Advanced Agro-Hydro- Meteorology

A MSc course for students of Atmospheric Sciences

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Lecture 6: Environmental Temperature and Crop Production

6.1 Introduction

Temperature governs the physical and chemical processes that in turn control biological reactions within plants. It controls the diffusion rate of gases and liquids within plants, and solubility of plant nutrient substances is dependent on temperature. As such, environmental temperature has a primary role in plant growth and its geographical distribution over the earth.

6.2 Soil Temperature

Soil temperature is an important environmental factor in plant growth and distribution. In comparison to air temperature, the amplitude of variation in soil surface temperature is much more pronounced because of the varying characteristics and composition of soil.

6.2.1 Factors Affecting Soil Temperature

- *Aspect and slope*: These factors are important in determining soil temperature outside the tropics. In the N. Hemisphere, a south-facing slope is always warmer than a north-facing slope or a level plain. The reverse is the case in the Southern Hemisphere. The difference in soil surface temperature exceeds the difference in air temperature.
- *Tillage*: By loosening topsoil and creating mulch, tillage reduces the heat flow between the surface and subsoil. Because a mulched surface has a greater exposed area and the capillary connection with moist layers below is broken, cultivated soil has greater temperature amplitude than uncultivated soil.
- *Soil texture*: Because of lower heat capacity, sandy soils warm up and cool down more rapidly than clay soils; hence, they are at a higher temperature during the day and a lower temperature at night.
- *Organic matter*: Organic matter reduces the heat capacity and thermal conductivity of soil, increases its water-holding capacity, and has a dark color which increases its solar radiation absorptivity. However, when organic soils are dry, they become warmer than mineral soils in summer and cooler in winter.

6.2.2 Factors Affecting Soil Temperature

Soil temperatures influence the germination of seeds, the functional activity of the root system, the incidence of the plant diseases, and the rate of plant growth. Excessively high soil temperatures are harmful to roots and cause lesions on the stem. Extremely low temperatures are equally detrimental. Low temperatures impede the intake of nutrients. Soil moisture intake by plants stops when they are at a temperature of 1 °C.

6.2.3 Impact of Soil Temperature on Plant Growth

After germination, soil temperature is important for the vegetative growth of crops. For each species, a favorable soil temperature is needed for ion and water uptake. The daytime soil temperature is more important than the nighttime temperature, because it is necessary to maintain a favorable internal crop water status to match the high evaporation rate.

6.3 Cardinal Temperatures

Three temperatures of vital plant activity have been recognized, which are often termed cardinal points.

1. A minimum temperature below which no growth occurs: For typical cool-season crops, it ranges between 0 and 5 ^{o}C, and for hot-season crops between 15 and 18 ^{o}C.
2. An optimum temperature at which maximum plant growth occurs: For cool-season crops, it ranges between 25 and 31 ^{o}C, and for hot-season crops between 31 and 37 ^{o}C.
3. A maximum temperature above which the plant growth stops: For cool-season crops, it ranges between 31 and 37 ^{o}C, and for hot-season crops between 44 and 50 ^{o}C.

6.4 Air Temperature

- Air temperature is the most important climatic variable that affects plant life. The growth of higher plants is restricted to a temperature between 0 and 60 C, and crop plants are further restricted to a narrower range of 10 to 40 C. However, each species and variety of plants and each age group of plants has its own upper and lower temperature limits. Beyond these limits, a plant becomes considerably damaged and may even be killed. It is therefore the amplitude of variations in temperature, rather than its mean value, that is more important to plant growth.
- The midday high temperature increases the saturation deficit of plants. It accelerates photosynthesis and ripening of fruits. The maximum production of dry matter occurs when the temperature ranges between 20 and 30 C, provided moisture is not a limiting factor.
- High temperature can devernalize cryophytes, especially the buds of sun-exposed deciduous trees. When high temperature occurs in combination with high humidity, it favors the development of many plant diseases. High temperature also affects plant metabolism.
- High night temperature increases respiration. It favors the growth of the shoot and leaves at the cost of roots, stolons, cambium, and fruits. High night temperature also affects plant metabolism. It accelerates the development of noncryophytes.
- Most crop plants are injured and many are killed when the night temperature is very low. Tender leaves and flowers are very sensitive to low temperature and frost. Plants that are rapidly growing and flowering are easily killed. Low temperature interferes with the respiration of plants.

6.5 Temperature and Photosynthesis

The rate of photosynthesis and respiration increases with an increase in temperature, until a maximum value of photosynthesis is reached. This value is maintained over a broad range of temperatures. Then, at considerably higher temperatures, when the enzyme becomes inactivated and various reactions are disturbed, photosynthesis decreases and ultimately stops.

6.6 Plant Injury Due to Sudden Changes in Temperature

Living organisms receive and transfer thermal energy through radiation, conduction, and convection. Transpiring water to the surrounding atmosphere also transfers thermal energy from growing plants. Through these processes, they remain in equilibrium with the surrounding environment and maintain normal growth and development. However, with the passage of weather systems, changes in atmospheric temperature are often very sudden, and plants cannot adjust to these severe variations and are damaged beyond recovery.

6.7 Leaf Temperature versus Air Temperature

Under normal conditions, leaf temperature remains around the ambient temperature but differs under certain situations. At a temperature of about 33 ^{o}C, there is a tendency for equality between air and leaf temperature. Below this temperature, leaves tend to be warmer than the air and vice versa. Where the temperature exceeds 33 ^{o}C, leaves appear to suffer from water stress.

- *Leaves exposed to sun*: Thick leaves that are not transpiring actively in still air are several degrees warmer than the air. Leaves under shade: Leaves shaded from direct sunlight are usually somewhat warmer than the surrounding air.
- Leaves exposed to a clear night: At night when the sky is clear, leaf temperature is usually lower than the air temperature. Leaves exposed to a cloudy night: With cloud cover, the difference in air and leaf temperature is small.

6.8 High-Temperature Injury to Plants

Thermal death point of active cells ranges from 50 to 60 ^{o}C for most plant species, but it varies with the species, the age of tissue, and the length of time of exposure to high temperature.

For aquatic and shade plants the lethal limit is 40 ^{o}C, and for most xerophytes it is 50 ^{o}C, when the plants are exposed to a saturated atmosphere for about half an hour. High temperature results in the desiccation of the plant and disturbs the balance between photosynthesis and respiration.

6.9 Low-Temperature Injury to Plants

Exposure to extremely low temperatures and heavy snowfall damages the plant in several ways including suffocation, desiccation, heaving, chilling, and freezing.

- *Suffocation*: Small plants may suffer from deficient oxygen when covered with densely packed snow.

- *Desiccation*: It is the removal of moisture from something. "long periods of drought have led to the desiccation of farming land".
- *Heaving*: Injury to a plant is caused by the soil layer lifting upward from the normal position and causing the root to stretch or break at a time when the plant is growing. The plants may die because of this mechanical damage and desiccation.
- *Chilling*: Chilling injury is damage to plant parts caused by temperatures above the freezing point (32°F, 0°C). Plants of tropical or subtropical origin are most susceptible. Chilling-injured leaves may become purple or reddish and in some cases wilt. Both flowers and fruit of sensitive species can be injured.

6.10 Freezing Injury

Plant parts or an entire plant may be killed or damaged beyond repair as a result of actual freezing of tissues. Freezing damage is caused by the formation of ice crystals, first in the intercellular spaces and then within the cells.

6.11 FROST: DAMAGE AND CONTROL

Frost is a climatic hazard that causes serious damage to standing crops in temperate and subtropical climates. Much distress can be avoided by properly understanding the characteristics of the frost, by using early warning information on frost, and by adopting frost protection measures. For this, the planning should begin before the crop is planted.

Frost is a weather hazard that occurs when the environmental temperature drops below the freezing point of water. It can be a white frost or a black frost. White frost occurs when atmospheric moisture freezes in small crystals on solid surfaces. Black frost occurs when few or no ice crystals are formed because air in the lower atmosphere is too dry, but the damaging effect of the low temperatures on vegetation is the same as that of white frost.

- Radiation frost occurs when a clear sky and calm atmosphere (winds less than 8 kph) allow an inversion to develop, and temperatures near the surface drop below freezing. The thickness of the inversion layer varies from 10 to 50 m.
- Advection frost occurs when a cold air mass invades a relatively warm area suddenly.

6.11.1 Frost Damage to Plants

Damage to plants from frost occurs because it results in freezing of the plant tissues. Freezing of plant tissues is a physical process triggered by ice nucleating bacteria, the intensity and duration of the night temperature to which the plants are exposed, and the plant growth stage. Green plants contain mostly water, and on freezing, the water expands and ruptures the cell walls of the plant tissues. Because of the presence of chemicals in the sap, plant tissues freeze at temperatures lower than 0 C, the freezing temperature of water. When frozen water melts, it leaks away from the cells. The rupturing of the cells and leakage of water results in the death of tissues, giving a typical “burn” appearance to the plants.

6.11.2 Methods of Protection against Frost

Frost protection methods may be divided into passive and active forms.

- Passive protection involves methods such as *site selection* and *variety selection* and several cultural practices such as brushing and soil surface preparation. These methods do not require expenditure of outside energy sources. Active protection systems replace radiant energy loss by using methods such as irrigation, heaters, and wind machines.
- Active methods require outside energy to operate. The proper choice of a protection method depends on many factors, such as site, crop, advantages and disadvantages of the protection methods, relative costs, and operating principles of the method.

  a. **Site Selection:** The site should be selected taking into account the climatic conditions prevailing in that location, its slope, and the soil characteristics.

  b. **Frost-Resistant Cultivars:** Planting frost-resistant cultivars and crop varieties is one approach to avoid frost damage to fruit trees and field crops.

  c. **Optimizing Sowing Dates:** The best and most cost-effective strategy to save field crops from frost is the choice of the optimum dates for crop plantings.

  d. **Storing Heat in the Soil:** Frost frequency and intensity is greater in orchards in which the soil is cultivated, dry, and covered with weeds or mulch as compared to orchards in which the soil is moist, compact, and weed free. Standing weeds increase the incidence of frost in three ways: by shading the soil; by drying the soil; and by raising the cold radiating surface which comes close to the fruit level.

  e. **Plant Cover:** Planting large canopy trees with orchard plants provides some freeze protection. During the day the shields act as windbreaks against cold wind, while at night they reduce radiation loss to the sky.

  f. **Nutrition:** Using midsummer or postharvest application of nitrogen can induce vigor for strong fruit bud development and some delay in flowering in stone fruits such as peaches. This nutrition may make benefits to prevent damage to the plant.

  g. **Chemicals:** A number of materials that could change the freezing point of plant tissue, reduce the ice nucleating bacteria on the crop and thereby inhibit frost formation, or affect growth, i.e., delay dehardening, have been examined.

  h. **Irrigation:** Irrigation is done with sprinklers mounted above or below the crop canopy. Sprinkling the canopy with water releases the latent heat of fusion when water turns from liquid to ice. As long as ice is being formed, latent heat released by water efficiently compensates for the heat lost from the crops to the environment.

  i. **Heaters:** There are several advantages to using heaters. Most heaters are designed to burn oil and can be placed as freestanding units or connected by a pipeline network throughout the crop area. Heaters provide protection by three mechanisms. The hot gases emitted from the top of the stack initiate convective mixing in the crop area and break the inversion. The bulk of a heater's energy is released in this form. The remaining energy is released by radiation from the hot metal stack. A relatively insignificant amount of heat is also conducted from the heater to the soil.

j. **Wind Machines:** The purpose behind using wind machines is to circulate warmer air down to the crop level. Wind machines are effective only under radiation frost conditions. They should be installed and operated after a thorough understanding of how frost affects a particular area or orchard.

6.12 Thermoperiodism

Definition of thermoperiodism: the sum of the responses living organisms especially of a plant to appropriately fluctuating temperatures either day/night or seasonal.

Thermoperiodism exerts effects on the seasonal biology of insects and the growth and development of plants. Crops such as soybean, maize, tomato, potato, and mango are classified as thermoperiodic, while wheat, oats, peas, and cucumber are classified as nonthermoperiodic.

6.13 Temperature as a Measure of Plant Growth and Development

6.13.1 Growing Degree-Days

Growing degree-days (GDD), also called heat units, effective heat units, or growth units, are a simple means of relating plant growth, development, and maturity to air temperature. The concept is widely accepted as a basis for building phenology and population dynamic models. Degree-day units are often used in agronomy, essentially to estimate or predict the lengths of the different phases of development in crop plants.

The GDD concept assumes a direct and linear relationship between growth and temperature. It starts with the assumption that the growth of a plant is dependent on the total amount of heat to which it is subjected during its lifetime. A degree-day, or a heat unit, is the departure from the mean daily temperature above the minimum threshold (base) temperature. This minimum threshold is the temperature below which no growth takes place.

6.13.2 Methods of Degree-Day Estimation

The three most dependable and commonly used methods for estimating degree-days are the standard method, the maximum instead of mean method, and the reduced ceiling method.

1. Standard degree-day method:

$$GDD = [(Tmax + Tmin)/2] - Tbase \qquad (6.1)$$

where $(Tmax + Tmin)/2$ is the average daily temperature and $Tbase$ is the minimum threshold temperature for a crop.

2. Maximum instead of means method:

$$GDD = \sum(Tmax - Tbase) \qquad (6.2)$$

3. Reduced ceiling method: where $Tmax \leq T_{ceiling}$, then

$$GDD = \sum(Tmax - Tbase), or \qquad (6.3)$$

where $Tmax \geq T_{ceiling}$, then

$$GDD = \sum[\left(T_{ceiling} - \left(Tmax - T_{ceiling}\right)\right) - Tbase] \qquad (6.4)$$

If maximum temperature (Tmax) is greater than the ceiling temperature ($T_{ceiling}$), then set Tmax equal to $T_{ceiling}$ minus the difference between Tmax and $T_{ceiling}$.

6.13.3 Uses and Limitations of Growing Degree-Day Methods

The use of degree-days for calculating the temperature-dependent development of insects, birds, and plants is widely accepted as a basis for building phenology and population dynamics models. The simplicity of the degreeday method has made it widely popular in guiding agricultural operations and planning land use. Most applications of the growing degree-day concept are for the forecast of crop harvest dates, yield, and quality. It helps in forecasting labor needs for factories, and in reducing harvesting and factory costs. A potential area of application lies in estimating the likelihood of the successful growth of a crop in an area in which it has not been grown before.