Science for Turfheads

PHOTOSYNTHESIS

Photosynthesis is the conversion of sunlight into chemical energy that drives the reactions that create carbohydrates used as the fuel for all plant growth processes.

C3 PHOTOSYNTHETIC PATHWAY (cool-season grasses)

Light

Sunlight is composed of a wide spectrum of energy, with wavelengths ranging from 200 to 1,800 nm. Plants use light wavelengths between 400 and 700nm for photosynthesis and growth, and this wavelength band is called photosynthetically active radiation, or PAR. PAR is measured using photosynthetic photon flux density (PPFD) in *u*mol m^{-2}s^{-1}. Light must be between certain minima and maxima PPFD for photosynthesis and photosynthetic light saturation has been reported as occurring between 500-1000 *u*mol m^{-2}s^{-1}.

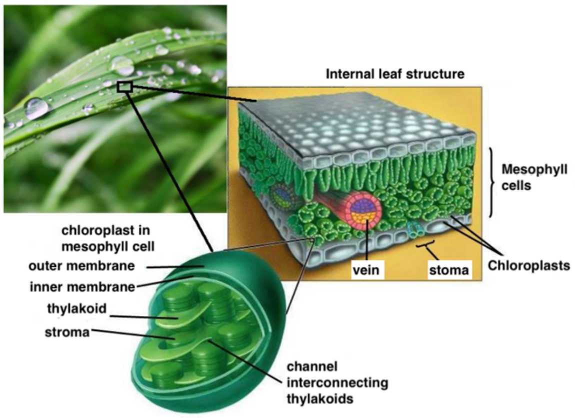

Fig 1. Location of structures involved in photosynthesis in turfgrass plants

There are two types of chlorophyll molecules: chlorophyll *a* and chlorophyll *b*. Chlorophyll *a* is the primary photosynthetic pigment and selectively absorbs light at wavelengths 410, 430 (blue light), and 660 nm (red light), and reflects green-yellow light. Chlorophyll *b* passes collected energy onto chlorophyll *a*, and absorbs light at 430, 455 and 640 nm. Blue light has a higher energy than red light, but this extra energy is lost during photosynthesis (Fig 2.).

Photosynthesis is the ultimate energy capture and assimilation process and takes place in chloroplasts, which are organelles located in plant leaves containing green chlorophyll molecules that absorb light (Fig 1.).

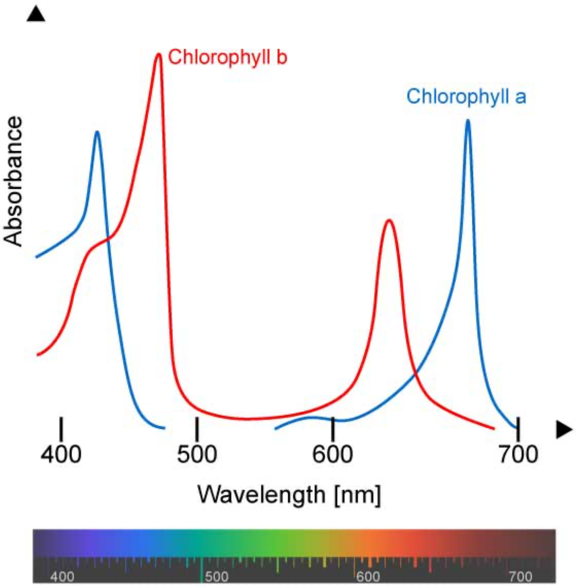

Fig 2. Wavelengths of light absorbed by chlorophyl *a* & *b.*

For turfgrass surfaces to achieve sustainability individual plants must be able to produce more energy from photosynthesis than is consumed for respiration. This is called the light compensation point, defined as the intensity at which photosynthesis and respiration reach equilibrium, have been reported to range from 3 to 24 *u*mol m^{-2}s^{-1} for cool season turfgrass species under a PPFD of 400 *u*mol m^{-2}s^{-1}. The minimum amount of light per day required to sustain acceptable turfgrass swards,

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called the Daily Light Integral (DLI) has been estimated to be between 2.2 and 11.1 mol m^{-2}d^{-1}. The optimum DLI is reported to be between 25-30 mol m^{-2}d^{-1}. Shade affected factors also have an impact on light compensation points, which can be light quality, temperature, relative humidity, and disease susceptibility.

C-3 Photosynthesis

In perennial ryegrass, optimum growth occurs in cool, temperate climates with average day temperatures of 20-25^{0}C, termed cool-season growth. Discovered in the 1950's by Melvin Calvin and his associates, cool-season plants photosynthesise using the reductive pentose phosphate cycle, or C-3 pathway. C-3 refers to the number of carbon atoms present in the first stable metabolite resulting from CO_2 assimilation, namely 3-phosphoglyceric acid (PGA).

A two-step process takes place in which:

i. Light Dependent reaction (light is essential): solar energy is converted to chemical energy;
ii. Light Independent reaction (takes place in the daytime but light is not required): the chemical energy in (i) is used to produce carbohydrates using carbon dioxide (CO_2) and water (H_2O) in a process called the Calvin Cycle, or Benson-Calvin Cycle (Fig 3.).

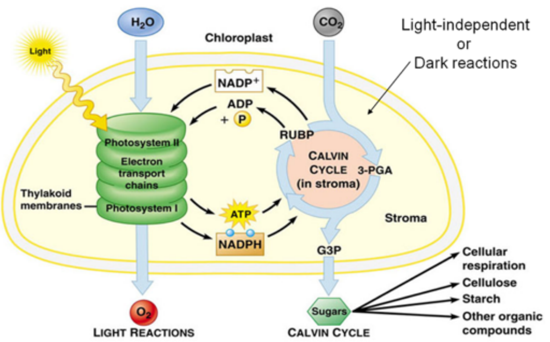

Fig 3. Summary of photosynthesis
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Solar energy absorption, or light dependent reactions, of photosynthetic active radiation (PAR) occurs in the antenna complexes that are located in or on the thylakoid membranes of the chloroplast (Fig. 1.). Thylakoid membranes are flattened disc-like structures stacked on top of each to form grana. A single thylakoid disc of about 0.5 um diameter may contain 10^5 chlorophyll and other pigments. Chlorophyll *a* is involved in splitting hydrogen and oxygen from water during photosynthesis. Several other pigments are present, including chlorophyll *b*, carotenes and xanthophylls, which pass energy from absorbed protons to chlorophyll *a*. A part of this energy is lost as heat and chlorophyll *a* fluorescence, which can be measured to assess photosynthetic activity and efficiency.

There are two structures that are responsible for the conversion of light to chemical energy, respectively named Photosystem I and II (PSI and PSII), and a light harvesting complex (LHCP) which can transfer energy (excitons) to the photosystems and from PSII to PSI by 'spill-over'. PSI is very receptive to light waves at the 700 nm wavelength. In comparison, PSII is very receptive to light wavelengths of around 680nm. The light reactions phase takes place in the thylakoid membranes of the chloroplast, and its purpose is to covert light energy to chemical energy (ATP and NADPH) with the help of the chlorophyll *a* pigment.

Illustrated in Fig 4, Photosystem II begins the process of photosynthesis when it receives photons from light (1). An electron from water molecules is removed breaking it down to oxygen and hydrogen (3). The excited electron (2) is 'walked' down an electron transport chain (4) and produces ATP as it returns to its rest state. The energy in ATP is contained in the bonds holding the molecule together. At this point, the electron is once again excited by Photosystem I to a much higher energy

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level (5). The excited electron then produces a NADPH molecule, a reducing molecule, (6) which is used by the Calvin cycle.

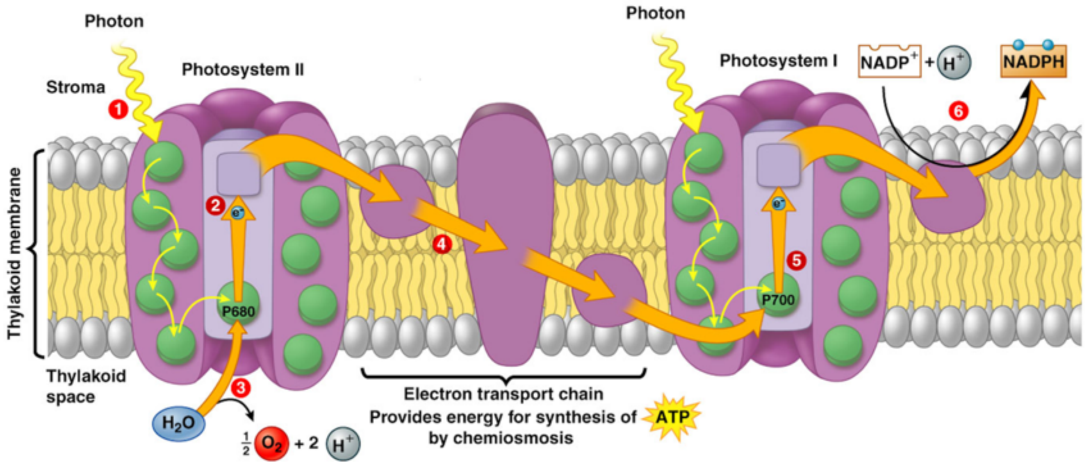

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Fig 4. Photosystems I & II, ending in the production of energy molecules ATP and NADPH
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The Calvin Cycle and Turfgrass Plant Growth

1. Light Reactions and the Calvin Cycle

Photosynthesis begins when chlorophyll in the chloroplast absorbs light energy. This energy drives the photolysis of water (H_2O), releasing oxygen (O_2) and generating ATP (adenosine triphosphate) and NADPH (nicotinamide adenine dinucleotide phosphate). These molecules serve as energy carriers and reducing agents, respectively.

The Calvin Cycle relies on ATP to provide the energy needed for carbon fixation and the subsequent biochemical transformations, and on NADPH for reducing power to convert 3-phosphoglycerate (3-PGA) into glyceraldehyde-3-phosphate (G3P), a carbohydrate precursor.

In healthy turfgrass, efficient light reactions ensure a constant supply of ATP and NADPH, allowing the Calvin Cycle to operate smoothly and support robust growth.

2. Carbon Fixation and Rubisco's Role

The Calvin Cycle comprises three main phases:

i. Carbon Fixation – CO_2 is fixed to a five-carbon sugar (RuBP) by the enzyme Rubisco (ribulose-1,5-bisphosphate carboxylase/oxygenase), forming two molecules of 3-PGA.
ii. Reduction – 3-PGA is reduced to G3P using ATP and NADPH.
iii. Regeneration – Some G3P is used to regenerate RuBP, enabling the cycle to continue.

Rubisco is a critical enzyme that enables all life on earth (no Rubisco no plant life no animals = no food) but is also inefficient by binding O_2 instead of CO_2, leading to photorespiration, a wasteful process that reduces photosynthetic output. This limitation is exacerbated under stress conditions.

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3. Environmental Stress and Calvin Cycle Impairment

Abiotic stresses such as drought, heat, salinity, and soil compaction have a direct impact on photosynthesis and the Calvin Cycle. These effects include closure of the stomata

a. Stomatal closure restricting the exit of O_2 molecules that damage and interrupt reactions in the plant, and limiting the ingress of CO_2 molecules reducing carbon fixation.
b. Disruption of chloroplast structure, impairing ATP and NADPH production leading to reduced energy for the Calvin Cycle.
c. Accumulation of reactive oxygen species (ROS), which oxidatively damage Rubisco and other enzymes.
d. Rubisco deactivation, particularly due to inhibition of Rubisco activase enzyme under heat and oxidative stress.

As a result, the Calvin Cycle slows down, leading to reduced sugar production, impaired turfgrass growth, poor recovery from damage, and increased susceptibility to disease.

4. Regulation of Rubisco Under Stress

Rubisco activity is regulated at both the transcriptional and post-translational level. Under stress, several factors inhibit its efficiency:

a. Rubisco activase (RCA), the enzyme that reactivates Rubisco, becomes less functional under heat stress.
b. ROS can chemically modify Rubisco's active site, reducing its ability to fix CO_2.
c. Hormonal changes (e.g., increased ABA) lead to stomatal closure and altered chloroplast metabolism.

Plants that maintain Rubisco function under stress typically show better growth and survival.

5. Broader Impacts on Turfgrass Physiology

The Calvin Cycle provides the carbon skeletons for many other metabolic processes, including:

a. Sucrose and starch biosynthesis, essential for energy storage and phloem transport.
b. Amino acid synthesis, feeding into protein metabolism.
c. Root exudate production, influencing rhizosphere microbial communities.
d. Growth regulators and secondary metabolites, which support adaptation to environmental stress.

Any factor that supports the Calvin Cycle will enhance turfgrass health, stress tolerance, and recovery from wear or damage. The effects of a quick and efficient process of photosynthesis in turfgrass leaves has a significant influence right through the plant, from leaf growth to the amount of root exudates and the population of microbes in the rhizosphere (the soil region influenced by roots).

Photosynthesis and Root Exudates

Photosynthesis Generates Carbon Compounds, i.e. turfgrass leaves produce carbohydrates (e.g., glucose, sucrose) through photosynthesis, which are translocated to the roots to support growth and metabolism. A portion of these carbohydrates is secreted as root exudates into the soil. These exudates include sugars, amino acids, organic acids, and other compounds that provide chemical signals, facilitate nutrient solubilization and uptake and modify the soil environment.

The amount and composition of exudates depend on photosynthetic efficiency and external factors such as light, temperature, and nutrient availability.

Root Exudates and Microbe Populations

Root exudates serve as a primary energy source for rhizosphere microbes, fostering microbial growth and activity. Different exudate compounds attract specific microbial populations, influencing community composition. Some microbes help improve plant nutrient uptake (e.g., nitrogen-fixing bacteria, phosphorus-solubilizing bacteria) and protect against pathogens, indirectly enhancing photosynthetic capacity and root exudation.

Photosynthesis and Microbial Populations

Healthy photosynthesis typically results in higher carbon allocation to the roots and more exudates, promoting microbial abundance. Factors that suppress photosynthesis (e.g., shading, drought, or nutrient deficiency) reduce carbohydrate supply to roots, leading to decreased exudation and microbial activity.

Practical Implications for Turfgrass Management

Practices that improve photosynthesis, such as adequate irrigation, fertilization, and light availability, indirectly boost root exudates and microbial health. Biostimulant and micronutrient products can enhance photosynthetic efficiency and stimulate beneficial rhizosphere interactions.

Fostering strong photosynthetic activity promotes a microbially vibrant rhizosphere, ultimately improving turfgrass health and soil ecosystem resilience.

6. The Role of 5-ALA in Supporting the Light-Dependent Reactions and Production of ATP and NADPH

5-Aminolevulinic acid (5-ALA) plays a foundational role in supporting and enhancing the performance of the light-dependent reactions in the following ways:

i. **Precursor to Chlorophyll Biosynthesis:**
5-ALA enhances chlorophyll biosynthesis, leading to increased chlorophyll content and improved light absorption.

ii. **Enhancement of Light-Harvesting Complexes:**
Higher chlorophyll content strengthens the light-harvesting complexes, improving energy transfer to photosystems and boosting quantum efficiency.

iii. **Support for Photosynthetic Electron Transport:**
5-ALA supports thylakoid stability and the synthesis of heme-containing electron carriers such as cytochromes, facilitating efficient electron flow.

iv. **Increased ATP and NADPH Production:**
Efficient electron transport and proton gradient formation lead to enhanced production of ATP and NADPH via photophosphorylation.

v. **Maintenance Under Stress Conditions:**
5-ALA increases antioxidant enzyme activity and stabilises photosynthetic proteins under stress, ensuring continued light energy conversion.

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In summary, 5-ALA enhances the structural and biochemical foundations of the light-dependent reactions. Through increased chlorophyll biosynthesis, stabilisation of electron transport chains, and protection against oxidative stress, it ensures a robust supply of ATP and NADPH. These molecules are the energetic and reductive drivers of the Calvin Cycle, linking 5-ALA's upstream action in light capture to downstream gains in carbon assimilation and healthy turfgrass development.

7. The Role of 5-ALA in Supporting the Calvin Cycle and Turfgrass Growth

5-Aminolevulinic acid (5-ALA) is a natural precursor to chlorophyll and heme synthesis, both of which are central to photosynthetic function. While not directly a component of the Calvin Cycle, it indirectly supports the cycle through several mechanisms:

1. Enhancement of chlorophyll content: Increasing the plant's ability to capture light energy.
2. Improved production of ATP and NADPH: Feeding into the Calvin Cycle's energetic demands.
3. Upregulation of Rubisco and Rubisco activase gene expression: Supporting sustained carbon fixation under drought or salinity.
4. Stimulation of antioxidant enzyme systems (e.g., SOD, CAT, POD): Protecting photosynthetic machinery from oxidative damage.
5. Improved stomatal function: Maintaining CO_2 intake during moderate stress.

Together, these effects result in:

- Sustained carbon assimilation under stress.
- Increased carbohydrate production and root exudation.
- Healthier microbial populations in the rhizosphere.
- Enhanced shoot density, colour retention, and recovery in turfgrass.

As can be seen from the above, PAR+ (5-ALA) is thoroughly researched treatment that only has beneficial effects on turfgrass plant health and the preparation and presentation of high quality turfgrass surfaces.

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