certain protoplasmic factors also influence the rate of photosynthesis. They affect the dark reactions. It has been shown that these factors are absent in the young stage and develop as the seedling becomes old.

That these protoplasmic factors appear to be enzymatic is indicated by the fact that the capacity for photosynthesis is lost at temperatures above 30°C or at strong light intensities in many plants even though cells are green and living.

Factor # 14. Accumulation of Carbohydrates:

Accumulation of photosynthate in the plant cells, if not translocate, slows down and finally stops the process. The accumulated products increase the rate of respiration. Sugar is also converted into starch and the accumulation of starch in chloroplasts reduces their effective surfaces and the process slows down.

Factor # 15. Blackman's Principle of Limiting Factors:

“When a process is conditioned as to its rapidity by a number of separate factors, the rate of the process is limited by the pace of the slowest factor.”

The slowest factor implies a factor which is present in intensity or quantity that is less than what is required for the process, when two to more factors act at the same time. To explain the meaning of his principle Blackman cited the following example.

Suppose a leaf is subjected to a light intensity sufficient to decompose 5 c.c. of CO_2 per hour and only 1 c.c. of the gas is available, photosynthesis will continue at a certain rate since light intensity is not a limiting factor.

Further any increase in light intensity will not result in an increase in the rate of photosynthesis. If the concentration of CO_2 is increased, the rate of photosynthesis will go up with the same light intensity. Clearly, CO_2 is the limiting factor. Increase in the CO_2 concentration till it attains 5 c.c. level will result in an increase in the rate of photosynthesis. At this concentration of CO_2 , energy is just sufficient to decompose it but not more.

If the concentration of CO_2 is raised still further, the rate of photosynthesis does not increase since light is now the limiting factor. When the light intensity is increased, then a higher concentration of CO_2 will be decomposed and the rate of photosynthesis increases till light again becomes a limiting factor.

Figure 14-2 represents the whole concept graphically. This experiment evidently shows that the photosynthetic rate responds to one factor alone at a time and there would be sharp break in the curve and a plateau formed exactly at the point where another factor becomes limiting.

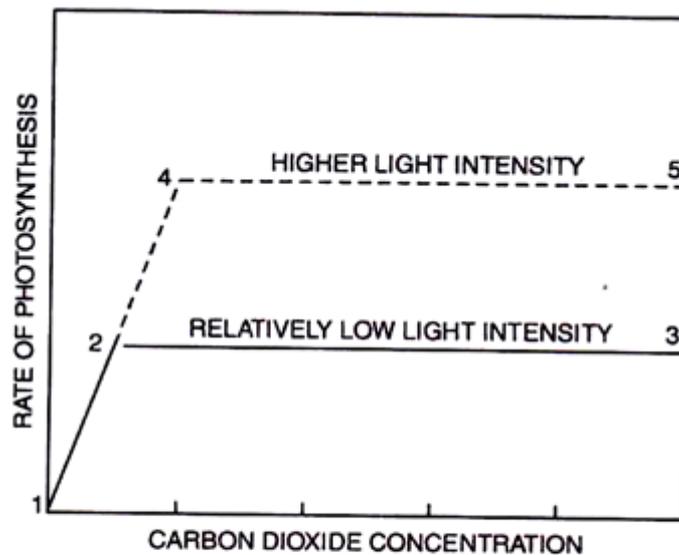


Fig. 14-2. Diagrammatic illustration of the law of limiting factors. Here a relationship between CO_2 concentration and rate of photosynthesis under low and high light conditions is shown. Under relatively low light intensity when the concentration of CO_2 is increased, the rate of photosynthesis increases from 1-2. The process becomes constant as shown from 2-3 even though CO_2 concentration is increased. At point 2 light is a limiting factor. If light intensity is increased the rate of photosynthesis also increases provided CO_2 concentration is also increased. This continues till point 4 is reached and then light becomes limiting and again the process of photosynthesis becomes limiting and it becomes constant as from 4-5.

Some workers have observed a "curving" approach to a plateau rather than a sharp break. For instance, with lower concentrations of the limiting factor (e.g., CO_2) there did appear to be a proportional relationship between rate and the quantity of the limiting factor present but at higher concentrations this was not so, since at higher concentrations another factor (e.g., light intensity) gradually replaced it as the factor is in relative minimum and this factor is only a weakness but does not entirely stop the influence of other factor (or factors).