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Bright Fields, Big Yields: The Science Behind Solar-Driven Crops

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Solar radiation is the driving force behind life on Earth, fueling photosynthesis and shaping the productivity of crops. This article explores how sunlight journeys through the atmosphere, interacts with plant canopies, and is converted into biomass through intricate biophysical processes. It also highlights how factors like canopy structure, weather, and location affect light interception and plant responses. Finally, it touches on modern tools and methods used to measure solar radiation on farms, linking science to practical farming outcomes and harnessing renewable energy more effectively.

Keywords: Biomass, Canopy, Photosynthesis, Solar energy

Introduction

Solar radiation is the set of electromagnetic radiation emitted by the Sun. The Sun behaves almost like a black body which emits energy according to Planck's law at a temperature of 6000 K. The solar radiation ranges goes from infrared to ultraviolet. Not all the radiation reaches Earth's surface, because the ultraviolet wavelengths, that are the shorter wavelengths, are absorbed by gases in the atmosphere, primarily by ozone. The atmosphere acts as a filter to the bands of solar spectrum, and at its different layers as solar radiation passes through it to the Earth's surface, so that only a fraction of it reaches the surface. The atmosphere absorbs part of the radiation reflects and scatters the rest some directly back to space, and some to the Earth, and then it is irradiated. All of this produce a thermal balance, resulting in a radiant equilibrium cycle by NASA CERES Team. (2022). *Earth's Energy Budget Diagram* as figure.1

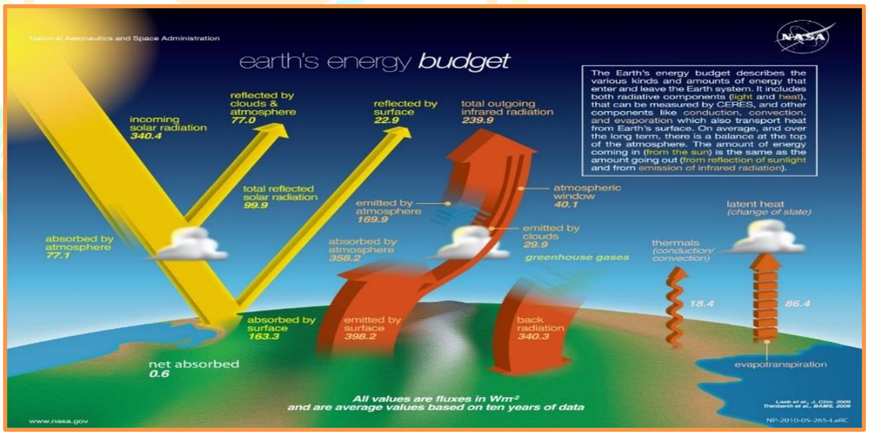

Fig.1 Earth's energy budget

Earth's Energy Budget: Earth's energy budget describes the balance between the radiant energy that reaches Earth from the sun and the energy that flows from Earth back out to space. Energy from the sun is mostly in the visible portion of the electromagnetic spectrum. About 30 percent of the sun's incoming energy is reflected back to space by clouds, atmospheric molecules, tiny suspended particles called aerosols, and the Earth's land, snow and ice surfaces. The Earth system also emits thermal radiant energy to space mainly in the infrared part of the electromagnetic spectrum. The intensity of thermal emission from a surface depends upon its temperature.

Types of solar radiation

Depending on the type of radiation, it is known that the 324 Wm^{-2} reaching the Earth in the upper atmosphere (1400 Wm^{-2} is the solar constant), 236 Wm^{-2} are reissued into space infrared radiation, 86 Wm^{-2} are reflected by the clouds and 20 Wm^{-2} are reflected by the ground as short-wave radiation. But part of the re-emitted energy is absorbed by the atmosphere and returned to the earth surface, causing the "greenhouse effect".

The average energy that reaches the outside edge of the atmosphere from the sun is a fixed amount, called solar constant. The energy contains between the 200 and 4000 nm wavelengths and it is divided into ultraviolet radiation, visible light and infrared radiation.

Ultraviolet radiation: Consists of the shorter wavelengths band (360 nm), it has a lot of energy and interacts with the molecular bonds. These waves are absorbed by the upper atmosphere, especially by the ozone layer.

Visible Light: This radiation band corresponds to the visible area with wavelengths between 360 nm (violet) and 760 nm (red), it has a great influence on living beings.

Infrared radiation: Consists of wavelengths between 760 and 4000 nm, it corresponds to the longer wavelengths and it has little energy associated with it. Its absorption increases molecular agitation, causing the increase of temperature.

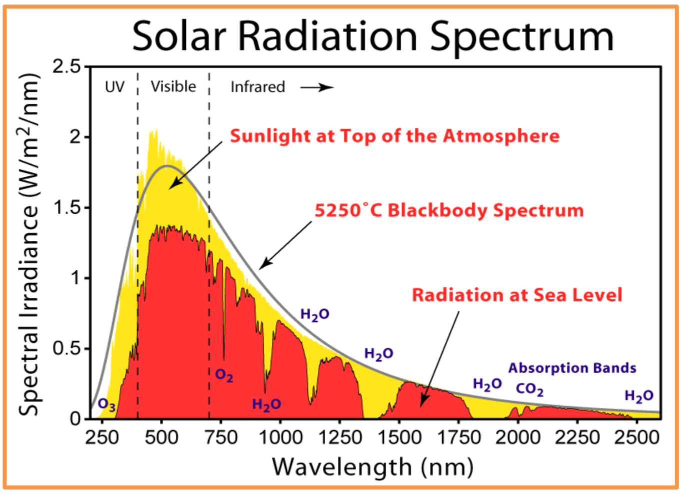

Fig. 2. Spectrum of solar radiation above the atmosphere and sea level prepared by Robert A. Rohde as part of the Global Warming Art project

Solar radiation on the earth can be classified as

Direct radiation: This radiation comes directly from the sun without any change in its direction. This type of radiation is characterized by projecting defined shadow onto the objects that intersect.

Diffuse radiation: This radiation comes from all over the atmosphere as a result of reflection and scattering by clouds, particles in the atmosphere, dust, mountains, trees, buildings, the ground itself, and so on.

Global radiation: Is the total radiation. It is the sum of the two radiations above. On a clear day with a clear sky, the direct radiation is predominant above the diffuse radiation.

Reflected radiation: Reflected Radiation Reflected radiation describes sunlight that has been reflected off of non-atmospheric things such as the ground. Asphalt reflects about 4% of the light that strikes it and a lawn about 25%.

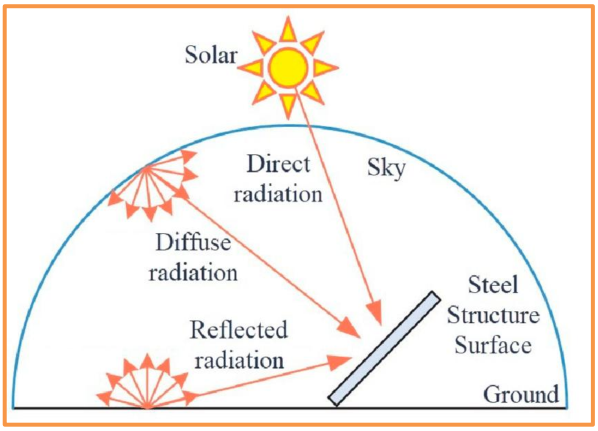

Fig. 3 Components of Solar radiation (Liou, K. N., 2002)

Factors influencing solar radiation input at the crop canopy level

Solar Irradiance: This is the total amount of solar radiation received per unit area at a particular location and time. It is influenced by factors such as time of day, latitude, season, and weather conditions. Solar irradiance can vary throughout the day and between different geographic locations.

Crop Canopy Architecture: The structure of the crop canopy, including the arrangement and density of leaves, affects how much solar radiation reaches the plants. Canopy architecture varies among different crops and can impact the efficiency of light interception.

Leaf Area Index (LAI): LAI is a measure of the amount of leaf surface area per unit ground area. A higher LAI indicates a denser canopy with more potential for light interception. LAI is a key parameter for estimating the interception and utilization of solar radiation by crops.

Cloud Cover: Clouds can significantly reduce the amount of solar radiation reaching the crop canopy. Overcast conditions reduce direct sunlight and diffuse radiation, affecting the availability of light for photosynthesis.

Shading: The presence of structures, neighboring crops, or topography that cast shadows on the crop canopy can also influence the amount of solar radiation received by plants.

Latitude and Seasonal Changes: The angle and duration of sunlight vary with latitude and change seasonally. This affects the intensity and duration of solar radiation received by crops.

Interation of solar radiation with crop canopy

Absorption, Reflection, and Transmission

<u>Absorption:</u> When solar radiation reaches the crop canopy, some of it is absorbed by the leaves and other plant parts. This absorbed energy is crucial for the process of photosynthesis, where plants convert light energy into chemical energy.

<u>Reflection:</u> Some solar radiation is reflected by the crop canopy. The amount of reflection depends on various factors, including the type of crop, leaf structure, and the angle of incidence of sunlight.

<u>Transmission:</u> A portion of the incoming radiation passes through the crop canopy without being absorbed or reflected. This transmitted radiation can reach lower leaves and the soil surface.

Photosynthesis: The absorbed solar radiation is used by chlorophyll in plant cells to drive the process of photosynthesis. During photosynthesis, carbon dioxide and water are converted into glucose and oxygen in the presence of sunlight.

Canopy Architecture: The structure of the crop canopy, including leaf orientation, arrangement, and density, influences how solar radiation is distributed within the canopy. Different crops have varying canopy architectures that affect light penetration and utilization.

Light Interception and Distribution: The ability of the crop canopy to intercept and distribute light is crucial for maximizing photosynthetic efficiency. Canopy architecture, leaf area index (LAI), and canopy closure all play roles in determining how effectively light is distributed within the canopy.

Light Quality: The spectral composition of solar radiation (different colors of light) also affects plant growth. Plants have specific pigments that absorb light in certain wavelength ranges, influencing processes like photomorphogenesis and photoperiodism.

Stress Responses: Excessive or inadequate solar radiation can induce stress in plants. High-intensity sunlight can lead to heat stress, while insufficient light can limit photosynthetic activity. Plants have developed mechanisms to cope with these stress conditions.

Environmental Factors: The environmental factors such as cloud cover, atmospheric conditions, and time of day, also influence the amount and quality of solar radiation reaching the crop canopy.

Radiation Use Efficiency

Radiation use efficiency (RUE) can be traced back to Wilson (1967b) as the relationship between the accumulation of biomass relative to the light intercepted by the crop. Loomis and Amthor (1999) stated that RUE would be a useful parameter to relate canopy photosynthesis to crop yield. The RUE is an important quantifier of crop production in relation to photosynthesis, as it combines both the amount of solar radiation captured by the crop and the efficiency of the crop to produce dry matter, assuming other factors are not limiting. Measurements of RUE determined for a range of crops and different management systems involve the collection of dry biomass, grain yield or carbon assimilated, and the accumulation of intercepted PAR by the canopy over the life cycle of the crop.

Mathematically, RUE is often calculated using the following formula:

$$RUE=PAR\ /\ NPP$$

Where:

RUE is the radiation use efficiency,

NPP is the net primary productivity (the amount of energy captured by plants through photosynthesis minus the amount used in respiration),

PAR is the photosynthetically active radiation, which represents the portion of the solar radiation spectrum that plants use for photosynthesis.

The unit of RUE is typically expressed as grams of biomass per megajoule of absorbed solar radiation (g MJ^{-1})

The Radiation use efficiency of C_3 and C_4 plants given in the table:

Crop	Radiation use efficiency	References
C_4 plants	4.0–5.8 g MJ^{-1}	Loomis and Amthor (1999)
C_3 plants	1.5–2.0 g MJ^{-1}	Loomis and Amthor (1999)

Solar Radiation Output

Long wave radiation: The radiation emitted by plants is known as terrestrial radiation or longwave radiation. This process is a natural consequence of the fact that all objects with a temperature above absolute zero (-273.15°C or -459.67°F) emit thermal radiation.

The Stefan-Boltzmann Law describes the relationship between the temperature of an object and the amount of thermal radiation it emits. The equation is:

$$P=\sigma \cdot A \cdot \varepsilon \cdot T^4$$

Where:

P is the power radiated,

σ is the Stefan-Boltzmann constant (5.67×10^{-8} W m^{-2} K^{-4}),

A is the surface area of the object,

ε is the emissivity (a dimensionless factor between 0 and 1),

T is the temperature in kelvins.

Measurement techniques in Solar Radiation

Pyranometers: Pyranometers are commonly used to measure global solar radiation in agricultural fields. Placing pyranometers at different locations within a field helps assess variations in solar radiation levels, which can influence crop growth.

Net Radiometers: Net radiometers measure both incoming and outgoing radiation. They can be used to calculate the net radiation balance, providing insights into how much energy is available for crop processes such as photosynthesis.

PAR (Photosynthetically Active Radiation) Sensors: PAR sensors specifically measure the solar radiation within the spectral range that plants use for photosynthesis (400-700 nm). Monitoring PAR helps understand the energy available for plant growth and development.

Sunshine Duration Recorders: These instruments record the duration of sunshine throughout the day. This information is useful for understanding the availability of sunlight, which influences crop photosynthesis and growth.

Solarimeters with Crop Canopy Sensors: Solarimeters, when equipped with sensors within or just above the crop canopy, can provide more accurate measurements of the radiation reaching the actual plant surfaces. This is especially important for crops with dense canopies.

Remote Sensing and Satellite Imagery: Remote sensing technologies, including satellite imagery and aerial surveys, provide a broader perspective on solar radiation across large agricultural areas. These data can help farmers and researchers monitor crop health, assess potential yield, and make informed decisions.

Weather Stations: Weather stations equipped with solar radiation sensors provide real-time data on solar radiation along with other meteorological parameters. This integrated information helps in understanding the relationship between solar radiation and crop performance.

Solar-Powered Weather Stations: Utilizing solar-powered weather stations ensures continuous monitoring of solar radiation levels in remote agricultural areas. These stations often include sensors for various meteorological parameters.

Light Interception Studies: Field studies involving the measurement of light interception by crop canopies provide insights into how efficiently crops are utilizing solar radiation for photosynthesis. This is particularly relevant for optimizing planting density and canopy management practices.

Radiation Balance Modeling: Mathematical models that simulate the radiation balance in agricultural systems can help predict solar radiation under different conditions. These models take into account factors such as latitude, time of year, and local topography to estimate solar radiation levels.

Conclusion

Sunlight is more than just a source of warmth, it's a lifeline for crops. From the moment solar rays touch the atmosphere to their final use in photosynthesis, every stage of light interaction affects plant health and yield. By learning how solar radiation works, how different light types impact leaves, and how to measure this invisible force using modern tools, we gain a powerful edge in agriculture. Whether it's adjusting planting density, choosing crop varieties, or monitoring field conditions, understanding solar radiation can help us make smarter, more sustainable decisions in farming. Harnessing the power of the sun is not just a natural process, it's a strategy for the future of food.

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