Role of Light in Agriculture

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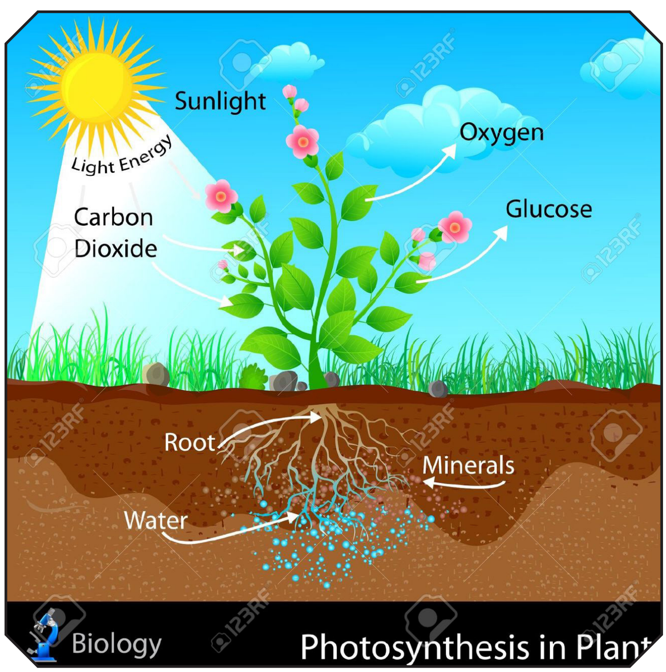
Light provided by the sun, called solar radiation, is the principal source of energy for all life on earth. Plants as the primary producers absorb solar radiation energy via chlorophyll in leaves and store part of it in the chemical bonds of glucose during the process of photosynthesis. Glucose acts as the 'raw material' to synthesize a wide range of biochemical substances which make up plant biomass. Agriculture involves the cultivation of a selected range of plant species for obtaining an economically-important product, which can be human food or beverage, animal feed, industrial products (e.g. cotton fibre, rubber etc.), bioenergy or stimulants (e.g. tobacco). As all products of Agriculture are synthesized within plants using glucose as the raw material, light energy captured during photosynthesis directly influences the agricultural productivity (i.e. amount of product per unit land area).



Many ancient civilizations worshipped the sun in their religious and cultural rituals as they realized its critical role in providing light to sustain their lives. For example, the Sinhala and Hindu New Year festival, which coincides with a period in which the sun is directly over Sri Lanka and which falls after collecting the harvest of agricultural crops during the major cultivation season, can be considered as an expression of peoples' gratitude to the sun, and rejoice in the sunny period that it provides. Interestingly, festivities during the Christmas which includes extensive lighting of towns, streets and homes, can also be regarded as peoples' appreciation of the importance of light as Christmas falls during the period when the solar radiation levels are lowest in the temperate zone of the Northern hemisphere.

As in the ancient past, light is no less important during the present times, especially in agriculture, which has to provide food for an increasing global population that is expected to exceed 10 billion before the end of this century. Different properties of light play different roles in Agriculture. Therefore, it is important to first understand the different characteristics of light.

Different characteristics of light: Wave-length distribution

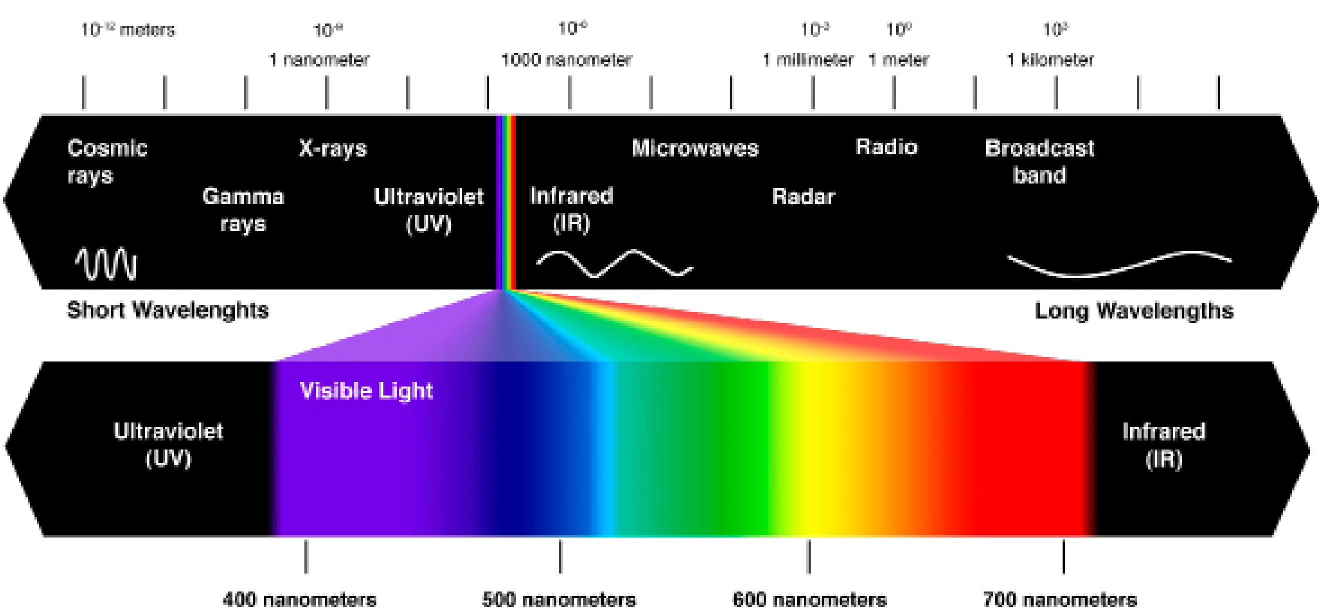
Light is a mixture of wavelengths ranging from 300 to 100,000 nm. Different 'types of light' can be identified based on its wavelength as: Ultra-violet (UV) radiation (300 – 400 nm); Photosynthetically-active radiation (PAR) (400 – 700 nm) and Infra-red (IR) (700 – 100,000 nm). Light within the PAR range, which contains ca. 46-47% of the total energy of solar radiation, is the most important, as only these wavelengths can provide energy for photosynthesis and contribute directly to the productivity of agricultural crops. Light in the IR range, which contains ca. 45% of total solar radiation energy, also carries out essential functions in plants by providing energy for transpiration and maintenance of plant tissue temperatures within a range favourable for cellular physiological processes.

Energy content in light

The energy in light is responsible for some of its most important functions in plants. As energy for photosynthesis in agricultural crops is provided by solar radiation, crops growing in sunny environments give higher yields than those in shaded or cloudy environments, when their growth is not limited by water availability. For example, in the major irrigation schemes in the dry zone of Sri Lanka, rice yields are higher in yala (May – August) than in maha (November – February), primarily because of the higher incident radiation levels and lower cloudiness during yala. Similarly, when adequate water and nutrients are provided, a longer duration crop variety (e.g. a 4-month rice variety) produces a higher yield than a shorter duration variety (e.g. a 3-month rice variety). This is because the 4-month variety captures a greater amount of light energy and thereby produces a greater biomass and yield through photosynthesis than the 3-month variety.

The energy content of solar radiation (i.e. light intensity), also controls the vital plant process of transpiration by providing the latent heat energy for conversion of liquid water in leaf cells to water vapour, which then escapes to the external environment through the stomata. Transpiration provides a mechanism to remove the enormous amount of energy that the plant leaves are forced to absorb when they intercept solar radiation to obtain energy for photosynthesis. As such transpiration plays a vital role in thermal regulation enabling plants to maintain their tissue temperatures within a favourable range. During dry periods when plants have to restrict transpiration by partially closing the stomata, leaf temperatures increase because of the accumulation of radiation energy on leaf tissue.

While the energy of light is essential for the vital process of photosynthesis, the high energy levels of solar radiation can be a problem to plants during certain times. For example, during dry periods, photosynthesis is restricted because partial stomatal closure reduces carbon dioxide absorption. However, light absorption cannot be restricted as the leaves are exposed to light during the daytime. In such situations, the excess light energy that accumulates in leaf tissue damages the chloroplasts, thus causing a drastic reduction in photosynthesis. This phenomenon is called photoinhibition. Therefore, in order to produce high yields, crops need mechanisms to prevent photoinhibition. These are called photoprotection

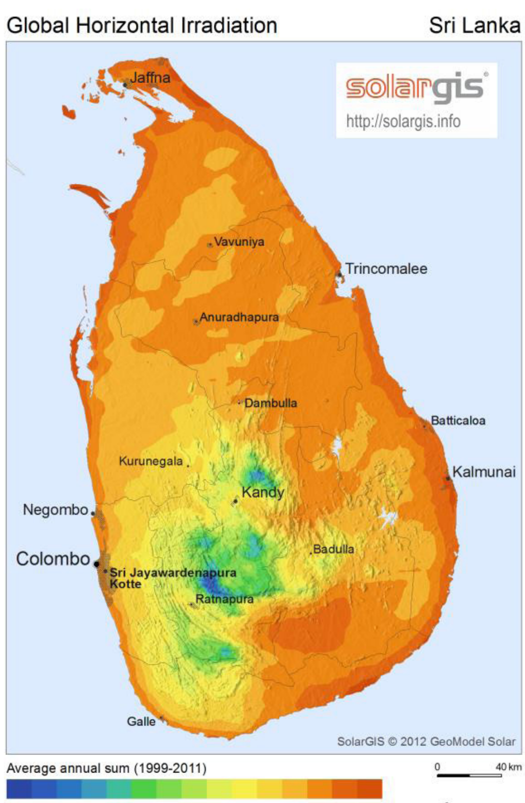


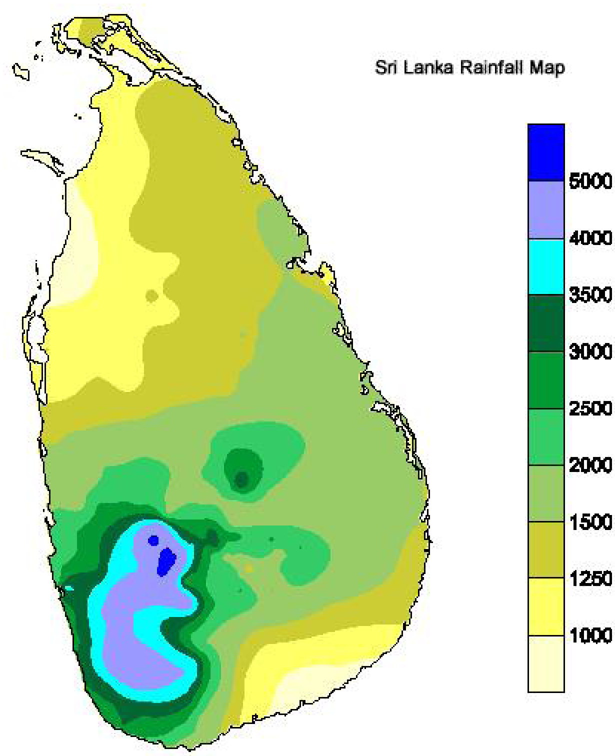
mechanisms. Xanthophyll, a pigment present in most plant leaves, and certain enzyme systems play vital roles in photoprotection. Interestingly, certain crops lack mechanisms of photoprotection and are thus highly vulnerable to photoinhibition. In order to obtain high yields, such crops have to be grown under shade. Our principal export crop, tea (Camellia sinensis) is an example of such a crop.

Photoperiod and photoperiodism

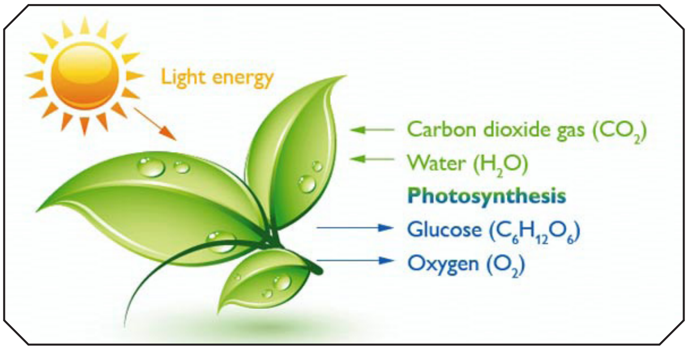
Photoperiod is the length of light period during a day. It is the time period between sunrise and sunset and is also termed the daylength. It is another characteristic of light, which plays a vital role in agriculture. In the tropical climatic zone, which is the area demarcated by latitudes of 23 ½° North (Tropic of Capricorn) and 23 ½° South (Tropic of Cancer), the photoperiod is around 12 hours and it does not vary substantially at different times of the year. However, in the temperate climatic zone, which is the area north and south of the tropical zone, the photoperiod fluctuates substantially within the year. Here, photoperiod can be as long as 18 hours during certain times of the year (summer) or as short as 5 hours during certain other times (winter). This variation in photoperiod has a profound influence on agriculture in the temperate zone as crops can be grown in the field only during periods of longer photoperiod. Crops cannot be grown during the winter because the shorter photoperiods do not provide enough radiation energy to support photosynthesis and crop growth. In contrast, crops can be grown throughout the year in the tropical zone, provided there is enough water, as 12 hours of photoperiod is sufficient to provide light energy for photosynthesis.

In addition to its role in determining the periods in which crops can be grown, photoperiod has a profound influence on flowering, which is essential for producing an economic yield in a large majority of agricultural crops. In most crop varieties, the timing of flower initiation is controlled by the photoperiod experienced during the vegetative phase (i.e. the period from germination to the initiation of the first flower). This phenomenon is called *photoperiodism* and crop varieties that show photoperiodism are called *photoperiod-sensitive* varieties. Most crop varieties that are adapted to grow in the tropical zone induce flowering when exposed to shorter photoperiods (usually shorter than 12 hours). A good example is





Maps showing the variation of annual solar radiation intensity (left) and annual rainfall in mm (right) in Sri Lanka



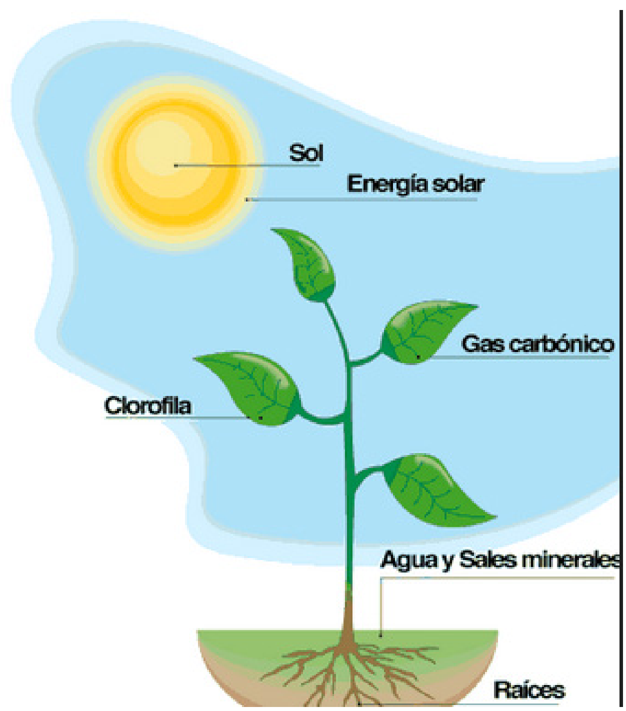
the traditional rice varieties in Sri Lanka, most of which produce panicles only during the *maha* season when the photoperiods are less than 12 hours. Such varieties are called *short-day plants*. In contrast, most crop varieties that are grown in the temperate zone induce flowering only when they experience longer photoperiods (usually longer than 12 hours) during the summer (long-day plants). Here, photoperiodism has evolved as a mechanism to prevent flowering during the shorter photoperiods of the winter when the conditions are extremely unfavourable for producing a high yield in a temperate crop. Similarly, evolution has determined that tropical crops are short-day plants as having a long-day response would make it impossible for them to flower during the shorter photoperiods of the tropical zone. Interestingly, photoperiod sensitivity prevents flower initiation of deep-water rice varieties grown in flood-prone countries such as Bangladesh during the flooding that occurs during periods of longer photoperiods in June-August. Flowering is initiated during the shorter photoperiods experienced during the subsequent period when the flood waters have receded.

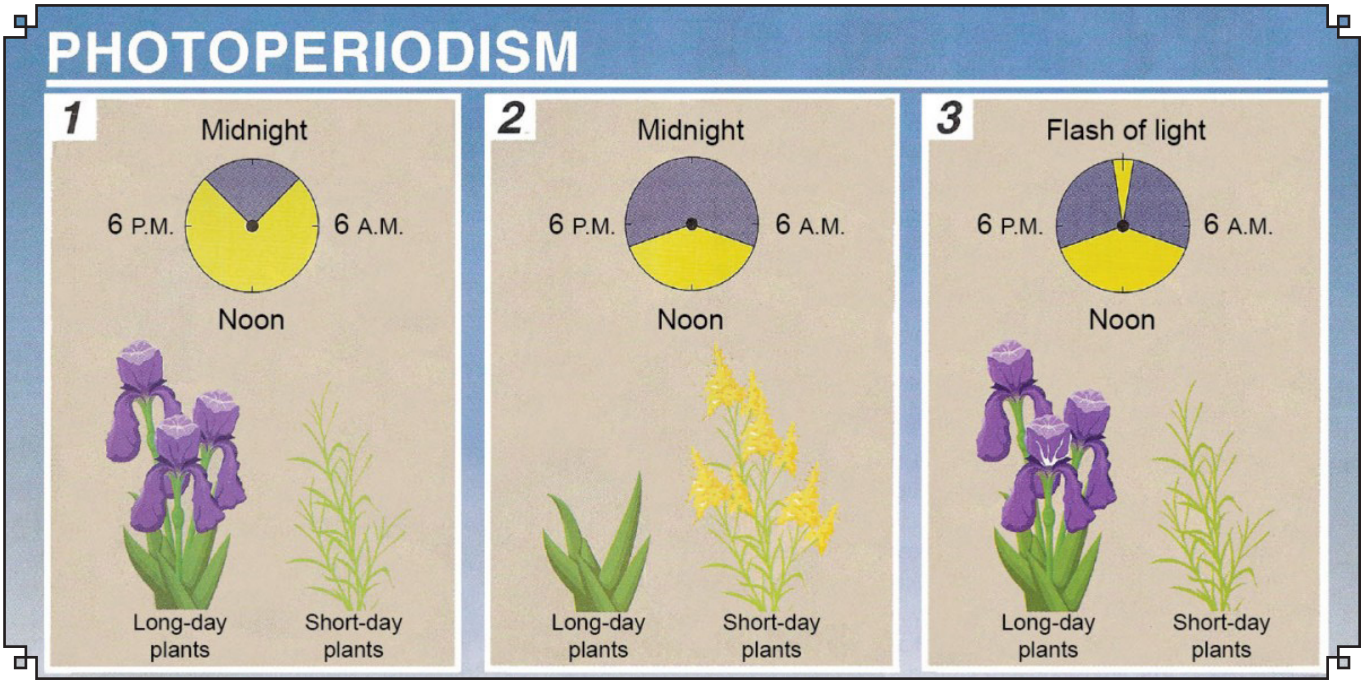
Despite its evolutionary significance in ensuring survival of the crop by inducing flowers during the most favourable periods, photoperiodism is regarded as a hindrance in modern agriculture. This is because photoperiod-sensitive crop varieties can be grown only during certain times of the year which fits-in with their specific photoperiod requirement. Therefore, most modern high-yielding varieties of the major crops have been bred to be photoperiod-insensitive (also called *day-neutral*). In these varieties, flowering is not sensitive to variations in photoperiod, thus enabling them to be grown at any time during the year, if other resources such as water are available and environmental conditions such as temperature are favourable.

Detailed experiments on photoperiodism have shown that it is controlled by *Phytochrome*, a pigment present in the leaves. These experiments have also shown that it is really the length of the night period, rather than the length of the daylight period, that controls the photoperiodic response. Therefore, short-day plants require night periods longer than 12 hours for flower induction while the long-day plants require shorter night periods for flowering.

Role of photoperiod and solar radiation intensity in determining agricultural productivity in the tropical and temperate zones

Crops grown in the temperate zone produce substantially higher yields in comparison to crops in the tropical zone. For example, rice crops in temperate climates such as Japan, Korea and China produce grain yields up to 15 tons per hectare while yields of rice crops in tropical climates (e.g. Sri Lanka, India, Thailand, The Philippines etc.) do not exceed 8 - 10 tons per hectare even when grown with adequate water, nutrients and protection from pests and diseases. This yield superiority of temperate crops is brought about by the longer photoperiods during the growing season (spring and summer) of the temperate zone, which enable greater photosynthesis and biomass production in comparison to the relatively shorter photoperiods in the tropical zone.





Interestingly, daily total solar radiation levels during the growing seasons are approximately similar in the tropical and temperate zones. However, in the tropical zone, the daily total energy of solar radiation is distributed over a shorter photoperiod with high radiation intensities during the middle part of the day. Photosynthesis of crops having the C3 pathway reaches its maximum rate at irradiance levels which are about 50% of maximum radiation intensity during the mid-day in a tropical climate. Therefore, a significant amount of light energy is wasted during the middle period of the day in a tropical climate because the radiation intensity is higher than the maximum intensity that is required to achieve maximum photosynthesis. This is called *light saturation*. In contrast, in the temperate zone, the daily total energy of solar radiation is distributed over a longer photoperiod, thus avoiding high radiation intensities during the middle hours of the day. This minimizes the wastage of light energy through light saturation, and ensures that a high proportion of solar radiation energy is used for photosynthesis, thus enabling achievement of the substantially higher crop yields of the temperate crops.

Variation of light intensities received in different parts of Sri Lanka

The examples described above highlight the importance of properly harnessing the energy of solar radiation in agriculture to achieve high yields. Thus, it is important to know the levels of light energy received in different regions of Sri Lanka.

The solar radiation map of Sri Lanka shows that the radiation intensities are highest in the dry zone, especially in the north-western, northern and eastern coastal belts. The radiation levels are lowest in the central highlands while they are generally lower in the wet zone in comparison to the dry zone. Interestingly, comparison of the solar radiation and rainfall maps of Sri Lanka show that solar radiation intensities are lower in regions of higher rainfall (e.g. wet zone). In contrast, radiation intensities are higher in regions of low rainfall. This creates a dilemma and a challenge for Sri Lankan agriculture as both solar radiation and rainfall are essential resources for increasing agricultural production. Accordingly, a proper balance between these two resources has to be achieved to maximize agricultural production and productivity in Sri Lanka.

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