Plant Physiology: Environmental Factors and Photosynthesis

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Introduction

The growth and development of plants is dependent on abiotic (physical) and biotic (biological) factors. Abiotic factors include the physical environmental conditions and biotic factors include animals, insects, and diseases.

Each plant has certain environmental requirements. To attain the highest potential yields a crop must be grown in an environment that meets these requirements. A crop can be grown with minimal adjustments if it is well matched with its climate or growing condition. Unfavorable environmental conditions can produce a stress on plants resulting in lower yields. In such cases the environment can be artificially modified, such as in greenhouses, to meet the crop requirements.

Temperature

Most plants function in a relatively narrow range of temperatures. The extremes of this range may be considered killing frosts at about 32ºF (0ºC) and death by heat and desiccation at about 105ºF (40ºC).

Air Temperature - Each kind of crop grows and develops most rapidly at a favorable range of air temperatures. This is called the optimum air temperature range. For most crops the optimum functional efficiency occurs mostly between 55 and 75ºF (12 and 24ºC). Most crops (and especially vegetables) can be classified according to the temperature requirements of their optimum air temperature range. However they are generally grouped into whether they require low or high air temperatures for growth. Temperature requirements are usually based on night temperature. Those that grow and develop below 65ºF (18ºC) are the cool season crops, and those that perform above 65ºF are the warm season crops. Crops that originated in temperate climates usually require low temperature, while those that originate in the tropical climates require warm temperature.

Soil Temperature - Soil temperature has direct dramatic effects on microbial growth and development, organic matter decay, seed germination, root development, and water and nutrient absorption by roots. In general, the higher the temperature the faster these processes occur. The size, quality, and shape of storage organs are greatly affected by soil temperature. Dark-colored soils absorb more solar energy than light colored soils. The capacity of water to move heat from one area to another (conduction) is greater than that of air. Heat is therefore released to the surface faster in clay soils than in dry sandy soils. The lower the air temperature, the more rapid the loss. Although light-colored sandy soils absorb less solar energy, less heat is also released to the atmosphere because of the low water-holding capacity of the soil.

Chilling Injury - Most crops are injured at temperatures at or slightly below freezing. Tropical or subtropical plants may be killed or damaged at temperatures above freezing but below 50ºF (10ºC). This latter type of injury is called chilling injury. Susceptibility to cold damage varies with different species and there may be differences among varieties of the same species. The susceptibility to cold damage varies with stage of plant development. Plants tend to be more sensitive to cold temperatures shortly before flowering through a few weeks after anthesis.

Heat Stress - When temperatures rise too high, heat destruction of the protoplast results in cell death. This occurs in the range of 113-122ºF (45-55ºC). In tomatoes, fruits exposed on vines to high temperatures and high solar radiation can reach 120-125ºF (49-52ºC). If green fruits are exposed at these temperatures for an hour or more, they become sunburned; and ripe fruits become scalded.

As with cold resistance, the plant cells can become gradually acclimated, to a certain extent, to heat by slowly raising the temperature and lengthening the exposure daily. Transpiration from the leaf stomata helps cool leaves. It has been calculated that transpiration can reduce heating by about 15 to 25%.

Symptoms of heat injury are the appearance of dead areas in leaves of hypocotyls and young leaves of many plants. Heat injury occurs over a wide range of plants depending on the species or tissue.

Vernalization - The biennials crops (those that flower in alternate years), and some of the cool season crops initiate flower formation after extended (several weeks or months) exposure to low temperature. The exposure of certain plants to low temperatures induces or accelerates flowering (bolting). This is vernalization. The required length of low temperature exposure varies with species.

Premature flowering is called bolting. This can cause substantial yield loss. This is particularly true for crops that require little cold exposure, like heat tolerant Chinese cabbage.

In some species, seedlings and young plants still in the juvenile stage are insensitive to conditions that promote flowering in older plants. In some species, seeds can be vernalized. The seeds must have sufficient water to allow to vernalization process to occur. Certain tubers, corms, and bulbs require low temperatures following moderately high temperatures before growth occurs.

Light

All light is made up of energy. Light to humans is the wavelengths of radiant energy in the electromagnetic spectrum that activates the light receptors in our eyes. When these light receptors are activated, the impulses are interpreted by our brain and we experience vision.

Light to plants is the wavelengths of the electromagnetic spectrum including the wavelengths that humans can see (visible light) and some of the wavelengths that humans can't see (such as microwaves and infrared light).

Light in human or animal vision typically acts only as a medium for transferring information about position and movement, shape and color of material objects. The human and animal interest in light perception is mainly centered on food, enemies, seeking other members of the same species for reproduction, etc. (Bjorn, 1994).

Light for the plant is not only used as an informational medium, but also for producing food through the process of photosynthesis. The characteristics of direction and spectral composition of light in the plant's environment is transferred to the plant through the interception and activation of pigment systems within the leaf. This information affects the morphological development (size/proportion of root and shoots) of the plant, hopefully imparting to the plant some type of ecological or physiological advantage for survival. Plants also use light for sensing and detecting competitors and keeping track of time.

Light Quality - Sunlight is often referred to as white light and is composed of all colors of light. A color of light would be the relative distribution of wavelengths from a radiation or reflective source.

Light Intensity - Light intensity is a major factor governing the rate of photosynthesis. The quantity or amount of light received by plants in a particular region is affected by the intensity of the incident (incoming) light and the length of the day. The intensity of light changes with elevation and latitude. The amount of sunlight also varies with the season of the year and time of day, as well as, other factors, such as clouds, dust, smoke or fog.

Plants have varying preferences for light intensity. The light saturation point of the plant determines the relative light requirement of plant. The light saturation point is the point above which an increase in light intensity does not result in an increase in photosynthetic rate. Crops such as corn, cucurbits, legumes, potato, and sweet potato require a relatively high level of light for proper plant growth while onions, asparagus, carrot, celery, cole crops, lettuce and spinach can grow satisfactorily with lower light intensity.

Light Duration - Due to the tilt of the earth's axis (23º from the vertical) and its travel around the sun, the length of the light period (also called photoperiod or daylength) varies according to the season of the year and latitude. It varies from a nearly uniform 12-hour day at the equator (0 latitude) to continuous light or darkness throughout the 24 hours for a part of the year at the poles.

Some plants change their growth in response to daylength and exhibit photoperiodism. One important plant response to daylength in some plants is flowering. Some plants flower when a specific daylength minimum has been passed. Short day plants flower rapidly when the days get shorter and long-day plants flower fast when days get longer. Plants that are not affected by daylength are called day-neutral plants. These plants can flower under any light period.

Light Energy Capture by Plants - Photosynthesis

One of the main roles of light in the life of plants is to serve as an energy source through the process of photosynthesis. Using water and carbon dioxide through photosynthesis, plants produce the foodstuffs (photosynthates) necessary for growth and survival. Subsequently, carbohydrates (starches and sugar) and stored chemical energy are produced during this biochemical process in plants.

Plants capture the energy in light using a green pigment called chlorophyll. A very precise number of photons at specific wavelengths (near 680 nm) are required to split a water molecule (H_2O) within the green leaf, which releases oxygen (O_2), and provides chemical energy to continue the long biochemical process to produce more complex molecules such as carbohydrates. Carbon dioxide from the air and water from within the leaf combine to produce oxygen and photosynthates.

In the research laboratory, chlorophyll can easily be extracted from plant tissue using chemical solvents. Chlorophyll can also be extracted by abrasion as anyone who has ever pruned tomato plants by hand or had grass stains on their clothes can attest.

Light Regulated Plant Development - Photomorphogenesis

Photomorphogenesis is defined as the ability of light to regulate plant growth and development, independent of photosynthesis. Plant processes that appear to be photomorphogenic include internode elongation, chlorophyll development, flowering, abscission, lateral bud outgrowth, and root and shoot growth.

Photomorphogenesis differs from photosynthesis in several major ways. The plant pigment responsible for light-regulated growth responses is phytochrome. Phytochrome is a colorless pigment that is in plants in very small amounts. Only the red (600 to 660 nm) and far red (700 to 740 nm) wavelengths of the electromagnetic spectrum appear to be important in the light-regulated growth of plants. The wavelengths involved in generating photosynthesis are generally broader (400 to 700 nm) and less specific.

Photomorphogenesis is considered a low energy response - meaning that it requires very little light energy to get a growth-regulating response. Plants generally require greater amount of energy for photosynthesis to occur.

Water

Waterlogging - Under waterlogged conditions, all pores in the soil or soilless mixture are filled with water; so the oxygen supply is almost completely deprived. As a result, plant roots cannot obtain oxygen for respiration to maintain their activities for nutrient and water uptake. Plants weakened by lack of oxygen are much more susceptible to diseases caused by soil-borne pathogens. Waterlogging due to lack of oxygen in the soil causes death of root hairs, reduces absorption of nutrients and water, increases formation of compounds toxic to plant growth, and finally retards growth of the plant.

The extent of flooding damage depends upon the susceptibility of species or variety, level of water constantly present in the soil, soil texture, air temperature and presence and type of microorganisms. Most plants are sensitive to flooding.

Water Balance - Water is essential to photosynthesis, it plays a key role in transpiration, and it regulates the stomata (openings in leaves to evaporate leaf moisture), and thus is crucial to growth and leaf expansion of plants. When water is in balance (the supply is equal to the need), the optimum performance of all components results in steady active plant growth. However, when the balance of water is affected either because there is insufficient available moisture in the soil (or soil mix), or the transpiration of water through the stomata exceeds the plant's capacity to compensate for the internal loss, the plant comes under stress.

Most crops have differing critical growth periods, and if water stress occurs during critical stages of growth, yield is directly affected. When moisture requirements are not met during this critical phase permanent, irreparable damage usually is the result. The plant quality is diminished, or the plant yield is reduced.

Drought - Drought is generally considered to be a meteorological term and is defined as a period without significant rainfall or moisture. Droughts may lead to plant water stress and growth may be impacted. Periods of even short drought stress can reduce crop growth and yields. The plant may adjust to short-term water stress by closing stomates and thereby reducing water loss through the leaves. When stomates are closed, the plant wilts, carbon dioxide CO_2 from the atmosphere cannot enter the leaf photosynthesis is reduced or stopped. Growth will be slowed if such conditions are not corrected.

Wind
A slight wind is necessary to replenish carbon dioxide (CO_2) near the plant leaf surface. CO_2 can be rapidly depleted at the leaf surface, unless there is some ventilation or air infiltration of the greenhouse.

Air movement and distribution within the greenhouse can be enhanced with horizontal airflow fans.

Growing Media
The purpose of the growing media for the root zone of the plant is to provide: moisture holding capacity, nutrient exchange capacity, gas exchange of oxygen and carbon dioxide, and a foundation for the plant roots to support the plant.

Many types of root zone media have been developed for greenhouse crops production. These range from combinations of organic materials (such as peat), to completely inert materials such as rockwool, perlite, or vermiculite.

Plant Fertility – The root zone is the main source of nutrients for plants, which are incorporated by the roots. Plant macronutrients (those required in relatively large amounts) that must be provided include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). Plant micronutrients (those essential for good growth, but required in relatively small amounts) include iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), boron (B), cobalt (Co), molybdenum (Mo), and chlorine (Cl). Excessive amounts can cause toxicity and insufficient amounts can cause poor or abnormal growth.

Definitions

Anthesis *– flowering.*

Air Temperature *-- day or nighttime environmental temperature of the plant canopy.*

Hypocotyl -- *plant stem of young seedling after germination.*

Photosynthates *-- the initial chemical products of the photosynthesis; these are utilized to build complex molecules and ultimately the plant's biomass.*

Photoperiodism *-- plant growth in response to the length of the day; an example of plant response to day length is flowering.*

Stomates *-- small openings on the leaf that allow carbon dioxide to enter the leaf for photosynthesis, and moisture and oxygen to exit to the atmosphere.*

Transpiration *-- water evaporating from the leaf; it is the natural cooling process for the plant, as well as, the process to move water (with dissolved nutrients) through the plant.*

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