UNIT II

ENVIRONMENT CONTROL SYSTEMS

Artificial light systems, management of crop growth in greenhouses, simulation of CO2 consumption in greenhouses, on-line measurement of plant growth in the greenhouse, models of plant production and expert systems in horticulture.

Introduction:

1. **Plants and light signaling**

   Energy is transported through the air by electromagnetic waves. Microwaves, radio or television waves, X-rays, ultraviolet rays or visible light are examples of electromagnetic waves, which are characterized by having different frequencies and wavelengths. The electromagnetic spectrum represents different frequencies and wavelengths that are known under different names (microwave, radio waves, visible light, etc.).

   Electromagnetic radiation has a dual nature; radiation propagates as waves, but they exchange energy as particles (photons). It was Albert Einstein who proposed in 1905 for the first time that light has both particle and wave nature.

   A beam of light includes a set of particles, called photons. Photons corresponding to longer wavelengths (lower frequencies) carry less energy than photons from short wavelength areas.

   Human eye captures visible light between 400 and 700 nanometer (nm) wavelength area, which corresponds approximately to the region of the spectrum that plants use for photosynthesis. Light between 400 and 700 nm is therefore referred to as PAR; photosynthetically active radiation. Sunlight has a continuous spectrum within and beyond the visible wavelengths.

   Human eye transforms different wavelengths into colors in human brain. Short wavelengths close to 400 nm are perceived as blue color and longer wavelengths in the 600nm area are seen as red light. Human eye has the most sensitive region in the yellow- green wavelength area.

2. **Plant pigments, photoreceptors, and photosynthesis**

   Plants absorb the light spectrum in an almost similar range as the human eye, but unlike humans, they absorb best red and blue light.

   One of the main molecules enabling plants to absorb light and use its energy to transform water and carbon dioxide into oxygen and complex organic molecules is called chlorophyll and the process is known as photosynthesis. Chlorophyll is a plant pigment found in the intracellular chloroplasts, they are green in color and are in fact responsible of the green coloration of leaves and stems. There are two main types of chlorophyll found in the higher plants; chlorophyll a and b, which differ from each other slightly by their light absorption curves. The small difference allows them to capture different wavelengths, catching more of the sunlight spectrum. Chlorophylls absorb mainly red and blue light and reflect green wavelengths, which is why we see plants green.

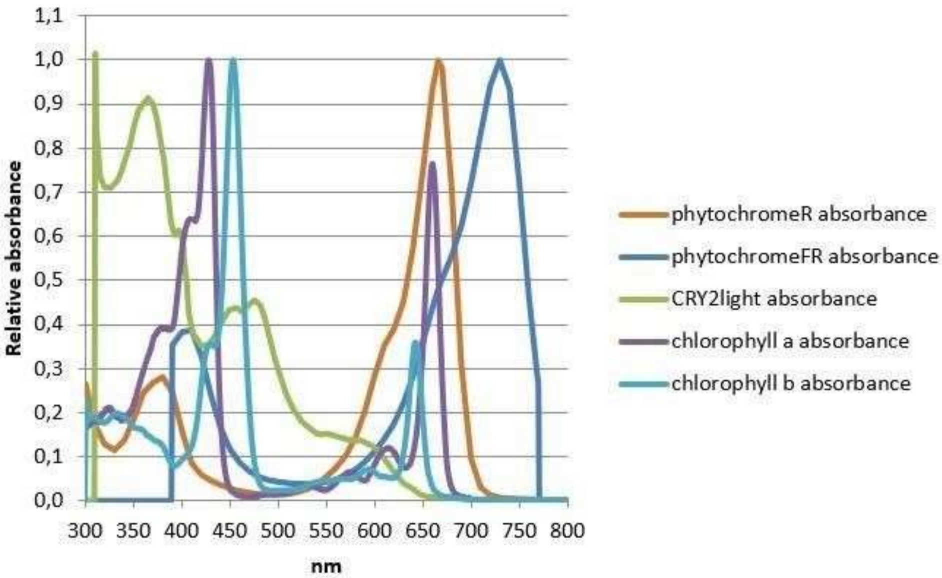
However, chlorophyll is not the only plant pigment; the so-called accessory pigments (carotenoids, xanthophylls, etc.) and phenolic substances (flavonoids, anthocyanins, flavones and flavonoids) capture wavelengths other than only red and blue. The accessory pigments are yellow, red and violet in color. These colors attract insects and birds, as well as help protect tissues from environmental stress, such as high light irradiation.

There are also other particles absorbing light; photoreceptors. The main photoreceptor groups are phytochromes, phototropins and cryptochromes. In addition, there is a specific photoreceptor for ultraviolet light; the UVR8. All photoreceptors capture light in different wavelength areas and are responsible of different responses in plants as described below:

- Phototropins affect the location of the chloroplasts and the stomatal opening. They absorb blue light.
- Cryptochromes capture external stimuli related to light and control the internal clock of plants. In addition, they are related to morphological responses, such as inhibition of stem elongation, expansion of cotyledons, production of anthocyanins and photoperiodic flowering. Cryptochromes absorb UVA (ultraviolet), blue, and green wavelengths.
- Phytochromes are responsible for flowering induction and seed development. Phytochromes regulate stem elongation, leaf expansion, and "shade avoidance syndrome". The responses regulated by phytochromes are mediated by the ratio of surrounding red and far-red light, which affects the photostationary state of the phytochrome molecule.

These responses are mediated by wavelengths within and beyond the PAR area, including also UV and far-red irradiation. The absorption curves for phytochromes, cryptochrome and chlorophylls are presented in Figure 1

Figure 1. Relative absorbance of different photoreceptors in plant



3. Light quality

The quality of light is as important as the quantity of light.

The fact that plants cannot move and escape from bad growing conditions has resulted in a sophisticated sensor system to read ques from their environment through photoreceptors. Sensing the light environment through photoreceptors enable plants to flower in the correct time of the year when the conditions are suitable for the next generation's survival. There are numerous environmental factors affecting plant development; light, temperature, humidity, water, nutrients, gravity, etc.; light being one of the most important ones as it provides energy to photosynthesis as well as information about the plant's surroundings.

Photosynthesis is a series of processes driven by photons absorbed by the plant pigments. Photosynthesis is not very efficient since only 4-6% of the energy available in the radiation is converted into biomass. Photosynthesis can be intensified with elevated CO_2 concentration, however an increase in photosynthesis rate does not translate into a linear increase in plant growth or yield increase. Plants control their own development so that they cannot grow indefinitely.

4. The colors of light

Plants respond to different wavelengths in the PAR range. McCree (1972) studied the spectrum used by plants, describing absorption peaks at different wavelengths and establishing the curve of the action spectrum of photosynthesis.

Within the spectrum of photosynthetically active radiation, McCree found that for all higher plant species (more than 20) that he studied, there were two broadly coincident highs in photosynthetic efficiency centered around 440 and 660 nm (Figure 2).

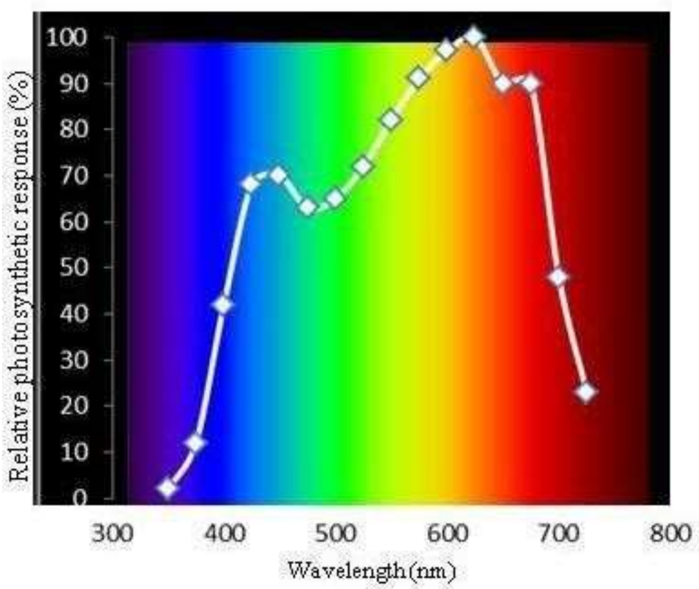


Figure 2. McCree's curve of the photosynthetic response (1972)

The effect of different wavelengths on plant growth and development:

- Ultraviolet. UV-B light is captured by the UVR8 photoreceptor. A large dose is harmful to plants, since it degrades DNA. However, in small doses, both UV-B and UV-A increase the stress tolerance of plants. In general, plants grown under ultraviolet light have thick leaves and stems and short internodes.
- Blue. Blue light is perceived by the blue light photoreceptors, phototropins and cryptochromes. Phototropins mediate stomatal regulation and plant movement towards light. Cryptochromes regulate many photomorphological responses, such as inhibition of stem elongation. Plants grown under high blue irradiation have short internodes, high dry matter content and low leaf temperature (efficient transpiration).
- Green. Green light is at least partially perceived by phototropins and cryptochromes (blue light receptors). Most green light is reflected or penetrated
through the canopy. However, green light contains valuable information about the plant's surroundings, guiding the growth accordingly. Plants grown under green light have long petioles internodes and high leaf temperature.
- Red. Red light is perceived by phytochromes. Phytochromes absorb both red and far-red light and are the main regulators of the shade avoidance syndrome. Red light converts phytochromes to their inactive state, Pr, which has an absorption peak at 660 nm. The Pr form of phytochrome is synthesized in dark conditions or in far-red light conditions. When the Pr absorbs red light, it transforms to the far- red

absorbing Pfr form, which has the absorption peak at 730 nm. The conversion from Pr to Pfr can be reversed with far-red light or darkness.

Far-red. Far-red light is absorbed by the phytochromes. Phytochromes absorb both red and far-red light and are the main regulators of the shade avoidance syndrome. High far-red irradiation causes premature flowering in many species, and elongation of stem and petioles.

5. Vernalization

In many species, photoperiod or R:FR ratio are not the only determining factors in flowering induction, but temperature plays a critical role as well. Temperature, especially the number of cold hours the plant senses, regulates the time of flowering of many species.

Some plants must go through a cold period prior to flowering. This phenomenon is calledvernalization and it takes place in numerous herbaceous plants. For example, cereals which are sown in autumn sense the cold winter months and are ready to produce flowerand seeds in the following spring and summer. The strength of the response is dependent on the length of the cold induction period as well as the temperature during the cold period.

Light, specifically, the light spectrum, influences also the vernalization process. It has been demonstrated that certain species or varieties require a shorter vernalization period in artificial growing conditions, if a light spectrum with low R:FR ratio has been given simultaneously. Long photoperiod together or right after the vernalization period have also been shown to fasten the time to flower.

1. Artificial lighting for plant growth

A plant grow light is a source of artificial light which has been designed to grow plants in spaces where there is little or no natural light available or when the natural day length is artificially extended.

Light for cultivation has traditionally tried to resemble sunlight in terms of the composition of the light spectrum, but it was not until the appearance of LEDs (Light Emitting Diode) that it was possible to produce customized spectra.

The most commonly used greenhouse lights, the high-pressure sodium (HPS) lamps, irradiate mainly in the yellow and red area of the visible spectrum, while fluorescent lights, which have traditionally been used in growth chambers have more blue light in their spectrum.

Artificial lighting applied to greenhouses has historically been linked to areas that receive few hours of sunshine during winter, or to the modification of the photoperiod to induce flowering of ornamental crops at times of the year in which they have greater commercial value.

The use of artificial light in horticultural applications results in better growth and larger yields due to photoperiod extension and increase in the daily light integral. Artificial light can also bring benefits to the growers via the manipulation of flowering induction by giving short/long day treatments or night interruption. In closed environments artificial light is of course the only supply of light for photosynthesis and plays therefore a more critical role than artificial light in greenhouse applications. The artificial light in horticulture allows a better growth by extending the photoperiod when there are only few hours of natural daylight available and thus increases the daily light integral. Artificial light is also used to control or inhibit flowering in long-day/short-day treatments and can supply natural light in closed growth chambers.

In recent years, great development has been made in lighting technology, including the reduction of operating costs thanks to the introduction of LEDs. LEDs have been introduced already into facilities which produce flowers, vegetables, fruits, grafted seedlings, microgreens, algae, and medicinal plants, etc. Due to its environmental and productive efficiency advantages, LED lighting has been described as the most revolutionary invention in horticultural lighting in recent decades.

In early 1966, Hardh suggested that the artificial lighting used for plants should adapt to the spectrum of photosynthetic function sensitivity, and in 1970 McCree offered a proposal for a generalized spectrum for

photosynthesis action that we have seen in Figure
2. The parameters to be considered in artificial lighting are the light spectrum, light intensity, and photoperiod.