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Photo Synthetic Efficiency and Crop Yield

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Abstract

Photosynthesis is the process of conversion of light energy to chemical energy by adopting certain mechanisms in green plants. It varies in plants which follow different mechanisms (C_3, C_4 etc.). There are many factors that alter the rate of photosynthesis. Carbon dioxide, water, sunlight, temperature and oxygen are the key external factors. The characteristic features of plant and other internal factors also contribute to the process up to a certain extent. Expected yield of crops can be achieved by detailed study of the plant mechanism and proper utilization of resources by minimizing the barriers.

Introduction

Agricultural yields of our major crops have risen in keeping with demand over the past 50 years. Mostly, these increases came about due to advanced approaches in agronomic and classical breeding that have maximized the plant architecture and light capture, resulting in high yielding varieties.

However, over years increase in yields of the major crops in many parts of the world have plateaued, and new technological solutions must be explored to develop high yielding varieties, to support the required food supply to meet the needs of the growing population (Fischer and Edmeades, 2010; Ray *et al.*, 2013; Long *et al.*, 2015; Ort *et al.*, 2015).

The global population has been estimated to increase from 7.6 billion to 9.7 billion by 2050, demanding yield of the major food crops in the range within 70to 100 per cent due to increase in living standards, requirements for plant-based proteins for animal feed (increased meat consumption) and requirements for plant-based fuels (Tilman and Clark, 2015; FAO, 2017).

Clearing of new land to bring it under cultivation is not a feasible option as there is little quality land available and therefore this approach would require an increase in the use of nutrient and water inputs in order to get the expected yields.

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Photosynthesis and Crop Yield

Photosynthesis is the deciding factor of crop yield, and the efficiency by which a crop captures light energy and converts it into biomass over the growing season (Long *et al.*, 2006). The maximum yield attained from a crop can be termed as yield potential and can be defined as the maximum yield obtained from the best adapted crop variety in optimal conditions without any biotic or abiotic stress (Evans and Fischer, 1999). Light availability, light capture, energy conversion and plant architecture are the determinants of yield potential. For our major crops *viz.*, rice, wheat and maize, one of these four components contributing to yield is below the potential maximum in energy conversion and is determined by photosynthetic efficiency (Long *et al.*, 2006; Zhu *et al.*, 2010). However, the efficiency of this conversion of energy to harvestable biomass, given that as much as 50 per cent of fixed carbon is lost through photorespiration under certain conditions has yet to be adequately explored.

Photosynthetic Efficiency

Photosynthetic efficiency refers to the amount of light energy that is converted into chemical energy through photosynthesis by green plants. This is ranges from 0.1 to 8 per cent depending on plant species. Many crops have a higher photosynthetic efficiency than average that allows for higher yields. The photosynthetic efficiency of plants is directly related to their ability to convert atmospheric carbon dioxide energy in the form of sugar in a process referred to as carbon fixation. The enzyme RuBisCo is responsible for this process, which is essential for plant growth and probably yield of a plant. This process is restricted to plant cells in which carbon dioxide is accumulated through shuttling by four-carbon compounds (e.g., malate, aspartate) from mesophyll cells to bundle-sheath cells. The fixation of this type of carbon, also known asC_4 fixation, is an elaboration of a more common type of carbon fixation known as C_3 fixation. Even though only 3 per cent of plant species use C_4 fixation, they account for nearly 25 per cent of the planet's primary productivity.

Photosynthetic Rate

Photosynthetic rate is an important parameter which shows the photosynthetic capacity of the photosynthetic apparatus. It is the number of molecules of CO_2 absorbed or O_2 released per unit leaf area per unit time, while quantum yield is the number of molecules of CO_2

absorbed or O_2 released per photon absorbed. Photon is the unit of measuring light in photosynthesis and express the rate of CO_2 fixed and O_2 evolved.

Factors Affecting Photosynthesis

Photosynthesis is affected by both ecological and genetic factors. The ecological factors are light, temperature, soil, water, CO_2 and nutrients etc. Genetic or internal factors are all related to leaf and include protoplasmic factors, chlorophyll contents, structure of leaf and accumulation of end products. Some of the important factors are discussed below:

1. **Concept of Cardinal Values:** The metabolic processes are affected by a number of factors of the environment. The rate of metabolic process is controlled by the magnitude of each factor. Sachs (1860) identified three critical values (minimum, optimum and maximum), the cardinal values or points of the magnitude of each factor. According to minimum cardinal value, the magnitudes of a factor below cannot proceed the metabolic process. Optimum value is the one at which the metabolic process proceeds at highest rate while in maximum, the magnitude of a factor beyond the process stops.
2. **Principle of Limiting Factors:** Liebig (1843) put forward the law of minimum according to which the rate of a process is limited by the pace (rapidity) of the slowest factor. Later on, it was modified by Blackman (1905) and formulated the "principle of limiting factors". It states that when a metabolic 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. This principle is also known as "Blackman's Law of Limiting Factors". As for example, if CO_2 is available in plenty but light is limiting because of cloudy weather, the rate of photosynthesis will be controlled by the light. Additionally, if both CO_2 and light are limiting, then the factor which is the most limiting of the two, will control the rate of photosynthesis.
3. **External Factors:** The environmental factors which can influence the rate of photosynthesis are carbon dioxide, light, temperature, water, oxygen, minerals, pollutants and inhibitors.
   - **Effect of Carbon dioxide:** It is one of the raw materials, whose concentration has profound effect on the rate of photosynthesis. The concentration of carbon dioxide in atmosphere is 0.03 to 0.04 per cent by volume. It has been experimentally

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proved that increase in carbon dioxide content up to one percent in air will rise the photosynthesis provided the intensity of light also increased.

- **Effect of Light:** Sun is the ultimate source of light. Solar radiation moves in the form of electromagnetic waves. Out of the total solar energy entering the earth, about 32% is used in photosynthesis and about 10 per cent is used in other metabolic activities.
- **Effect of Temperature**: The rate of photosynthesis increases significantly with an increase in temperature provided other factors such as CO_2 and light are not limiting. The temperature affects the velocity of enzyme-controlled reactions in the dark stage. With the low intensity of light, the reaction is limited by the small quantities of reduced coenzymes to reduce the effect of increase in temperature on overall rate of photosynthesis.
- **Effect of Water:** The amount of water required during photosynthesis is hardly one percent of the total amount of water absorbed by the plant, yet any change in the amount of water absorbed by C_4 plant has significant effect on the rate of photosynthesis. Water rarely seems to be a controlling factor as the chloroplasts contain plenty of water under normal conditions.
- **Effect of Oxygen**: Excess oxygen may inhibit the process. Increased supply of O_2 enhances the rate of respiration simultaneously decreasing the rate of photosynthesis. The concentration for oxygen in the atmosphere is about 21 per cent by volume and it rarely fluctuates. The phenomenon of decrease in photosynthesis with increase in oxygen concentration is called Warburg effect. [Reportedby German scientist Warburg (1920) in Chlorella algae]. This is because of competitive inhibition of RuBP-carboxylase at increased O_2 levels, i.e., O_2 competes for active sites of RuBP-carboxylase enzyme with CO_2. If the amount of oxygen in the atmosphere decreases, then photosynthesis will increase in C_3 cycle and no change occurs in C_4 cycle.
- **Effect of Minerals:** Presence of Mn++ and CI– is essential for smooth operation of light reactions (Photolysis of water/evolution of oxygen) Mg++, Cu++ and Fe++ ions are necessary for synthesis of chlorophyll.

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- **Effect of Pollutants and Inhibitors:** Peroxyacetyl nitrate (PAN) and ozone are formed as a result of reaction between oxides of nitrogen and hydrocarbons. PAN is known to inhibit Hill's reaction. Diquat and Paraquat (commonly called as Viologens) block the transfer of electrons between Q and PQ in Photosystem II. Monouron or CMU (Chlorophenyl dimethyl urea), diuron or DCMU (Dichlorophenyl dimethyl urea), bromocil and atrazine etc., are other inhibitors of photosynthesis which have the same mechanism of action as that of violates. At low light intensities potassium cyanide appears to have no inhibiting effect on photosynthesis.

4. **Internal Factors:** The internal factors that regulate the rate of photosynthesis are:

- **Protoplasmic factors:** Some unknown factor in protoplasm affects the dark reactions of photosynthesis. The decline in the rate of photosynthesis at temperature above 30°C or at strong light intensities in many plants suggests the enzyme nature of these unknown factor.
- **Chlorophyll content:** Chlorophyll is the key factor for photosynthesis. The amount of CO_2 absorbed by a gram of chlorophyll in an hour is called photosynthetic number or assimilation number which is usually constant for a plant species and hardly varies. The assimilation number of photochromatic variety was found to be higher than green leaves variety.
- **Accumulation of end products:** Deposition of food in the chloroplasts reduces the rate of photosynthesis.
- **Structure of leaves:** The amount of CO_2 that reaches the chloroplasts rely on structural features of the leaves like the size, position, behaviour of the stomata and the number of intercellular spaces. The features like thickness of cuticle, epidermis, presence of epidermal hairs, amount of mesophyll tissue, etc., affects the intensity and quality of light reaching the chloroplast.
- **CO_2 Compensation Point:** It is the value or point in light intensity and atmospheric CO_2 concentration when the rate of photosynthesis is just equivalent to the rate of respiration in the photosynthetic organs to prevent gaseous exchange. The value of light compensation point is 2.5 - 100 ft. candles for shade plants and 100-400 ft. candles for sun plants. The value of CO_2 compensation point is low in

C_4 plants (0-5 ppm), and high in C_3 plants (25-100 ppm). A plant cannot survive for long period of time at compensation point as net loss of organic matter takes place due to respiration of non-green organs and dark respiration.

Conclusion

Increasing the yield potential of the major food grain crops has contributed significantly to a rising food supply over the past 50 years, which has until recently more than kept pace with rising global demand. Whereas improved photosynthetic efficiency has played only a minor role in remarkable increase in productivity achieved in the last half century.

However, increases in yield potential rely on improved photosynthesis. Moreover, it is necessary to know the different traits which leads to increase in photosynthesis. Photosynthesis improvement is an approach which targets increase in yield potential. In addition to this, it is essential to minimize the yield gap and this can be achieved by improving water use efficiency (WUE), nitrogen use efficiency (NUE), and response to biotic and abiotic factors.

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