- **Content Creator:** Vallal Kannan Sankaralingam, Tamil Nadu Agricultural University, Coimbatore
- **Course Reviewer:** Dr. Vijay Gopal More, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Lesson	Lesson Name

Number	
Lesson 1	Agricultural Meteorology - Introduction, definition of meteorology, scope, and practical utility of Agricultural meteorology
Lesson 2	Composition and structure of atmosphere, definition of weather and climate, aspects involved in weather and climate
Lesson 3	Atmospheric temperature & soil temperature
Lesson 4	Solar radiation, atmospheric pressure, atmospheric humidity, evaporation, and transpiration
Lesson 5	Monsoons, rainfall, clouds, drought
Lesson 6	Weather disasters and their management
Lesson 7	Atmospheric pollution and role of meteorology, basics of weather forecasting
Lesson 8	Climate change causes, global warming causes, and remote sensing
Lesson 9	Effect of climate change on horticulture, past and future changes in greenhouse gases, sources and sinks for greenhouse gases
Lesson 10	Atmospheric chemistry, plants' response to CO_2 concentration changes, C_3 and C_4 species effects
Lesson 11	Plant development affected by elevated CO_2, nitrogen use, soil fertility, and its implication for production
Lesson 12	Change in secondary metabolites, pest-disease reactions, ozone and UV damage tolerance in plants
Lesson 13	Increased temperature effects on plants in tropical/sub-tropical climates, flowering timing, fruit development, and crop yields
Lesson 14	Interaction of temperature with other abiotic/biotic

	stresses
Lesson 15	Mitigation strategies and genetic manipulation of crops for future atmospheric conditions
Lesson 16	Modifying Rubisco, acclimation, metabolism of oxidizing radicals, and sink capacity strategies

Course Name	Agro-meteorology and climate change
Lesson 1	Agricultural Meteorology- Introduction, definition of meteorology, scope and practical utility of Agricultural meteorology
Content Creator Name	Vallal Kannan Sankaralingam
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	Dr. Vijay Gopal More
University/College Name	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Lesson 1

Objectives:

- To understand difference of meteorology and agricultural meteorology
- To empower knowledge on scope and practical utility of agricultural meteorology

Agricultural Meteorology

Introduction:

Agriculture is defined as **“**The art and science of production and processing of plant and animal life for the use of human beings”. It is also defined as “A system for harvesting or exploiting the solar radiation”. Agriculture deals with three most complex entities viz., soil, plant and atmosphere and their interactions. Among these three, atmosphere is the most complex entity over the other two.

1. **Atmosphere**

The earth is elliptical in shape. It has three spheres. They are:
1 Hydrosphere: the water portion.
2 Lithosphere: the solid portion.
3 Atmosphere: the gaseous portion.
The atmosphere is defined as “The colourless, odourless and tasteless physicalmixture of gases which surrounds the earth on all sides”. It is mobile, compressible andexpansible.
1.1 Uses of atmosphere for agriculture: The uses of atmosphere are: It
1. Provides oxygen which is useful for respiration in crops.
2. Provides carbon-dioxide to build biomass in photosynthesis.
3. Provides nitrogen which is essential for plant growth.
4. Acts as a medium for transportation of pollen.
5. Protects crop plants on earth from harmful U.V. rays.
6. Maintains warmth to plant life.
7. Provides rain to field crops as it is a source of water vapour, clouds etc.

2. Definition of Meteorology

Greek word “Meteoro” means ‘above the earth’s surface’ (atmosphere) “logy” means‘indicating science’. Branch of science dealing with that of atmosphere is known asmeteorology. Lower atmosphere extending up to 20km from earth’s surface is where frequentphysical process takes place.Meteorology is a combination of both physics and geography. This science utilizes the principles of Physics tostudy the behaviour of air.

It is concerned with the analysis of individual weather elements for ashorter period over a smaller area. In other words, the physical state of the atmosphere at agiven place and time is referred to as “weather”. The study of weather is called ‘meteorology’. Itis often quoted as the “physics of atmosphere”.

3. Agricultural meteorology

It is defined as “The study of those aspects of meteorology that have direct relevance to agriculture".

It is also defined as

1. A branch of applied meteorology which investigates the physical conditions of theenvironment of growing plants or animal organisms
2. An applied science which deals with the relationship between weather/climatic conditions andagricultural production.
3. A science concerned with the application of meteorology to the measurement and analysis ofthe physical environment in agricultural systems. The word ‘Agro meteorology’ is theabbreviated form of agricultural meteorology.
4. To study the interaction between meteorological and hydrological factors on the one handand agriculture in the widest sense, including horticulture, animal husbandry and forestry on theother (WMO).

Designed and developed under the aegis of NAHEP Component-2 Project “Investments In ICAR Leadership In Agricultural Higher Education”
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Table1: Meteorology Vs. Agricultural Meteorology

Meteorology	Agricultural Meteorology
Branch of atmospheric physics	Branch of applied meteorology or a branch of agriculture as it deals with agriculture
It is a weather science	It is a product of agriculture and meteorology
It is a physical science	It is a biophysical science
It aims at weather forecasting	It aims at improving quantity and quality of crop production through meteorological skills
Weather service is the concern	Agro advisory service to the farmers is the concern based on weather forecast
It is a linking science to the society	It is a linking science to the farming community

3.1: Scope of Agricultural meteorology

1. To study climatic resources of a given area for effective crop planning.
2. To evolve weather based effective farm operations.
3. To study crop weather relationships in all important crops and forecast crop yields based on agro climatic and spectral indices using remote sensing.
4. To study the relationship between weather factors and incidence of pests and diseases of various crops.
5. To delineate climatic/agro ecological/agro climatic zones for defining agro climatic analogues so as to make effective and fast transfer of technology for improving crop yields.
6. To prepare crop weather diagrams and crop weather calendars.
7. To develop and validate crop growth simulation models for assessing/obtaining potential yields in different agro climatic zones.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

8. To monitor agricultural droughts on crop-wise for effective drought management.
9. To develop weather based agro advisories to sustain crop production utilizing various types of weather forecast and seasonal climate forecast.
10. To investigate microclimatic aspects of crop canopy in order to modify them for increased crop growth.
11. To study the influence of weather on soil environment on which the crop is grown.
12. To investigate the influence of weather in protected environment (e.g. Glass houses) for improving their design aiming to increasethe crop production.
13. To prepare contingency plan for aberrant weather condition

3.2: Applications/Practical utility of agricultural meteorology

Weather and climate is a resource and considered as basic input or resources in **agricultural planning**, every plant process related with growth development and yield of a crop is affected by weather.Similarly every farm operation such as ploughing, harrowing, land preparation, weeding, irrigation, manuring, spraying, dusting, harvesting, threshing, storage and transport of farm produce are affected by weather.

The scope of Agricultural Meteorology can be illustrated through the following few applications.

3.2.1Characterization of agricultural climate: For determining crop growing season, solar radiation, air temperature, precipitation, wind, humidity etc. are important climatic factors on which the growth, development and yield of a crop depends. Agro-meteorology considers and assesses the suitability of these parameters in a given region for maximum crop production and economic benefits. Different zones are delineated based on similarity in weather and edaphic characters of region.

b. Crop planning for stability in production: To reduce risk of crop failure on climatic part, so as to get stabilized yields even under weather adversity, suitable crops/cropping patterns/contingent cropping planning can be selected by considering water requirements of crop, effective rainfall and available soil moisture.

c. Crop management: Management of crop involves various farm operations such as, sowing fertilizer application,plant protection, irrigation scheduling, harvesting, etc. can be carried out on the basis of specially tailored weather support. Operational forecasts available from agro met advisories is used for tailoring the farm operations,e.g. 1) Weeding harrowing, mulching etc are undertaken during dry spells forecasted. 2) Fertilizer application is advisable when rainfall is not heavy, wind speed is<30 km/hr and soil moisture is between 30 to 80 per cent.3) Spraying/dusting is undertaken when there is no rainfall, soil moisture is 90 per cent and wind speed is<25km/hr.

d. Crop Monitoring: To check crop health and growth performance of a crop, suitable meteorological tools such as crop growth models. Water balance technique or remote sensing (NDVI) etc., can be used.

e. Crop modelling and yield –climate relationship: Suitable crop models, devised for the purpose can provide information or predict the results about the growth and yield by using current and past weather data.

f. Research in crop –climate relationship: Agro-meteorology can help to understand crop-climate relationship so as to resolve complexities of plant process in relation to its micro climate.

g. Climate extremities: Climatic extremities such a frost, floods, droughts, hail storms, high winds can be forecasted and crop can be protected.

h. Climate as a tool to diagnose soil moisture stress: Soil moisture can be exactly determined from climatic water balance method, which is used to diagnose the soil moisture stress, drought and necessary protective measures such as irrigation, mulching application of anti-transparent, defoliation, thinning etc. can be undertaken.

i. Livestock production: Livestock production is a part of agriculture. The set of favourable and unfavourable weather conditions for growth, development and production of livestock is studied in Agricultural Meteorology. Thus to optimize milk production poultry production, the climatic normal are worked out and on the suitable breeds can be evolved or otherwise can provide the congenial conditions for the existing breeds.

j. Soil formation: Soil formation process depend on climatic factors like temperature, precipitation, humidity, wind, etc.Thus climate is a major factor in soil formation and development.

3.3: Role of Agricultural meteorologists

- Agricultural meteorologists collect and interpret weather and climate data needed to understand the interactions between vegetation and animals and their atmospheric environments.
- The climatic information developed by agricultural meteorologists is valuable in making proper decisions for managing resources consumed by agriculture, for optimizing agricultural production, and for adopting farming practices to minimize any adverse effects of agriculture on the environment. Such information is vital to ensure the economic and environmental sustainability of agriculture now and in the future.
- Agricultural meteorologists also quantify, evaluate, and provide information on the impact and consequences of climate variability and change on agriculture.
- Increasingly, agricultural meteorologists assist policy makers in developing strategies to deal with climatic events such as floods, hail, or droughts and climatic changes such as global warming and climate variability.
- Agricultural meteorologists are involved in many aspects of agriculture, ranging from the production of agronomic and horticultural crops, trees, and livestock to the final delivery of agricultural products to market. They study the energy and mass exchange processes of heat, carbon dioxide, water vapor, and trace gases such as methane, nitrous oxide, and ammonia, within the biosphere on spatial scales ranging from a leaf to a watershed and even to a continent.
- They study, for example, the photosynthesis, productivity, and water use of individual leaves, whole plants, and fields.
- They also examine climatic processes at time scales ranging from less than a second to more than a decade.

3.4: FUTURE SCOPE OF AGRICULTURAL METEOROLOGY

1. To study climatic resources of a given area for effective crop planning.
2. To evolve weather based effective farm operations.
3. To study crop weather relationships in all important crops and forecast crop yields based onagro climatic and spectral indices using remote sensing.
4. To study the relationship between weather factors and incidence of pests and diseases ofvarious crops.
5. To prepare crop weather diagrams and crop weather calendars.
6. To develop crop growth simulation models for assessing/obtaining potential yields in differentagro climatic zones.
7. To monitor agricultural droughts on crop-wise for effective drought management.
8. To develop weather based agro advisories to sustain crop production utilizing various typesof weather forecast and seasonal climate forecast.
9. To investigate microclimatic aspects of crop canopy in order to modify them for increasedcrop growth
10. To study the influence of weather on soil environment on which the crop is grown
11. To investigate the influence of weather in protected environment (eg. Glass houses) for improving their design aiming at increasing crop production.

Glossary:

Agriculture: The art and science of production and processing of plant and animal life for the use of human beings".

Agricultural Meteorology: "The study of those aspects of meteorology that have direct relevance to agriculture".

Atmosphere: "The colourless, odourless and tasteless physical mixture of gases which surrounds the earth on all sides".

Meteorology: The study of weather is called 'meteorology'. It is often quoted as the "physics of atmosphere".

Reference:

Bishnoi OP. (2007(. Principles of Agricultural Meteorology. Oxford Book Co.

G S L H V. Prasada Rao. (2008). Agricultural Meteorology, Prentice Hall India Learning Private Limited.

Mahi, G.S. and Kingra, P.K. (2014) FUNDAMENTALS OF AGROMETEOROLOGY AND CLIMATE CHANGE. Kalyani publisher. New Delhi.

Mavi HS and Tupper GJ. (2004). Agrometeorology: Principle and Application of climate Studies in Agriculture. Haworth Press

SR Reddy and D S Reddy. (2008). Agrometeorology Kalyani publisher

Varshneya MC &Pillai PB. (2003). Text Book of Agricultural Meteorology. ICAR.

Course Name	Agro-meteorology and climate change
Lesson 2	Composition and structure of atmosphere -definition of weather and climate- aspects involved in weather and climate
Content Creator Name	Vallal Kannan Sankaralingam
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	Dr. Vijay Gopal More
University/College Name	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Lesson 2

Objectives:

1. To understand the atmosphere
2. To understand the difference of weather and climate

1 Composition of the atmosphere:

The atmosphere is a mixture of many gases. In addition, it contains large quantities of solid and liquid particles collectively called "aerosols". The lower part of the atmosphere contains water vapour from 0.02 to 4 per cent by volume. Nitrogen and oxygen make up approximately to 99 per cent and the remaining 1 per cent by other gases. Innumerable dust particles are also present in the lower layers of the atmosphere. They are microscopic and play an important role in absorption and scattering of insolation.

The proportion of gases changes in the higher layers of the atmosphere in such a way that oxygen will be almost in negligible quantity at the height of120 km. Similarly, carbon dioxide and water vapour are found only up to 90 km from the surface of the earth.

There is no definite upper layer to the atmosphere. The decrease of air (density) with altitude (height) is so rapid that half of the atmosphere lies within 5.5 km (3.5 miles) from the surface and nearly 3/4thof the atmosphere lies upto 11 km (7 miles).

1.1Gases

Carbon dioxide is meteorologically a very important gas as it is transparent to the incoming solar radiation but opaque to the outgoing terrestrial radiation. It absorbs a part of terrestrial radiation and reflects back some part of it towards the earth's surface. It is largely responsible for the ***green house effect*.** The volume of other gases is constant but the volume of carbon dioxide has been rising in the past few decades mainly because of the burning of fossil fuels. This has also increased the temperature of the air.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Ozone is another important component of the atmosphere found between 10 and 50 km above the earth's surface and acts as a filter and absorbs the *ultra-violet rays* radiating from the sun and prevents them from reaching the surface of the earth.

Table1: **Composition of the atmospheric gases**

Sr.No	Name of the gases	(%)
1	Nitrogen	78.08
2	Oxygen	20.94
3	Argon	0.93
4	Carbon-dioxide	0.03
5	Others	0.02

- Carbon-dioxide is important for Photosynthesis, CO_2 taken by the plants by diffusion process from leaves through stomata.CO_2 is returned to atmosphere during decomposition of organic materials, all farm wastes and by respiration
- Oxygen is important for respiration of both plants and animals while it is released by plants during Photosynthesis
- Nitrogen is one of the important major plant nutrient, Atmospheric N is fixed in the soil by lightning, rainfall and N fixing microbes in pulses crops and available to plants
- Certain gases like SO_2, CO, CH_4 and HF released to atmosphere are toxic to plants

1.2Water Vapour

Water vapour is also a variable gas in the atmosphere, which decreases with altitude. In the warm and wet tropics, it may account for four per cent of the air by volume, while in the dry and cold areas of desert and Polar Regions; it may be less than one per cent of the air. Water vapour also decreases from the equator towards the poles. It also absorbs parts of the insolation from the sun and preserves the earth's radiated heat. It thus, acts like a blanket allowing the earth neither to become too cold nor too hot. Water vapour also contributes to the stability and instability in the air.

1.3Dust Particles

Atmosphere has a sufficient capacity to keep small solid particles, which may originate from different sources and include sea salts, fine soil, smoke-soot, ash, pollen, dust and disintegrated particles of meteors. Dust particles are generally concentrated in the lower layers of the atmosphere; yet, convectional air currents may transport them to great heights. The higher concentration of dust particles is found in subtropical and temperate regions due to dry winds in comparison to equatorial and Polar Regions. Dust and salt particles act ashygroscopic nuclei around which water vapour condenses to produce clouds.

2Physical structure of the atmosphere

The atmosphere consists of different layers with varying density and temperature. Density is highest near the surface of the earth and decreases with increasing altitude. The column of atmosphere is divided into five different layers depending upon the temperature condition. They are troposphere, stratosphere, mesosphere, thermosphere and exosphere.

On the basis of vertical temperature variation, the atmosphere is divided into different spheres or layers as detailed below:

2.1 Troposphere

- The word “Tropo” means mixing or turbulence and “Sphere” means region.
- The average height of this lower most layer of the atmosphere is about 14 km above the mean sea level; at the equator it is 16 km and 7- 8 km at the poles.
- Under normal conditions the height of the troposphere changes from place to place and season to season
- Various types of clouds, thunderstorms, cyclones and anti cyclones occur in this sphere because of the concentration of almost all the water vapour and aerosols in it. So, this layer is called as “Seat of weather phenomena”.
- The wind velocities increase with height and attain the maximum at the top of this layer.

- Another striking feature of troposphere is that there is a decrease of temperature with increasing elevation at a mean lapse rate of about 6.5°C per km or 3.6°F per 1,000 feet.
- Most of the radiation received from the sun is absorbed by the earth's surface. So, the troposphere is heated from below.
- In this layer, about 75 per cent of total gases, most of the moisture and dust particles are present.
- At the top of the troposphere there is a shallow layer separating it from stratosphere which is known as “Tropopause”.
- The tropopause layer is thin and its height changes according to the latitudes and in fact this is a transitional zone and distinctly characterised by no major movement of air.

2.2 Stratosphere/ Ozonosphere

- This layer exists above the tropopause (around 20 km onwards) and extends to altitudes of about 50-55 km.
- This layer is called as "Seat of photochemical reactions".
- In any particular locality, the temperature remains practically constant at around 20 km and is characterised as isothermal because the air is thin, clear, cold and dry.
- The temperature of this layer increases with height and also depends upon troposphere because troposphere is higher at equator than at poles.
- The increase in temperature with height occurs because of absorption of ultraviolet (UV) radiation from the sun by this ozone. Temperatures in the stratosphere are highest over the summer pole, and lowest over the winter pole.
- In the upper parts of the stratosphere the temperatures are almost as higher as those near the earth's surface, which is due to the fact that the ultra violet radiation from the sun is absorbed by ozone in this region.
- By absorbing dangerous UV radiation, the ozone in the stratosphere protects us from skin cancer and other health damage. However

Designed and developed under the aegis of NAHEP Component-2 Project “Investments In ICAR Leadership In Agricultural Higher Education”
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

chemicals (called CFCs or freons, and halons) which were once used in refrigerators, spray cans and fire extinguishers have reduced the amount of ozone in the stratosphere, particularly at polar latitudes, leading to the so-called "Antarctic ozone hole".

- Less convection takes place in the stratosphere because it is warm at the top and cold at the bottom.
- There is also persistence of circulation patterns and high wind speeds.
- The upper boundary of the stratosphere is called stratopause and above this level there is a steep rise in temperature.
- There is a maximum concentration of ozone between 30 and 60 km above the surface of the earth and this layer is known as ozonosphere.
- A property of ozone is that it absorbs ultra violet rays. Had there been no layer of ozone in the atmosphere, the ultra violet rays would have reached the surface of the earth and no life on it.
- The temperature of the ozonosphere is high (warm) due to selective absorption of ultra violet radiation by ozone.
- In this layer the temperature increases with height at the rate of 5°C per each kilometer.

2.3 Mesosphere

- According to some leading scientists the ionosphere is supposed to start at a height of 80 km above the earth's surface. The layer between 50 and 80 km is called Mesosphere. In this layer the temperature decreases with height. The upper boundary of this layer is called the mesopause.
- The mesosphere lies between thermosphere and stratosphere. “Meso” means middle, and this is the highest layer of the atmosphere in which the gases are all mixed up rather than being layered by their mass. It extends from about 50 to 85 km (31 to 53 miles) above our planet.

- Temperature decreases with height throughout the mesosphere. The coldest temperatures in Earth's atmosphere, about -90° C (-130° F), are found near the top of this layer.
- The boundary between the mesosphere and the thermosphere is called the mesopause. At the bottom of the mesosphere is the stratopause, the boundary between the mesosphere and the stratosphere.
- The mesosphere is difficult to study, so less is known about this layer of the atmosphere than other layers. Weather balloons and other aircraft cannot fly high enough to reach the mesosphere. Satellites orbit above the mesosphere and cannot directly measure the traits of this layer. Scientists use instruments on sounding rockets to sample the mesosphere directly, but such flights are brief and infrequent. Since it is difficult to take measurements of the mesosphere directly using instruments, much about the mesosphere is still mysterious.
- Most meteors vaporize in the mesosphere. Some material from meteors lingers in the mesosphere, causing this layer to have a relatively high concentration of iron and other metal atoms.
- Very strange, high-altitude clouds called "noctilucent clouds" or "polar mesospheric clouds" sometimes form in the mesosphere near the poles. These peculiar clouds form higher up than other types of clouds. The mesosphere, like the stratosphere below it, is much drier than the moist troposphere making the formation of clouds in this layer a bit of a surprise. Odd electrical discharges akin to lightning, called "sprites" and "ELVES", occasionally appear in the mesosphere dozens of km (miles) above thunderclouds in the troposphere below.
- The stratosphere and mesosphere together are sometimes referred to as the middle atmosphere. At the mesopause (the top of the mesosphere) and below, gases made of different types of atoms and molecules are thoroughly mixed together by turbulence in the atmosphere. Above the mesosphere, in the thermosphere, and

beyond, gas particles collide so infrequently that the gases become somewhat separated based on the types of chemical elements they contain.

- Various types of waves and tides in the atmosphere influence the mesosphere. These waves and tides carry energy from the troposphere and the stratosphere upward into the mesosphere, driving most of its global circulation.
- Because of the preponderance of chemical process this sphere is called as "Chemosphere".

2.4 Thermosphere and Ionosphere

- Located between about 80 and 700 kilometers (50 and 440 miles) above Earth’s surface is the thermosphere, whose lowest part contains the ionosphere. The energetic solar radiation knocks electrons off molecules and atoms, turning them into "ions" with a positive charge. The atmosphere in ionosphere is partly ionised. Enriched ion zones exist in the form of distinct ionised layers. So, this layer is called as ionosphere.
- In this layer, temperatures increase with altitude due to the very low density of molecules found here. This temperature increase is caused by the absorption of energetic ultraviolet and X-Ray radiation from the sun.
- It is both cloud- and water vapor-free.
- The aurora borealis and aurora australis are sometimes seen here.
- The International Space Station orbits in the thermosphere.
- The temperature of the thermosphere varies between night and day and between the seasons, as do the numbers of ions and electrons which are present.
- The ionosphere reflects and absorbs radio waves, allowing us to receive shortwave radio broadcasts.
- The ionosphere reflects radio waves because of one or multiple reflections of short-wave radio beams from the ionised shells. So, long distance radio communication is possible due to this layer.

Designed and developed under the aegis of NAHEP Component-2 Project “Investments In ICAR Leadership In Agricultural Higher Education”
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

2.5 Exosphere

- Located between about 700 and 10,000 km (440 and 6,200 miles) above Earth's surface, the exosphere is the highest layer of Earth's atmosphere and, at its top, merges with the solar wind.
- Molecules found here are of extremely low density, so this layer doesn't behave like a gas, and particles here escape into space so low that collisions between neutral particles become extremely rare.
- While there's no weather at all in the exosphere, the aurora borealis and aurora australis are sometimes seen in its lowest part.
- Most Earth satellites orbit in the exosphere.
- Hydrogen and Helium gases predominate in this outer most region.

2.6 Magnetosphere

- The earth behaves like a huge magnet.
- It traps electrons (negative charge) and protons (positive), concentrating them in two bands about 3,000 and 16,000 km above the globe - the Van Allen "radiation" belts.
- This outer region surrounding the earth, where charged particles spiral along the magnetic field lines, is called the magnetosphere.

2.7 The Edge of Outer Space

- While there is really no clear boundary between where Earth's atmosphere ends and outer space begins, most scientists use a delineation known as the Karman line, located 100 km (62 miles) above Earth's surface, to denote the transition point, since 99.99997 percent of Earth's atmosphere lies beneath this point. A February 2019 study using data from the NASA/European Space Agency Solar and Heliospheric Observatory (SOHO) spacecraft suggests, however, that the farthest reaches of Earth's atmosphere, a cloud of hydrogen atoms called the geocoronamay actually extend nearly 629,300 km(391,000 miles) into space, far beyond the orbit of the Moon.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

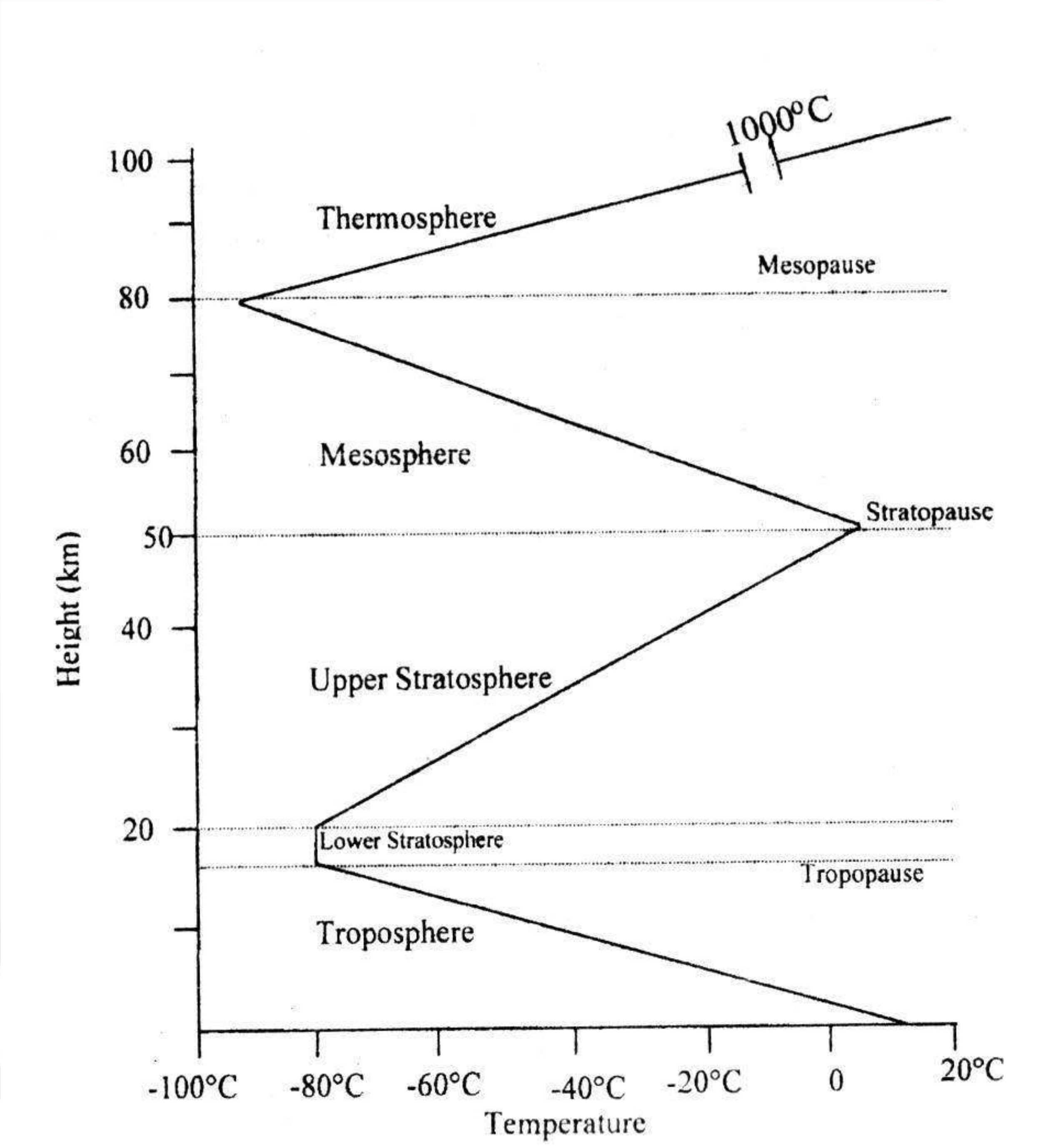


Fig-1: Atmospheric layers based on temperature

3. DEFINITIONS OF WEATHER AND CLIMATE, MICRO-CLIMATE

3.1 Weather

i) 'A state or condition of the atmosphere at a given place and at a given instant of time'.Eg. Cloudy day

ii) 'The daily or short-term variations of different conditions of lower air in terms of temperature, pressure, wind, rainfall, etc'.

iii) State of atmosphere at a particular time as defined by the various meteorological elements.(WMO).

The aspects involved in weather include small areas and duration, expressed in numerical values, etc. The different weather elements are solar radiation, temperature, pressure, wind, humidity, rainfall, evaporation, etc. is highly variable. It changes constantly sometimes from hour to hour and at other times from day to day.

3.2Climate

i) 'The generalized weather or summation of weather conditions over a given region during comparatively longer period'. Eg. Winter season

ii) 'The sum of all statistical information of weather in a particular area during a specified interval of time, usually, a season or a year or even a decade'.

iii) Synthesis of weather conditions in a given area, characterized by long-term statistics (mean values, variances, probabilities of extreme values, etc,) of the meteorological elements in that area. (WMO)

The aspects involved are larger areas like a zone, a state, a country and is described by normal. The climatic normal are generally worked out for a period of 30 years.

Table2 Differentiate Weather Vs. Climate

	Weather	**Climate**
1.	A typical physical condition of the atmosphere.	Generalized condition of the atmosphere, which represents and describes characteristics of a region
2.	Changes from place to place even in a small locality	Different in different large region
3.	Changes according to time (every moment)	Change requires longer (years) time.

4.	Similar numerical values of weather of different places usually have same weather	Similar numerical values of climate of different places usually have different climates
5.	Crop growth, development and yield are decided by weather in a given season.	Selection of crops suitable for a place isdecided based on climate of the region
6.	Under abnormal weather conditions planners can adopt a short-term contingent planning.	Helps in long-term agricultural planning.

3.3Climatology

It is defined as “The science dealing with the factors which determine and control the distribution of climate over the earth's surface”.

3.3.1 Factors affecting climate

3.3.1.1 Latitude

The distance from the equator, either south or north, largely creates variations in the climate. Based on the latitude, the climate has been classified as i) Tropical ii) Sub-tropical iii) Temperate and iv) Polar.

3.3.1.2 Altitude (elevation)

The height from the MSL creates variation in climate. Even in the tropical regions, the high mountains have temperate climate. The temperature decreases by 6.5 ºC km^{-1} from the sea level. Generally, there is also a decrease in pressure and increase in precipitation and wind velocity. The above factors alter the kind of vegetation, soil types and the crop production.

3.3.1.3 Precipitation

The quantity and distribution of rainfall decides the nature of vegetation and the nature of the cultivated crops. The crop regions are classified on the basis of average rainfall which is as follow.

Table 3 Classification of climatic region based on rainfall

Rainfall(mm)	Name of the climatic region
Less than 500	Arid
500-750	Semi-arid
750-1000	Sub-arid
More than 1000	Humid

3.3.1.4 Soil type

Soil is a product of climatic action on rocks as modified by landscape and vegetation over a long period of time. The colour of the soil surface affects the absorption, storage and reradiation of heat. White colour reflects while black absorbs more radiation. Due to differential absorption of heat energy, variations in temperature are created at different places. In black soil areas, the climate is hot while in red soil areas, it is comparatively cooler due to lesser heat absorption.

3.3.1.5 Nearness to large water bodies

The presence of large water bodies like lakes and sea including ocean current affect the climate of the surrounding areas, e. g. Islands and coastal areas. The movement of air from earth's surface and from water bodies to earth modifies the climate. The extreme variation in temperature during summer and winter is minimized in coastal areas and island.

3.3.1.6 Topography

The surface of landscape (plain or undulating surface areas) produces marked change in the climate. This involves the altitude of the place, steepness of the slope and exposure of the slope to light and wind.

3.3.1.7 Vegetation

Kinds of vegetation characterize the nature of climate. Thick vegetation is found in tropical regions where temperature and precipitation are high. General types of vegetations present in a region indicate the nature of the climate of that region.

4 Scales of climate and their importance

4.1 Microclimate

Microclimate deals with the climatic features peculiar to small areas and with the physical processes that take place in the layer of air very near to the ground. Soil-ground conditions, character of vegetation cover, aspect of slopes, and state of the soil surface, relief forms – all these may create special local conditions of temperature, humidity, wind and radiation in the layer of air near the ground which differ sharply from general climatic conditions. One of the most important tasks of agricultural meteorology is to study the properties of air near the ground and surface layer of soil, which falls under the micro climate.

4.2 Mesoclimate

The scale of mesoclimate falls between micro and macro climates. It is concerned with the study of climate over relatively smaller areas between 10 to 100 km across.

4.3 Macroclimate

Macro climate deals with the study of atmosphere over large areas of the earth and with the large-scale atmospheric motions that cause weather.

The scales of air motion in different climates are given in the Table below.

Table 4 Types of climates and their scales

Type of climate	Horizontal scale(km)	Vertical scale(km)	Time Scale(hrs.)
A. Macroclimate			
1. Planetary scale	2000-5000 and more	10	200 to 400
2. Synoptic scale	500-2000	10	100

B. Mesoclimate	1 to 100	1-10	1-10
C. Microclimate	<100m	200 m	6-12 minutes

If any weather system develops under different types of climates, it persists longer periods under the macroclimate while smaller periods under micro climates.

Glossary

Aerosols:Solid and liquid particles in the atmosphere is collectively called "aerosols"

Climate: Long term regime of atmospheric variables of a given place or area.

Climatology: "The science dealing with the factors which determine and control the distribution of climate over the earth's surface".

Exosphere: The outer most layer of the earth's atmosphere is named as exosphere and this layer lies between 400 and 1,000 kilometres.

Mesosphere: The layer between 50 and 80 kilometer is called Mesosphere.

Stratopause: The upper boundary of the stratosphere is called stratopause and above this level there is a steep rise in temperature.

Thermosphere: The layer between 80 and 140 kilo meter is known as "Thermosphere".

Tropopause: At the top of the troposphere there is a shallow layer separating it from stratosphere which is known as "Tropopause

Weather: Physical state of the atmosphere at a given place and given time.

Isothermal process: In thermodynamics, an **isothermal process** is a type of thermodynamic process in which the temperature (T) of a system remains constant ($\Delta T = 0$). This typically occurs when a system is in contact with an outside thermal reservoir, and a change in the system occurs slowly enough to allow the system to be continuously adjusted to the temperature of the reservoir through heat exchange. In contrast, an *adiabatic process* is where a system exchanges no heat with its surroundings (*Q* = 0).

Adiabatic process: In thermodynamics **adiabatic process**, an **adiabaticprocess** (Greek: *adiábatos*, "impassable") is a type of thermodynamic process that occurs without transferring heat or mass betweenthe thermodynamic system and its environment. Unlike an isothermal process, an adiabatic process transfers energy to the surroundings only as work. As a key concept in thermodynamics, the adiabatic process supports the theory that explains the first law of thermodynamics.

Some chemical and physical processes occur too rapidly for energy to enter or leave the system as heat, allowing a convenient "adiabatic approximation". For example, the adiabatic flame temperature uses this approximation to calculate the upper limit of flame temperature by assuming combustion loses no heat to its surroundings.

In meteorology and oceanography, adiabatic cooling produces condensation of moisture or salinity, oversaturating the parcel. Therefore, the excess must be removed. There, the process becomes a *pseudo-adiabatic process* whereby the liquid water or salt that condenses is assumed to be removed upon formation by idealized instantaneous precipitation. The pseudoadiabatic process is only defined for expansion because a compressed parcel becomes warmer and remains undersaturated.

Aurora: An **aurora**(plural: **auroras** or **aurorae**), also known as the **polar lights** or **aurora polaris**, is a natural light display in Earth's sky, predominantly seen in high-latitude regions (around the Arctic and Antarctic). Auroras display dynamic patterns of brilliant lights that appear as curtains, rays, spirals, or dynamic flickers covering the entire sky.

Auroras are the result of disturbances in the magnetosphere caused by solar wind. These disturbances alter the trajectories of charged particles in the magnetospheric plasma. These particles,

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

mainly electrons and protons, precipitate into the upper atmosphere (thermosphere/exosphere). The resulting ionization and excitation of atmospheric constituents emit light of varying colour and complexity. The form of the aurora, occurring within bands around both polar regions, is also dependent on the amount of acceleration imparted to the precipitating particles.

The word "**aurora**" is derived from the name of the Roman goddess of the dawn, Aurora, who travelled from east to west announcing the coming of the sun.Ancient Greek poets used the name metaphorically to refer to dawn, often mentioning its play of colours across the otherwise dark sky. The word "**borealis**" is derived from the name of the Ancient Greek god of the north wind, Boreas, while the word "**australis**" is derived from the Latin *auster* (“south”).

Images of auroras from around the world, including those with rarer red and blue lights

Van Allen radiation belt: A **Van Allen radiation belt** is a zone of energetic charged particles, most of which originate from the solar wind, that are captured by and held around a planet by that planet's magnetosphere. Earth has two such belts, and sometimes others may be temporarily created. The belts are named after James Van Allen, who is credited with their discovery.Earth's two main belts extend from an altitude of about 640 to 58,000 km (400 to 36,040 mile)above the surface, in which region radiation levels vary. Most of the particles that form the belts are thought to come from solar wind and other particles by cosmic rays. By trapping the solar wind, the magnetic field deflects those energetic particles and protects the atmosphere from destruction.

The belts are in the inner region of Earth's magnetic field. The belts trap energetic electrons and protons. Other nuclei, such as alpha particles, are less prevalent. The belts endanger satellites, which must have their sensitive components protected with adequate shielding if they spend significant time near that zone. In 2013, the Van Allen Probes detected a transient, third radiation belt, which persisted for four weeks.

Reference:

https://climate.nasa.gov/news/2919/earths-atmosphere-a-multi-layered-cake/

https://niwa.co.nz/education-and-training/schools/students/layers

Mavi.H.S.(2018). Introduction to Agromteorology 2Ed (PB 2019). Oxford & IBH Publishing Co Pvt.Ltd. New Delhi.

Mote, D.D. and Sahu. B.M.(2014). Principles of Agricultural Meteorology. Scientific Publishers.Jodhpur, Rajasthan. ISBN-10 : 8172339097ISBN-13 : 978-8172339098.

Prasada Rao. G. S. L. H. V. (2008). Agricultural Meteorology, Prentice Hall India Learning Private Limited. Delhi. ISBN-10 : 8120333381ISBN-13 : 978-8120333383.

Reddy,S.R. and Reddy.D.S. (2008). Agrometeorology, Kalyani publisher, New Delhi. ISBN: 9789327225945, 9327225945.

Course Name	Agro-meteorology and climate change
Lesson 3	Atmospheric temperature and soil temperature
Content Creator Name	Vallal Kannan Sankaralingam
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	Dr. Vijay Gopal More
University/College Name	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Lesson 3

Objectives:

- To understand the atmospheric temperature and their changes.
- To understand the soil temperature and their role in crop production.

1. Definition of Temperature and Heat:

Temperature is defined as “The measure of speed per molecule of all themolecules of a body” whereas heat is “The energy arising from random motion of allthe molecules of a body”.The temperature of a body is the condition which determines its ability totransfer heat to other bodies or to receive heat from them. In a system of two bodies theone which loses heat to the other is said to be at a higher temperature.Heat measures total molecular energy. Temperature measures average energy ofindividual molecules. Temperature is that characteristic of a body which determines thedirection of heat flow by conduction.

1.1Air temperature

1.1.1Temperature Distribution

Each day the earth receives energy in the form of incoming solar radiation from the sun as short wave solar radiation and long wave solar radiation.Shortwave solar radiation ranges mostly from ultra-violet (0.2 µm wavelength) to the near infrared (3.0 microns wavelength), but reaches its maximum at around 0.5 microns wavelength (Blue-green visible light).This insolation is absorbed by the earth’s surface and is converted to heat (long wave radiation)The earth’s (terrestrial) longwave radiation reaches its peak intensity at 10 microns wavelength (thermal infrared) and is responsible for heating the lower atmosphere.

1.1.1.1Horizontal temperature distribution

Sun rays make different angles at the same place at different times. Also different angles at the same time at different places as the axis of the earth makes an angle of 23-50 with the vertical. Due to the variation in angle of sunrays distribution of solar heat on earth decreases both ways from equator to polar. This is known as horizontal distribution of air temperature. On maps, the horizontal distribution of temperature is shown by isotherms. The isotherms are imaginary lines drawn the connecting points that have equal temperature.The lines connecting points of equal temperature is called as **isotherm**

1.1.1.2 Factors affecting horizontal air temperature

i. Latitude
ii. Altitude
iii. Distribution of land and water
iv. Ocean currents
v. Prevailing winds
vi. Cloudiness
vii. Mountain barriers
viii. Nature of surface
ix. Relief
x. Convection and turbulence etc.

1.1.1.2.1 Latitude

The time of occurrence of maximum monthly mean temperature and minimummonthly mean temperature also depends on latitude of a place. The coldest month is January in northern regions of India while December in the south. Similarly, thewarmest month is May in the south while June in the north across the country.

1.1.1.2.2 Altitude

The surface air temperature decreases with increasing altitude from the meansea level as the density of air decreases. Since the density of air is less at higheraltitudes, the absorbing capacity of air is relatively less with reference to earth's long wave radiation. At surface, high density of air, high water vapour content and more dust particles results in more absorption of earth's long wave radiation.

1.1.1.2.3 Distribution of land and water

Land and water surfaces react differently to the insolation. Because of the greatcontrasts between land and water surfaces their capacity for heating the atmospherevaries. Variations in air temperature are much greater over the land than over the water.The differential heating process between land and sea surfaces are due to theirproperties. It is one of the reasons for Indian monsoon.

1.1.1.2.4 Ocean currents

The energy received over the ocean surface carried away by the ocean currentsfrom the warm areas to cool areas. This results in temperature contrast between theequator and poles. The occurrence of El-Nino is due to change in sea surfacetemperature between two oceanic regions over the globe.

1.1.1.2. 5 Prevailing winds

Winds can moderate the surface temperature of the continents and oceans. Inthe absence of winds, we feel warm in hot climates. At the same time, the weather ispleasant if wind blows.

1.1.1.2.6 Cloudiness

The amount of cloudiness affects the temperature of the earth’s surface and theatmosphere. A thick cloud reduces the amount of insolation received at a particularplace and thus the day time temperature is low. At the same time, the lower layers in theatmosphere absorb earth’s radiation. This results in increasing atmospheric temperatureduring night. That is why, cloudy nights are warmer. This is common in the humidtropical climates.

1.1.1.2.7 Mountain barriers

Air at the top of the mountain makes little contact with the ground and is thereforecold while in the valley at the foothills makes a great deal of contact and is thereforewarm. That is, the lower region of the earth’s atmosphere is relatively warmer whencompared to hillocks.

1.1.1.2.8 Topography and relief

In the northern hemisphere north facing slopes generally receive less insolation than south facing slopes and temperatures are normally lower.

1.1.2Vertical temperature distribution

The decrease of air temperature with altitude is known as vertical temperature distribution.Ex: Permanent snow caps in high mountains.

1.1.2.1The vertical distribution of temperature is due to adiabatic lapse rate

An adiabatic process is one in which the system being considered does notexchange heat with its environment.The most common atmospheric adiabatic phenomena are those involving the change of air temperature due to change of pressure.If an air mass has its pressure decreased, it will expand and do mechanical workon the surrounding air.If no heat is taken from the surroundings, the energy required to do work istaken from the heat energy of the air mass, resulting in a temperature decrease.When pressure is increased, the work done in the air mass appears as heat,causing its temperature to rise.The rates of adiabatic heating and cooling in the atmosphere are described aslapse rates and are expressed as the change of temperature with height.The adiabatic lapse rate for dry air is very nearly 1^{o}C per 100 m. If condensation occurs in the air parcel, latent heat is released, therebymodifying the rate of temperature change. This is known as wet adiabatic lapse rate. However, the average adiabatic lapse rate is 6.5^{o}C per km height and it isassumed as 0.5^{o}C per 100 m.

Large scale atmospheric motions are approximately adiabatic and clouds andsnow or rain associated with them are primarily adiabatic phenomena in thatthey result from cooling air associated with decreasing pressure of upward airmotion. Simpler adiabatic phenomena on a smaller scale. A common example is that ofrising “bubbles” of air on a warm day, leading to cumulus cloud forms.The growth of such cumulus clouds into thunder clouds is more complex butstill largely adiabatic phenomena.

1.1.2.2Temperature inversion

Occasionally at some altitude the temperature abruptly increases instead ofdecreasing. This condition in which this abrupt rise instead of fall in temperatureoccurs in the air is known as the temperature inversion. This may occurs underthe following conditions.

- When the air near the ground cools off faster than the overlying layer, because ofheat loss during cooling nights.
- When an actual warm layer passing over a lower cold layer
- Cold air from hill tops and slopes tend to flow downward and replaced by warmair.

1.1.2.3 Types of temperature inversion

Surface inversion: Earth surface loses heat more than it gains, resulting a cool air near earth surface and air above this layer remains warm, and such type of inversion is called as surface inversion.

Warming by subsidence: When cool air mass from top of hill, tends to flow downward and it replaces the warm air near the earth surface. This type of surface inversion is call as warming by subsidence.

From turbulence: Cold air masses replaced by warm air mass when air mass with different temperature come together due to turbulence and temperature inversion take place which is called as inversion due to turbulence.

1.1.2.4Significance of Temperature inversion

- Cloud formation, precipitation and atmospheric visibility are greatly influenced by
  inversion phenomenon
- Fog formation may take place near the ground which may affect the visibility toboth human beings and animals. Affects air navigation.
- Diurnal temperature is affected by temperature inversions.
- The incoming solar radiation and its conversion in to heat are affected.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

1.1.3Periodic temperature variation

The air temperature changes continuously during a day or a year.

1.1.3.1Mean daily cycle of air temperature

From sun rise insolation is supplied and the air temperature continuously rises.Maximum air temperature occurs between 1 PM and 4 PM and minimumtemperature occurs just before sun riseunder clear sky condition.Maximum insolation is received around noon (12 noon) but maximumtemperature is recorded from 1 PM to 4 PM and this delay is known asthermal lag or thermal inertia.

1.1.3.2 Mean annual cycle of temperature

The annual temperature changes from one location to other due to many factors.In the northern hemisphere winter minimum occurs in January and summermaximum in July and vice-versa in southern hemisphere.When loss of longwave radiation exceeds the shortwave radiations receivedthen temperature falls and under reverse of this situations the temperatureincreases in a cycle.

1.1.3.2 Cardinal temperatures

There are three points of temperature which influence the growth of crop plants.These are termed as "cardinal points" and the synonymous term is ‘cardinaltemperature’. A minimum temperature below which growth ceases (minimum cardinaltemperature),an optimum temperature at which the plant growth proceeds with greatestrapidly (optimum cardinal temperature) and a maximum temperature above which plant growth ceases (maximumcardinal temperature).

1.1.3.3Diurnal and seasonal variation of air temperature

The minimum air temperature occurs at about sunrise, after which there is aconstantrise till it reaches to maximum.The maximum air temperature is recorded between 13.00 hrs and 14.00 hrs although the maximum solar radiation is reaches at the Noon.A steady fall in temperature till sunrise is noticed after is attains maximum. Thusthe daily march displays one maximum and one minimum. The differencebetween the two is called the diurnal range of air temperature.

- The diurnal range of air temperature is more on clear days while cloudy weathersharply reduces daily amplitudes.
- The diurnal range of temperature is also influenced by soils and their coverage inaddition to seasons.
- Addition of daily maximum and minimum temperature divided by two is nothingbut daily mean / average temperature.
- In northern hemisphere winter minimum occurs in January and summermaximum in July.

1.2Role of temperature in crop production

1. Temperature influences distribution of crop plants and vegetation.
2. The surface air temperature is one of the important variables, which influences all stages of crop during its growth development and reproductive phase.
3. The growth and development of crop plants are chiefly influenced by airtemperature.
4. Air temperature affects leaf production, expansion and flowering.
5. The diffusion rates of gases and liquid changes with temperature.
6. Solubility of different substances is dependent on temperature.
7. Physical and chemical processes within the plants are governed by air temperature
8. Biochemical reactions in crops (double or more with each 10°C rise) are influenced byair temperature.
9. Equilibrium of various systems and compounds is a function of temperature.
10. Temperature affects the stability of enzymatic systems in the plants.
11. Most of the higher plants grow between 0°C – 60°C and crop plants are furtherrestricted from 10 – 40°C, however, maximum dry matter is produced between 20 and 30°C
12. At high temperature and high humidity, most of the crop plants are affected by pestsand diseases.
13. High night temperature increases respiration and metabolism.

14. A short duration crop becomes medium duration or long duration crop dependingupon its environmental temperature under which it is grown.

1.3Heat Units

It is a measure of relative warmth of growing season of a given length. Normallyit is indicated as Growing Degree Days (GDD). A heat unit is the departure fromthe mean daily temperature above the minimum threshold temperature.The minimum threshold temperature is the temperature below which no growthtakes place.Usually ranges from 4.5 to 12.5 ºC for different crops (Most commonly usedvalue is 6.0ºC)

1.3.1 Degree Day

A degree day is obtained by subtracting the threshold temperature from dailymean temperature. Summation of the daily values over the growth period gives degreedays of the crops.

$$GDD = \Sigma \frac{Tmax + Tmin}{2} - Tb$$

Where

Tmax – Maximum air temperature of the day

Tmin – Minimum air temperature of the day

Tb - Base temperature of the crop. The base temperature is the threshold temperature.

1.3.2 Advantages / Importance of growing degree day concept

1. In guiding the agricultural operations and planting land use.
2. To forecast crop harvest dates, yield and quality
3. In forecasting labour required for agricultural operations
4. Introduction of new crops and new varieties in new areas
5. In predicting the likelihood of successful growth of a crop in an area.

1.4 Air temperature and plant injury

1.4.1 Thermal death point

The temperature at which, the plant cell get killed whenthe temperature ranges from 50-60°C. This varies with plant species. The aquatic andshade loving plants are killed at comparatively lower temperature (40°C).

1.4.1.2 High temperature

High temperature results in desiccation of plants, disturbs the physiological activities like photosynthesis and respiration, and increases respiration leading to rapid depletion of reserve food.

1.4.1.2.1 Sun clad

Injury caused on the barks of stem by high temperature during day time and lowtemperature during the night time.

1.4.1.2. 2 Stem griddle

The stem at ground level scorches around due to high soil temperature. It causesdeath of plant by destroying conductive tissues. Eg. This type of injury is very common inyoung seedlings of cotton in sandy soil when soil temperature exceeds 60°C.

1.4.2Low air temperature and plant injury

On exposure of crop plants to low temperature the following effects are observed. The primary effect of low air temperature below their optimum temperature is the reduction of rates of growth and metabolic processes.

1.4.2.1 Chilling injury

Plants which are adapted to hot climate, if exposed to low temperature forsometime, are found to be killed or severely injured or development of chloratic condition(yellowing) when the night temperature is below 20°C.

1.4.2.2 Freezing injury

This type of injury is commonly observed in plants of temperate regions. Whenthe plants are exposed to very low temperature, water freezes into ice crystals in theintercellular spaces of plants. The protoplasm of cell is dehydrated resulting in the deathof cells. E.g. Frost damage in potato, tea, etc.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

1.4.2.3Suffocation

In temperature regions, usually during the winter season, the ice or snow forms athick cover on the soil surface. As a result, the entry of oxygen is prevented and cropsuffers for want of oxygen. Ice coming in contact with the root prevents the diffusion ofCO_2 outside the root zone. This prevents the respiratory activities of roots leading toaccumulation of harmful substances.

1.4.2.4Heaving

This is a kind of injury caused by lifting up of the plants along with soil from itsnormal position. This type of injury is commonly seen in temperate regions. Thepresence of ice crystals increases the volume of soil. This causes mechanical lifting ofthe soil.

Thermo periodic response: Response of living organism to regular changes in temperature either day ornight or seasonal is called thermoperiodism.

2.Soil temperature

The soil temperature is one of the most important factors that influence the crop growth. The sown seeds, plant roots and micro organisms live in the soil. The physiochemical as well as life processes are directly affected by the temperature of the soil. Under the low soil temperature conditions signification is inhibited and the intake of water by root is reduced. In a similar way extreme soil temperatures injures plant and itsgrowth is affected.Eg. On the sunny side, plants are likely to develop faster near a wall that store andradiates heat. If shaded by the wall, however, the same variety may mature later. In such cases soil temperature is an important factor.

2.1Importance of soil temperature on crop plants

The soil temperature influences many process.

1. Governs uptake of water, nutrients etc needed for photosynthesis.
2. Controls soil microbial activities and the optimum range is 18-30°C.
3. Influences the germination of seeds and development of roots.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

4. Plays a vital role in mineralization of organic forms of nitrogen. (Increase in soil temperature increases the soil nitrogen mineralization rates through the increase in microbial activity and increase in the decomposition of organic matter in the soil.)
5. Influences the presence of organic matter in the soil.(more under low soil temperature)
6. Affects the speed of reactions and consequently weathering of minerals.
7. Influences the soil structure (types of clay formed, the exchangeable ions present, etc.)

2.2Factors affecting soil temperature

Heat at ground surface is propagated downward in the form of waves. The amplitude deceases with depth. Both meteorological and soil factors contribute in bringing about changes of soil temperature.

2.2.1 Meteorological factors

2.2.1.1 Solar radiation

a) The amount of solar radiation available at any given location and point of time is directly proportional to soil temperature.
b) Even though a part of total net radiation available is utilized in evapo-transpiration and heating the air by radiation (latent and sensible heat fluxes) a relatively substantial amount of solar radiation is utilized in heating up of soil (ground heat flux) depending up on the nature of surface.
c) Radiation from the sky contributes a large amount of heat to the soil in areas wherethe sun’s rays have to penetrate the earth’s atmosphere very obliquely.

2.2.1.2Wind

Air convection or wind is necessary to heat up the soil by conduction from the atmosphere.E.g.the mountain and valley winds influence the soil temperature.

2.2.1.3 Evaporation and condensation

a) The greater the rate of evaporation the more the soil is cooled. This is the reason for coolness of moist soil in windy conditions.

b) On the other hand whenever water vapour from the atmosphere or from other soil depths condenses in the soil it heats up noticeably. Freezing of water generates heat.

2.2.1.4 Rainfall (Precipitation)

Depending on soil temperature, precipitation can either cool or warm the soil.

2.2.2Soil factors

2.2.2.1. Aspect and slope

a) In the middle and high latitudes of the northern hemisphere, the southern slopes receive more insolation per unit area than the northern exposure.

b) The south west slopes, are usually warmer than the south east slopes. The reason is that the direct beam of solar radiation on the south east slope occurs shortly after prolonged cooling at night, but the evaporation of dew in the morning also requires energy.

2.2.2.2. Soil texture

a) Because of lower heat capacity and poor thermal conductivity, sandy soils warm up more rapidly than clay soils. The energy received by it is concentrated mainly in a thin layer resulting in extraordinary rise in temperature.

b) Radiational cooling at night is greater in light soils than in heavy soils. In the top layer, sand has the greatest temperature range, followed by loam and clay.

c) The decrease of range with depth is more rapid in light soils than heavy soils when they are dry but slower when they are wet.

d) A soil with rough surface absorbs more solar radiation than one with a smooth surface.

2.2.2.3. Tillage and Tilth

a) By loosening the top soil and creating mulch, tillage reduces the heat flow betweenthe surface and the sub soil.

b) Since, the soil mulch has a greater exposure surface than the undisturbed soil and no capillary connection with moist layers below, the cultivated soil dries up quickly by evaporation, but the moisture in the sub-soil underneath the dry mulch is conserved.

c) In general soil warms up faster than air. The diurnal temperature wave of the cultivated soil has much larger amplitude than that of the uncultivated soil.

d) The air 2-3 cm above the tilled soil is often hotter (10°C or above) than that over an untilled soil.

e) At night loosened ground is colder and more liable to frost than the uncultivated soil.

2.2.2.4. Organic matter

a) The addition of organic matter to a soil reduces the heat capacity and thermal conductivity. But, the water holding capacity increases.

b) The absorbtivity of the soil increases because of the dark colour of the organic matter.

c) At night, the rapid flow of heat from sub-soil by radiation is reduced with the additionof organic matter because of its low thermal conductivity.

d) The darker the colour, the smaller the fraction of reflected radiation.

e) The dark soils and moist soils reflect less than the light coloured and dry soils.

2.2.2.5. Soil moisture

a) Moisture has an effect on heat capacity and heat conductivity.

b) Moisture at the soil surface cools the soil through evaporation.

c) Therefore, a moist soil will not heat up as much as a dry one.

d) Moist soil is more uniform in temperature throughout its depth as it is a better conductor of heat than the dry soil.

2.3Variations in soil temperature

There are two types of soil temperature variations; daily and seasonal variation of soil temperature

2.3.1Daily variations of soil temperature

a) These variations occur at the surface of the soil.

b) At 5 cm depth the change exceeds 10°C. At 20 cm the change is less and at 80 cm diurnal changes are practically nil.

c) On cooler days the changes are smaller due to increased heat capacity as the soils become wetter on these days.
d) On a clear sunny day a bare soil surface is hotter than the air temperature.
e) The time of the peak temperature of the soil reaches earlier than the air temperature due to the lag of the air temperature.
f) At around 20 cm in the soil the temperature in the ground reaches peak after the surface reaches its maximum due to more time the heat takes to penetrate the soil. The rate of penetration of heat wave within the soil takes around 3 hours to reach 10 cm depth.
g) The cooling period of the daily cycle of the soil surface temperature is almost double than the warming period.
h) Undesirable daily temperature variations can be minimized by scheduling irrigation.

2.3.2 Seasonal variations of soil temperature

a) Seasonal variations occur much deeper into the soil.
b) When the plant canopy is fully developed the seasonal variations are smaller.
c) In winter, the depth to which the soil freezes depends on the duration and severeness of the winter.
d) In summer the soil temperature variations are much more than winter in tropics andsub tropics.

Glossary:

Cardinal temperatures: There are three points of temperature which influence the growth of crop plants. These are termed as "cardinal points" and the synonymous term is `cardinal temperature’ A minimum temperature below which growth ceases (minimum cardinal temperature). An optimum temperature at which the plant growth proceeds with greatest rapidly (optimum cardinal temperature).A maximum temperature above which plant growth ceases (maximum cardinal temperature).

Designed and developed under the aegis of NAHEP Component-2 Project “Investments In ICAR Leadership In Agricultural Higher Education”
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Heat Units: It is a measure of relative warmth of growing season of a given length.

Heat: The energy arising from random motion of all the molecules of a body. Heat measures total molecular energy.

Isotherm: The isotherms are imaginary lines drawn the connecting points that have equal temperature. The lines connecting points of equal temperature is called as **isotherm.**

Temperature inversion: Occasionally at some altitude the temperature abruptly increases instead ofdecreasing. This condition in which this abrupt rise instead of fall in temperatureoccurs in the air is known as the temperature inversion.

Temperature: The measure of speed per molecule of all the molecules of a body. Temperature measures average energy of individual molecules.

Thermoperiodism: Response of living organism to regular changes in temperature either day or night or seasonal is called thermoperiodism.

Reference:

Alok Kumar Patra.(2020).Introduction to Agrometeorology and Climate Change. NIPA, New Delhi. ISBN. 9789387973619.

Lalitha,B.S., Kalyana Murthy,K.N., Jayadeva., H.M. and Prajwal Kumar, G.K. (2018). Introduction to Agricultural Meteorology & Climate Change. Agro India Publications, Allahabad. ISBN-10 : 9384188093ISBN-13 : 978-9384188092.

Mahi, G.S. and Kingra P.K.(2014). FUNDAMENTALS OF AGROMETEOROLOGY AND CLIMATE CHANGE. Kalyani publisher. New Delhi. ISBN: 9788056972311, 8056972315.

Mavi, H.S., 1996. Introduction to Agrometeorology, oxford and IBH Publishing Co., New Delhi. Gopalaswamy, N. 1994. Agricultural Meteorology, Rawat publications, Jaipur.

Course Name	Agro-meteorology and climate change
Lesson 4	Solar radiation, atmospheric pressure, atmospheric humidity, evaporation and transpiration
Content Creator Name	Vallal Kannan Sankaralingam
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	Dr. Vijay Gopal More
University/College Name	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Lesson 4

Objectives:

- To understand the characters of solar radiation and their effect on crop production
- To understand the other atmospheric characters and their influence

1. Solar radiation

Solar radiation is the primary source of energy on earth, and life depends on it.Solar radiation is defined as “The flux of radiant energy from the sun”. All matter at atemperature above the absolute zero, imparts energy to the surrounding space. Thisenergy is transformed by green plants in the process of photosynthesis into the potentialenergy of organic material. In inorganic bodies the rays absorbed are used in heating.The variations of the total radiation flux from one site to another on the surface of theearth are enormous and the distribution of plants and animals responds to this variation.

Heat energy is transmitted by three processes.

Radiation: Radiation is the process of transmission of thermal energy in the form of Electromagnetic waves from one place to another even through vacuum with the speed of light and is the means by which energy emitted by the sun reaches the earth.

Every material and biological body in our vicinity i.e., soil, water, plants, animals, etc. with temperature greater than absolute zero emits characteristic radiation specific to its own body temperature. Thus, all bodies are in interaction with other bodies through radiation process.

Conduction: Conduction is the process of heat transfer through matter by molecular activity. In this process heat is transferred from one part of a body to another or between two objects touching each other. Conduction occurs through molecular movement.

Convection: Convection is the process of the transfer of heat, through movement of a mass or substance from one place to another. Convention

is possible only in gases or fluids, for they alone have internal mass motions. In solid substances this type of heat transfer is impossible.
Of the above three processes of transmission of energy convection is the predominantform of transmission of energy on the earth. All the weather related processes involvethis process.

1.1 Solar Radiation

When the radiation is transmitted from the sun, it is known as solarradiation.

Radiation flux: The amount of radiant energy emitted, received, transmitted across a particular area is known as radiant flux.

Radiant flux density: The radiant flux divided by the area across which the radiation is transmitted is called radiant flux density.

Emissive power: The radiant flux density emitted by a source is called its emissive power.

1.2 Solar spectrum

Radiant energy is transmitted in the form of electromagnetic waves by the sun. Theenergy from the sun is spread over a very broad band of wave lengths known as solarspectrum. It is also known as electromagnetic spectrum. The spectrum does notconstitute only one band, but a combination of different waves which are characterisedindividually.

Example: U.V. rays, light part, Near I.R., Far I.R. Radio weaves, micro waves, radarwaves, etc.

Table-1: Energy content of different bands in solar spectrum.

Spectrum	**Wave length in microns**	**Percentage of insolation**
Gamma r-rays, f-rays and x-rays	0.005-0.20	7%
U.V. rays	0.2 - 0.4	
Violet	0.4 - 0.43	41 %
Blue	0.43 - 0.49	
Green	0.49 - 0.53	
Yellow	0.53 - 0.58	
Orange	0.58 - 0.66	

Red	0.63 - 0.70	
Infrared rays	> 0.70	52%

Different bands of solar spectrum are:

1. The shorter wave lengths of the spectrum are known as U.V. rays. These are chemically very active. Unless these are filtered in the atmosphere, there is a danger for life on the earth. This band ranges between 0.005 to 0.4 microns.
2. The part of the spectrum which is visible known as `light'. It is the part of the spectrum which is essential for all the plant processes and ranges from 0.4 to 0.70microns.
3. The third part of the solar spectrum (last band) is known infra red band. This is essential for thermal energy of the plant (the source of heat to the plant). This band is having wavelength more than 0.70 microns.

1.3Solar radiation and crop plants

Crop production is exploitation of solar radiation. Three broad spectra

1.3.1. Shorter than visible range: Chemically very active, when plants are exposed to this radiation the effects are detrimental.Atmosphere acts as regulator for this radiation and none of cosmic, Gamma andXraysreaches to the earth.The UV rays of this segment reaching to the earth are very low and it is normallytolerated by the plants.

1.3.2. Higher than visible wavelength: Referred to IR radiation, it has thermal effect on plants, In the presence of water vapour, this radiation does not harm plants, rather itsupplies the necessary thermal energy to the plant environment.

1.3.3. Visible spectrum: Between UV and IR radiation and also referred as light, all plant parts are directly or indirectly influenced by the light, intensity, quality and duration are important for normal plant growth, poor light leads to plant abnormalities, light is indispensable to photosynthesis, light affect the production of tillers, the stability, strength and length ofculms. It affects the yield, total weight of plant structures, size of the leaves androot development.

1.3.4 Solar constant: It is the energy falling in one minute on a surface of 1 cm^2 at the outer boundary layer of the atmosphere, held normal to the sunlight at the mean distance of the earth from the sun. The units are $calcm^{-2}min^{-1}$. "$calcm^{-2}$ "is also known as "Langley". The estimated value of this constant is from 1.94 to 2.0 $langelymin^{-1}$. The average value is 2 $LYmin^{-1}$.

It depends on:

1. Output of solar radiation.
2. Distance between the earth and the sun.
3. Transparency of the atmosphere.
4. Duration of the sunlight period
5. The angle at which the sun's rays strike the earth.

Net radiation

The difference between the incoming radiation from the sun and the outgoing radiation from the earth is known as net radiation. The net radiation values become –ve after late evening hours to early morning hours. It is a conservative term and plays an importance role in the energy processes of the crops.

Black body: It is an ideal hypothetical body which absorbs all the electromagnetic radiation falling on it. It neither reflects nor transmits any radiation striking it. However, when heated it emits all the possible wavelengths of solar radiation and becomes a perfect radiator. So, an ideal black body is a perfect absorber and a perfect radiator.

Black body radiation: The radiation radiated by an ideal black body is known as black body radiation.

Emittance: It is the ratio of the emitted radiation of a given surface at a specified wavelength to the emittance of an ideal black body at the same wavelength and temperature. For other than a black body the value of emittance is always less than one and for black body the emittance value is one.

Absorptivity: For an object this is the ratio of the electromagnetic radiant power absorbed to the total amount incident upon the same object. Like emissivity the values are less than one for other than a black body and one for a black body.

Reflectivity: The ratio of the monochromatic beam of electromagnetic radiation reflected by a body to that incident upon it. The unitof expression is %.

Transmissivity: This is the ratio of transmitted to the incident radiation on a surface preferably a crop canopy.

Albedo: It is defined as the ratio between reflected radiation to the incident radiation on a crop field, snow, leaves etc. For white bodies the albedo values are high. For fresh snow cover the albedo values range between 75 and 95; for cropped fields - it is 12-13; dark cultivated soil 7-10; human skin 15-25, etc. Albedo determines how much of the heat that reaches the ground in the form of radiation will remain available for use.

1.4Factors affecting the distribution of solar radiation within the plant canopy

1.4.1 Type of plants

a) The leaves cereal crops like paddy, wheat etc., and have a transmissivity in the range of 5 to 10 per cent.
b) The broad leaves of ever green plants have lower value of 2 to 8 per cent, whereas aquatic plants have the transmissibility of 4 to 8 per cent.
c) Transmissivity changes with age of a leaf: the transmissivity of young leaves ismore as compared to old leaves.

1.4.2Age of the leaves: The transmissivity of young leaves is more as compared to old leaves

1.4.3 Chlorophyll content:As the chlorophyllcontent increases the values of transmissibility decreases.

1.4.4 Arrangement of leaves

a) The relative light interception by horizontal and erect foliage is 1: 0.44

b) When the leaf area index is one (1) the light transmissibility of more uprightleaves is 74 as against 50 per cent for horizontal leaves

1.4.5 Angle of leaves

a) In full sunlight, the optimum inclination for efficient light use is 81°.

b) At full sunlight, a leaf placed at the optimum inclination is 4-5 times as efficientin using light as a horizontal leaf.

c) The ideal arrangement of leaves (shall be) is that the lowest 13 per cent of theleaves lay at angles between 0° and 30° to the horizontal, that the adjoining 37per cent of the leaves lay at 30° to 60° and the upper 50 per cent of the leaveslay at 60° to 90°.

1.4.6 Plant density

In case of sparse crop stands not only the per cent of light transmissivity is morebut it is also variable with the time of the day. It is minimum at noon and maximumduring morning and evening hours. In dense crop canopies the light transmissivity isless.

1.4.7 Plant height

When the plant height increases the transmissivity of light by the canopydecreases.

1.4.8 Angle of the sun

a. The highest radiation penetration occurs at noon

b. Relatively high radiation penetration also occurs both in the morning as well asbefore sunset due to high proportion of diffuse light.

The Dutch Committee on plant irradiation has divided the solar spectrum into thefollowing eight bands. This was done on the basis of the physiological response ofplants to the incident radiation.

Table-2: **Physiological responses of plants to different bands of incidentRadiation.**

Band No	**Spectral region (microns)**	**Character of absorption**	**Physiological effect**
1st	Infrared >1.000	By water in tissues	Converted into heat; this has no specific effects on

			photochemical and biochemical processes
2nd	1.000 to 0.700	Slight	Stimulator elongation in plants
3rd	0.700 to 0.610	Very strong by chlorophylls	Large effect onphotosynthesis and photoperiodism
4th	0.610 to 0.510	Somewhat less	Small effect on photosynthesis; small morphogenic effect
5th	0.510 to 0.400	Very strong by chlorophylls and carotenoids	Large effect on photosynthesis; large morphogenic effect
6th	0.400 to 0.315	By chlorophylls and protoplasm	Small effect on photosynthesis. Produces fluorescence in plants
7th	0.315 to 0.280	By protoplasm	Significant germicidal action;Large morphogeniceffect; stimulating some biosynthesis; large effect on physiological processes
8th	<0.280	By protoplasm	Large germicidal effects. Lethal in large doses

2. Light – effect of light intensity, quality, direction and duration on crop production

2.1. Light

Light is the visible portion of the solar spectrum with wavelength range is from0.39 to 0.76μ. Light is one of the important climatic factors for many vital functions of theplant. It is essential for the synthesis of the most important pigment i.e. Chlorophyll.Chlorophyll absorbs the radiant energy and converts it into potential energy ofcarbohydrate. The carbohydrate thus formed is the connecting link between solar energyand living world. In addition, it regulates the important physiological functions. Thecharacteristics of light viz. intensity, quality, duration and direction are important forcrops.

2.1.2Functions of light: The functions of light are:

1. All the plant parts are directly or indirectly influenced by light
2. Light of correct intensity, quality and duration is essential to normal plant development
3. Availability of poor light causes abnormalities and disorders in plants
4. Light is indispensable to photosynthesis
5. Light governs the distribution of photosynthates among different organs of plants
6. Effects tiller production
7. Effects stability, strength and length of culms
8. Effects dry matter production
9. Effects the size of the leaves
10. Effects the root development
11. Effects the flowering and fruiting
12. Effects the dormancy of the seed

2.1.3Light intensity: The intensity of light is measured by comparing with a standard candle. Theamount of light received at a distance of one metre from a standard candle isknown as “Meter candle or Lux”. The light intensity at one foot from a standardcandle is called ‘foot candle’ or 10.764 lux and the instrument used is called aslux meter.About one percent of the light energy is converted into biochemical energy.Very low light intensity reduces the rate of photosynthesis resulting in reducedgrowth.Similarly, very high intensity is detrimental to plant in many ways viz.,it increases the rate of respiration.It also causes rapid loss of water i.e. increases the transpiration rate of waterfrom the plants.

The most harmful effect of high intensity light is that it oxidises the cell contentswhich is termed as 'Solarisation'. This oxidation is different from respiration andis called as photo-oxidation.

Under field conditions the light is not spread evenly over the crop canopy butcommonly passed by reflection and transmission through several layers ofleaves.The intensity of light falls at exponential rate with path length through absorbinglayers according to Beer's law. i.e. the relative radiation intensity decreasesexponentially with increasing leaf area.At ground level the light intensity is below the light compensation point (The lightintensity at which the gas exchange resulting from photosynthesis is equal to thatresulting from respiration)

Based on the response to light intensities the plants are classified as follows.

Sciophytes (shade loving plants): The plants grow better under partially shadedconditions. E.g. Betel vine, buck wheat, etc.

Hetrophytes (Sun loving): Many species of plants produce maximum dry matterunder high light intensities when the moisture is available at the optimum level. E.g.Maize, sorghum, rice, etc.

2.2Quality of Light

When a beam of white light is passed through a prism, it is dispersed intowavelengths of different colours. This is called the visible part of the solar spectrum.

Thedifferent colours and their wave length are as follows:

Colour	Wave length
Violet and indigo	400 – 435 m µ
Blue	435 – 490 m µ
Green	490 – 574 m µ
Yellow	574 – 595 m µ
Orange	595 – 626 m µ
Red	626 – 750 m µ

The principal wavelength absorbed and used in photosynthesis are in the violet –blue and the orange - red regions. Among this, short rays beyond violet such as X rays,gamma rays and larger rays beyond red such as infrared, are detrimental to plantgrowth. Red light is the most favorable light for growth followed by violet – blue. Ultra –violet and shorter wave lengths kill bacteria and many fungi.

Blue Light (↓↑ 440-510 nm)

Blue light is essential at the beginning of a plant's growth cycle as this is the type light that plants first absorb to help with chlorophyll production. Plants need lots of blue light during the seeding process and right through the first part of their growth cycle to ensure healthy roots, strong stems, and healthy leaves. Without blue light plants will never get out of the ground, so any lighting system that together should include a healthy dose of exposure to this type of light.

Green Light (↓↑ 515-555 nm)

While there has been some debate recently on the merits of green light during a plant's growth cycle there's good reason plants normally have green lives – that's because they are least effective at absorbing this type of light. In general, plants use less of the green light they absorb than any other part of the spectrum and that's why plants appear green, but that light is retained by the plants for photosynthesis; leaving this part of the spectrum out altogether can negatively affect the growth of the plants.

Yellow and white Light (↓↑ 565-595 nm)

Yellow light isn't the most effective part of the spectrum for plant growth, but it is still present in sunlight and so it's still important to ask the question of how plants use yellow light during the process of photosynthesis. This is certainly debatable, but what is certain is that yellow light is one of the least effective parts of the spectrum during your plants growth cycle. It might seem intuitive to assume that yellow and white light are close to each other on the spectrum, but that's not the case at all. White light is actually made by combining other colors on the spectrum such as red, green, and blue. Therefore, white light will actually be much more beneficial for the photosynthesis process than yellow light.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Red Light (↓↑ 620-690 nm)[4] and Edge or dark red (↓↑ 690-740 nm)

Red light has longer wave lengths than blue light and is therefore a lot less energetic. It's important that plants are exposed to red light during the blooming or flowering stages, but this type of light is not essential during the vegetative stage of plants growth in fact use of only red light during the initial stages of plants growth cycle will have negative results. It's best to use red light towards the end of the growth cycle in combination with some blue light as well.

A full spectrum of Light/NIR-1 (↓↑ 780-900 nm)and NIR-2 (↓↑ 930-960 nm)

For the heal theist plants really need light from right across the color spectrum. It's true that certain types of light may be more effective at different stages of the growth cycle, plants still need light from across the spectrum at any stage of their growth.

2.2.1 Duration of light

The duration of light has greater influence than the intensity for canopydevelopment and final yield. It has a considerable importance in the selection of cropvarieties. The response of plants to the relative length of the day and night is known asphotoperiodism. The plants are classified based on the extent of response to day lengthwhich is as follows.

2.2.1.1 Long day plants

The plants which develop and produce normally when the photoperiod is greaterthan the critical minimum (greater than 12 hours). E. g. Potato, Sugarbeet, Wheat, Barleyetc.

2.2.1.2 Short day plants

The plants which develop normally when the photoperiod is less than the criticalmaximum (less than 12 hours). E. g. Rice, Sorghum, cotton, Sunflower

2.2.1.3 Day neutral plants or Indeterminate

Those plants which are not affected by photoperiod. E. g. Tomato, Maize

The photoperiodism influences the plant character such as floral initiation ordevelopment, bulb and rhizome production, etc. In long day plant, during periods of shortdays, the growth of internodes are shortened and flowering is delayed till the long dayscome in the season. Similarly, when short day plants are subjected to long day periods,there will be abnormal vegetative growth and there may not be any floral initiation.

2.2.2Direction of light

The direction of sunlight has a greater effect on the orientation of roots andleaves.In temperate regions, the southern slopes plants produce better growth than thenorthern slopes due to higher contribution of sunlight in the southern side.The change of position or orientation of organs of plants caused by light isusually called as phototropism i.e., the leaves are oriented at right angles toincidence of light to receive maximum light radiation.

Photomorphogenesis: Change in the morphology of plants due to light. This is mainly due to U.V andviolet ray of the sun.

3. Atmospheric pressure

Atmospheric pressure is defined as the pressure exerted by a column of air with a cross sectional area of a given unit i.e., a square inch or a square centimetre extending from the earth surface to the upper most boundary of the atmosphere.

The atmospheric pressure is the weight of the air, which lies vertically above a unit areacentered at a point. The weight of the air presses down the earth with the pressure of 1.034 $gmcm^{-2}$. It is expressed in millibar (mb) equal to 100 Nm^{-2} or 1000 $dynescm^{-2}$. Unequal heating ofthe earth and its atmosphere by the sun and rotation of the earth bring about differences inatmospheric pressure.

3.1. Standard atmospheric pressure

The atmospheric pressure varies continuously over a relatively small range and the average of these fluctuations is very close to a value adopted for certain standard conditions defined as “Standard atmosphere”. At a temperature of 15^{o}Cand at 45^{o} latitude the standard normal pressure is

Designed and developed under the aegis of NAHEP Component-2 Project “Investments In ICAR Leadership In Agricultural Higher Education”
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

1013.2 millibars which is equivalent to 29.92 inches (or) 760 mm of mercury at the sea level, which is considered as standard atmospheric pressure.

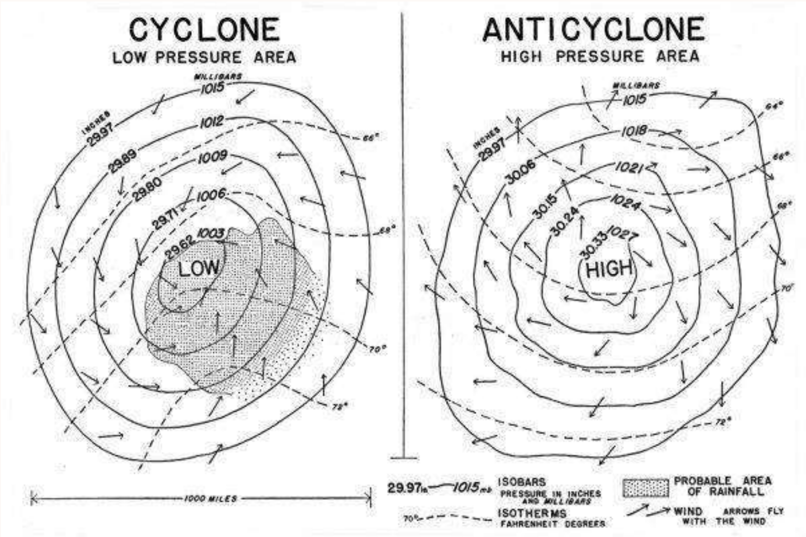
Isobars: The distribution of pressure is represented on maps by 'isobars'. Isobars are defined asthe imaginary lines drawn on a map to join places having the same atmospheric pressure.

3.1.2Basic atmospheric pressure patterns

These are various smaller pressure systems closely identified with daily weather changes. These are seen on daily weather maps.

3.1.2.1Low pressure systems or cyclones

When the isobars are circular or elliptical in shape, and the pressure is lowest at the centre, such a pressure system is called "low" or "depression" or "cyclone". The movement will be anti-clockwise in the Northern hemisphere while it is clockwise in the southern hemisphere. Wind speed hardly exceeds 40 km per hour. A line of low pressure is called a "Trough" when the isobars are not joined at the ends. The word "cyclone" is derived from a Greek word "cyclos" meaning the coils of a snake.In India cyclones occur during the monsoon seasons especially in north-east monsoon. The gales accompanying a cyclone give rise to confused seas, torrential rains and usually approach the coast at 300 to 500 km per hour. The diameter of a cyclone ranges from a few hundreds to 2000 km. Floods are the results of the cyclones. Cyclones are recurring feature in India.



3.1.2.2. High pressure systems or anticyclones

When isobars are circular, elliptical in shape and the pressure is highest at thecentre such a pressure system is called “High” or “Anticyclone”. When the isobars areelliptical rather than circular the system is called as a “Ridge” or “Wedge”.

Table -3:Differences between cyclones and anticyclones

Sr.No.	**Cyclones**	**Anticyclones**
1	Lowest pressure at the centre and it increases towards the outer rim gradually	Highest pressure at the centre and it decreases towards the outer rim gradually
2	Relative humidity increases towards centre and bring cloudy weather.	Relative humidity decreases and clouds are dissipated giving fair weather
3	Variety of clouds lies at different heights.	Little clouds with cool dry air are usually associated.
4	Highest rainfall occurs at the front side.	Rainfall is almost negligible.
5	Wind velocity increases from outer rim to the centre.	Wind velocities are much lesser than cyclones (Wind spirally

		rushes outward from the centre to periphery).
6	Move in anti-clock wise in northern hemisphere and clock wise in southern hemisphere	Move in clock wise in northern hemisphere and anti clock wise in southern hemisphere.

3.2.1Storm

Low pressure center surrounded by winds having their velocities in the range of 40 to 120 kmhour^{-1}. A more favourable atmosphere condition for their occurrence exists during the summer season. The Bay of Bengal and Arabian sea offer ideal condition for origin and growth of the storms. These storms produce heavy precipitation and bring about a change in the existing weather. It occurs very rarely. It causes wide spread damage.

3.2.2Hurricane

A severe tropical cyclone with wind speed exceeding 120 km per hour. The name hurricane is given to the tropical cyclones in the North Atlantic and the eastern North Pacific Ocean. The tropical cyclones of Hurricane force in the western North pacific are known as typhoons. In Australia this type of storm is given the name willy-willy, whereas in the Indian Ocean they are called as Cyclones. Hurricanes are fueled by water vapour that is pushed up from the warm ocean surface, so they can last longer and sometimes move much further over water than over land. A combination of heat and moisture along with the right wind conditions can create a new hurricane.

3.2.3Thunderstorms

Storms produced by cumulonimbus clouds and always accompanied by lightning andthunder. They are usually of short duration, seldom over 2 hours. They are also accompaniedby strong wind gusts, heavy rain and sometimes hail.

3.2.4Tornadoes

Defined as a violently rotating column of air attended by a funnel-shaped or tubular cloudextending downward from the base of cumulonimbus cloud. Tornadoes are the most violentstorms of lower troposphere. They are very small in size and of short duration. They mostlyoccur during spring and early summer. They have been reported at widely scattered locations inthe mid latitudes and tropics. Crop losses are heavy due to this event. Unknown in other parts ofthe world.

3.2.5Waterspouts

It is column of violently rotating air over water having a similarity to a dust devil oftornado. In other words, tornadoes are weak visible vortices occurring over water are calledwaterspouts. They are formed over tropical and subtropical oceans.

3.3.Diurnal and seasonal variation

3.3.1 Diurnal pressure variation: There is a definite rhythm in the rise and fall of the pressure in a day.Radiational heating (air expansion) and radiational cooling (air contraction) are the mainreasons for diurnal variation in the air pressure.Diurnal variation is more prominent near the equator than at the mid latitudes.The areas closer to sea level record relatively larger amount of variation than in land areas.Equatorial regions absorb more heat than it loses while the polar region gives up more heatthan they receive.

There are two maximum and two minimum pressure per day, and they occur at constant local time every day. From a maximum 10.00 hr., the pressure falls to a minimum at 16.00 hr., raise to another maximum at 22.00 hr., and falls again to a second minimum at 04.00 hr. local time

3.3.2 Seasonal pressure variation: Due to the effect caused by annual variation in the amount of insolation, distinct seasonalpressure variations occur. These variations are larger in the tropical region than the mid latitude and Polar Regions. Usually, high pressures are recorded over the continents during the cold season and over theoceans during the warm season.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

3.4Causes of variation

The atmospheric pressure changes continuously due to several factors. The most important factors are changes with temperature, altitude, watervapour content and rotation of earth.

3.4.1 Temperature: Hot air expands and exerts low pressure. Cold air contracts and exerts high pressure.So the equator has a low pressure due to prevalence of high temperature but poles have a highpressure.

3.4.2 Altitude: At sea level, the air column exerts its full pressure, but when we stand on a hill or whenwe go in the upper layers of atmosphere, we leave a portion of air which cannot exert its fullpressure. At sea level, a coastal town enjoys high pressure but on high altitude one will registera low pressure. For every 10 m of ascend, the pressure gets reduced by 1 hPa.

3.4.3 Water vapour: The water vapour content is lighter in cold area than in air which is dry with the resultthat moist air of a high temperature exerts a less pressure when compared to cold air.

3.4.4Rotation of the earth: On account of rotation of the earth, the pressure at 60-70°N and S becomes low. Therotation of the earth near sub-polar belts, makes the air to escape from these belts which movetowards the horse latitude (30° - 35°N and 30 – 35°S). These latitudes absorb the air from subpolar belts making the pressure high.

Humidity –absolute humidity – specific humidity –relative humidity – mixing ratio, dew point temperature – vapour pressure deficit – diurnal variation in relative humidity and its effect on crop production.

4 Humidity: The amount of water vapour that is present in atmosphere is known asatmospheric moisture or humidity.

4.1Expression or Measures of humidity

4.1.1 Mass and volume-based measures

4.1.1.1 Specific humidity: It is defined as the ratio of the mass of water vapour in a sample of moist air to the total mass of the sample. It is expressed as grams of water vapour per kilogram of air (gkg^{-1}).

4.1.1.2 Absolute humidity: It is the ratio of the mass of water vapour to the volume of moist air in which it is contained. It is weight of water vapour in a given volume of air and expressed in g/$m^{3.}$

4.1.1.3**Mixing ratio:** It is the ratio of the mass of water vapour contained in a simple of moist air tothe mass of dry air. It is expressed as kg water vapour per kg dry air.

4.2.Saturation based measure

4.2.1 Relative humidity: The ratio between the amount of water vapour present in a given volume of air and the amount of water vapour required for saturation under fixed temperature and pressure. There are no units and this is expressed as percentage. In other terms it is the ratio of the air's water vapour content to its maximum water vapour capacity at a given temperature expressed in percentage. The relative humidity gives only the degree of saturation of air. The relative humidity of saturated air is 100 per cent. It is expressed as the ratio of actual vapour pressure to the saturated pressure expressed in terms of percentage. It is most common measure of atmospheric humidity.

4.2.2 Vapour pressure deficit: It is another measure of moisture in the atmosphere. It is the difference between the saturated vapour pressure and actual vapour pressure. The difference between the saturated vapour pressure (SVP) and actual vapour pressure (AVP) at a given temperature. This is another measure of moisture in the atmosphere which is useful in crop growth studies. When air contains all the moisture that it can hold to its maximum limit, it is called as saturated air, otherwise it is unsaturated air, at that temperature. The vapour pressure created at this temperature under saturated conditions is vapour pressure or saturated vapour pressure (SVP).

4.2.3 Dew point: It is defined as the temperature to which a given parcel of air must be cooled at constant pressure and constant water vapour content in order to become saturated.In this case, the invisible water vapour begins to condense into visible form like water droplets.

4.3Importance of Humidity on crop plants

The humidity is not an independent factor. It is closely related to rainfall, windand temperature. It plays a significant role in crop production.

1. The humidity determines the crops grown in a given region.
2. It affects the internal water potential of plants.
3. It influences certain physiological phenomena in crop plants including transpiration
4. The humidity is a major determinant of potential evapotranspiration. So, it determinesthe water requirement of crops.
5. High humidity reduces irrigation water requirement of crops as the evapotranspirationlosses from crops depends on atmospheric humidity.
6. High humidity can prolong the survival of crops under moisture stress. However, veryhigh or very low relative humidity is not conducive to higher yields of crops.
7. There are harmful effects of high humidity. It enhances the growth of somesaprophytic and parasitic fungi, bacteria and pests, the growth of which causesextensive damage to crop plants. E.g.Blight disease on potato, the damagecaused by thrips and jassids on several crops.
8. High humidity at grain filling reduces the crop yields.
9. A very high relative humidity is beneficial to maize, sorghum, sugarcane etc, while it isharmful to crops like sunflower and tobacco.
10. For almost all the crops, it is always safe to have a moderate relative humidity ofabove 40 per cent.

4.4Variation in Humidity:

1. Absolute humidity is highest at the equator and minimum at the poles.
2. Absolute humidity is minimum at sunrise and maximum in afternoon from 2 to 3 p.m.The diurnal variations are small in desert regions.
3. The relative humidity is maximum at about the sunrise and minimum between 2 to 3p.m.
4. The behaviour of relative humidity differs a lot from absolute humidity. At the equator itis at a maximum of 80 per cent and around 85 per cent at the poles. But, near horselatitudes it is around 70 per cent.

Evaporation and transpiration – definitions -factors affecting rate of evaporation and transpiration

5. Evaporation

The sun is the source of energy that activates the hydrologic cycle i.e. the heat required for evaporation is supplied by the sun. The moisture in the atmosphere is supplied by evaporation.

Evaporation is defined as "A physical process in which liquid water is converted into its vapour".

In this process molecules of water having sufficient kinetic energy to overcome the attractive forces tending to hold them within the body of liquid water are projected through the water surfaces.

5.1. Factors affecting the evaporation

Evaporation losses from a fully exposed water surface are essentially the functions of several factors.

5.1.1. Environmental factors

5.1.1.1 Water temperature

With an increase of temperature, the kinetic energy, of water molecules increases and surface tension decreases. So, the rate of evaporation increases with a rise in temperature. The maximum amount of water vapour that can exist in any given space is a function of temperature.

5.1.1.2 Wind

The velocity of wind is directly proportional to evaporation from a fully exposed surface and vice versa. The reason is that the dry wind replaces the moist air near the water. The process of evaporation takes place continuously when there is a supply of energy to provide latent heat of evaporation (approximately 540 calories per gram of water evaporated at 100^{o}C).

5.1.1.3 Relative humidity: A mechanism to remove the vapour so that the vapour pressure of the water vapour in the moist layer adjacent to the liquid surface is less than the saturated vapour pressure of the liquid i.e., a vertical gradient of vapour pressure exists above the surface.When the air above water is dry or has low relative humidity, the evaporation will be greater than when air has high relative humidity over the water.

5.1.1.4 Pressure

The evaporation is more at low pressure and vice versa.

5.2. Water factors

5.2.1. Composition of water

The dissolved salts and other impurities decrease the rate of evaporation.Evaporation is inversely proportional to the salinity of water. The rate of evaporation from the surface of the sea is less than that of fresh water in rivers. Under equivalent conditions ocean water evaporates 5 per cent less than fresh water in rivers.

5.2.2. Area of evaporation

If two volumes of water are equal in two containers, evaporation will be greater for the one having the larger exposed surface.

6. Transpiration

Transpiration is defined as “The loss of water from living parts of the plant”. There are three kinds of transpiration.

6.1 Stomatal transpiration

It is the evaporation of water from the stomata of the plants. Most of the water from the plants is transpired this way. The water near the surface of the leaves changes into vapour and evaporates when the stomata are open.

6.2 Lenticular transpiration

Lenticels are minute openings in the bark of branches and twigs. Evaporation of water from the lenticels of the plants is known as lenticular transpiration.Lenticels are not present in all the plants. A minimal amount of water is lost through lenticels.

6.3 Cuticular transpiration

It is the evaporation of water from the cuticle of the plants. The cuticle is a waxy covering on the surface of the leaves of the plants. About 5-10 per cent of the water from the leaves is lost through cuticular transpiration. During dry conditions when the stomata are closed, more water is transpired through the cuticles.It is also called as guttation.

6.2 Factors affecting the transpiration

6.2.1 Environmental Factors

6.2.1.1Light

Light plays predominant role in transpiration both directly and indirectly.The direct effect of light is on the opening and closing of stomata. Bright light is the main stimulus which causes stomata to open. It is because of this reason that all plants show a daily periodicity of transpiration rate. The indirect effect of light is that the increasing light intensity raises the temperature of leaf cells. This increases the rate at which liquid water is transformed into vapour.

6.2.1.2 Atmosphere humidity

The rate of transpiration is almost inversely proportional to atmospheric humidity. The rate of transpiration is greatly reduced when the atmosphere is very humid. However, as the air becomes dry, the rate of transpiration also increases proportionately. These effects occur in accordance with the low of simple diffusion.

6.2.1.3 Air temperature

Increase in the temperature results in opening of stomata. Temperature has significant effect on the permeability of the wall of the guard cells and therefore greatly effects the osmatic phenomenon. This phenomenon is responsible for the movement of guard cells.

6.2.1.4Wind velocity

The velocity of wind affects the rate of transpiration to a greater extent. Fast moving wind and air currents bring fresh and dry masses of air in contact with leaf surfaces. So, higher the wind speed higher the transpiration.

6.2.2 Plant Factors

Some plants adopt physiological modifications to check the excess transpiration. Some other plants modify their structure for this purpose, thereby withstand drought.Such characters greatly affect the transpiration.

6.2.2.1 Plant height

The water need of a crop varies with its height. In general, the rate of transpiration of a tall crop will be more (around 50 %) than when the crop is cut or clipped to half.

6.2.2.2 Leaf characteristics

In some plants like *cacti* and other desert plants leaves are altogether absent and their function is taken up by the stem itself. In case of *Pines,Firs* etc., the leaf size is very much reduced. In such cases reduction in leaf area brings about reduction in transpiration. Some graminaceae family plants (maize), flower plants, etc., roll up or turn the edges of their leaves when exposed to bright sun and fast breeze. This causes reduction in the transpiration.

6.2.2.3 Availability of water to the plant

If there is little water in the soil, the tendency for dehydration of leaf causes stomatal closure and a consequent fall in transpiration. This situation occurs during a) periods of drought b) when the soil is frozen and c) at a temperature so low that water is not absorbed by roots.

Glossary:

Albedo: It is defined as the ratio between reflected radiation to the incident radiation on a crop field, snow, leaves etc.

Black body radiation: The radiation radiated by an ideal black body is known as black body radiation.

Dew point: It is defined as the temperature to which a given parcel of air must be cooled at constant pressure and constant water vapour content in order to become saturated.

Emissive power: The radiant flux density emitted by a source is called its emissive power.

Humidity: The amount of water vapour that is present in atmosphere is known asatmospheric moisture or humidity.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Isobars: The distribution of pressure is represented on maps by 'isobars'. Isobars are defined as the imaginary lines drawn on a map to join places having the same atmospheric pressure.

Net radiation: The difference between the incoming radiation from the sun and the outgoing radiation from the earth is known as net radiation.

Photomorphogenesis: Change in the morphology of plants due to light.

Photoperiodism: The response of plants to the relative length of the day and night is known as phtoperiodism.

Radiant flux density: The radiant flux divided by the area across which the radiation is transmitted is called radiant flux density.

Radiation flux: The amount of radiant energy emitted, received, transmitted across a particular area is known as radiant flux.

Solar constant: It is the energy falling in one minute on a surface of 1 cm^2 at the outer boundary layer of the atmosphere, held normal to the sunlight at the mean distance of the earth from the sun. The units are $cal/cm^2/min$. "cal/cm^2 "is also known as "Langley". The estimated value of this constant is from 1.94 to 2.0 langley/min. The average value is 2 LY/mn.

Solar radiation: it is defined as "The flux of radiant energy from the sun".

Reference:

Alok Kumar Patra.(2020).Introduction to Agrometeorology and Climate Change. NIPA, New Delhi. ISBN. 9789387973619.

Lalitha,B.S., Kalyana Murthy,K.N., Jayadeva., H.M. and Prajwal Kumar, G.K. (2018). Introduction to Agricultural Meteorology & Climate Change. Agro India Publications, Allahabad. ISBN-10 : 9384188093 ISBN- 13 : 978-9384188092.

Gopalaswamy, N. 1994. Agricultural Meteorology, Rawat publications, Jaipur.

Mahi, G.S. and Kingra P.K.(2014). FUNDAMENTALS OF AGROMETEOROLOGY AND CLIMATE CHANGE. Kalyani publisher. New Delhi. ISBN: 9788056972311, 8056972315.

Course Name	Agro-meteorology and climate change
Lesson 5	Monsoons, rainfall, clouds, drought
Content Creator Name	Vallal Kannan Sankaralingam
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	Dr. Vijay Gopal More
University/College Name	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Lesson 5

Objectives:

- To understand about the formation of monsoon and rainfall and their importance on crop production.
- To enhance the knowledge on types of cloud formation
- To empower the knowledge and drought and their management.

1. Monsoons

The term monsoon is derived from an Arabic word “Mausim” means “Season”. There are different concepts to explain Indian monsoons. Of them the “Thermal concept” proposed by Halley in 1636 is of more practical relevance than other concepts like aerological, Flohins, etc. The two types of distinguished monsoons over India are a) South West Monsoon and b) North East Monsoon.

1.1 South West Monsoon

Beginning of the year temperature of the Indian Peninsular rapidly rises under the increasing heat of the sun. A minimum barometric pressure is established in the interior parts of the Peninsular by the month of March. Westerly winds prevail on the west Kerala and south winds on the west of northern Circars, Orissa and Bengal. During April and May the region of high temperature is shifted to north viz., upper Sind, lower Punjab and Western Rajasthan. This area becomes the minimum barometric pressure area to which monsoon winds are directed.

The western branch of South West monsoon touches North Karnataka, Southern Maharashtra and then it make its way to Gujarat. When the South West Monsoon is fully operating on the Western India, another branch of the same is acting in the Bay of Bengal. It carries rains to Burma, Northern portions of the east coast of India, Bengal, Assam and the whole of North India in general.

1.2 North East Monsoon

During September end, the South West Monsoon penetrates to North Western India but stays on for a full month in Bengal. On account of the increase in barometric pressure in Northern India, there is a shift of the barometric pressure to the South East and North Easterly winds begin to flow on the eastern coast. These changes bring on heavy and continuous rainfall to the Southern and South Eastern India.

1.3 Winter Rainfall

It is restricted more to Northern India and is received in the form of snow on the hills and as rains in the plains of Punjab, Rajasthan and Central India. Western disturbance is a dominant factor for rainfall during these months in northwestern India.

1.4 Summer Rainfall

The summer Rainfall is received from March to May as local storms. It is mostly received in the South East of Peninsular and in Bengal. Western India does not generally receive these rains.

1.5 Withdrawn of monsoon

The South west monsoon withdraws from northern India around mid-September.

The North east monsoon withdraws from extreme South of Indian Peninsula by December.

Break and Active in monsoon: A period of lean rainfall occurs when "Trough" shifts towards foot hills of Himalayas which is known as break in the monsoon over Indian sub-continent. When the "Trough" shifts south of its normal position, monsoon becomes activeover India.

1.6 Importance of rainfall (water) on crop plants

One centimetre of rain over an area of one hectare or 100 m^3 (1,00,000 litres) contains 4,339 grams of oxygen at 20^{oC}. This is equivalent to 3,000 litres of pure oxygen at atmospheric pressure. Consequently, a rain usually has a much more invigorating effect on a crop than does irrigation. Rain water has extraordinary qualities.

1. Water has high solvent power and this plays an important role in crop plants as the plants get their nourishment from soil only in solution form.

2. Water plays an important role in life processes of crop plants (in the exchange of gases).
3. The heat capacity of water is high and its high thermal stability helps in regulation of the temperature of crop plants.
4. Water has highest heat conduction capacity and due to this the heat produced by the activity of a cell is conducted immediately by water and distributed evenly to all plant parts.
5. The viscosity of water is higher than that of many solvents and this property helps in protecting the crop plants and trees against mechanical disturbances.
6. Water is driest at 4^{o}C. The freezing point of fresh water being 0^{o}C and that of sea water about – 2.5^{o}C, the ice can float on the surface and plant life in deeper parts of sea is made possible.
7. The transparency of water facilitates the passage of light to great depths and this helps for the survival of aquatic plants.
8. The high surface tension that water has helps in movement of water into and through the plant parts.
9. Rainfall influences the distribution of crop plants in particular and vegetation in general, as the nature of vegetation of a particular place depends on the amount of rainfall (the vegetation of a desert where rainfall is less differs a lot from the vegetation of a rainforest).

1.7Types of rainfall

There are mainly 3 types of rainfall which are as follows:

1.7.1 Convectional rains

The air near the ground becomes hot and light due to heating. Then it starts upward movement. This process is known as convection As the air moves upward it cools at about 10^{o}C per km i.e., at dry adiabatic lapse rate, as it becomes saturated, relative humidity reaches to 100 per cent and dew point is reached where the condensation begins. This level (height) is known as condensation level. Above this level, air cools at about 4^{o}C per km slightly less than i.e., saturated adiabatic lapse rate. First, cloud is formed. Then, the further condensation results into precipitation. These rains are known as convectional rains and mostly occur in the tropics.

1.7.2 Orographic rains

When moist air coming from the sea or ocean strikes mountain it cannot move horizontally. It has to overcome the mountains. When this air rises upward, cools down, cloud is formed and condensation starts giving precipitation these rains are known as orographic rains. These are also known as **relief rains,** as the rains also occurs when the air from sea or ocean strike or pass over relief barriers, due to these processes rains with high intensity are possible on the windward side of the mountain.

1.7.3 Cyclonic and frontal rains

The rains received from cyclones are known as **cyclonic rains**.When two opposing air currents with different temperatures meet, vertical lifting takes place, this convection gives rise to condensation and precipitation which is known as frontal precipitation.

1.8 Monsoon Rainfall Variability

Indian continent receives its annual rainfall by the peculiar phenomenon known as monsoon. It consists of series of cyclones that arise in India Ocean. These travel in northeast direction and enter the Peninsular India along its west coast. The most important of these cyclones usually occur from June to September resulting in summer monsoon or southwest monsoon. This is followed by a second rainy season from October to December. A third and fourth rainy seasons occur from January to February and from March to May respectively. Of the four rainy seasons, southwest monsoon is the most important as it contribute 80 – 95 per cent of the total rainfall of the country.

2. Clouds

“An aggregation of minute drops of water suspended in the air at higher altitudes” is called as cloud. A cloud is a visible aggregate of tiny water droplets and/or ice crystals suspended in the atmosphere and can exist in a variety of shapes and sizes. Some clouds are accompanied by precipitation such as rain, snow, hail, sleet, and even freezing rain.

Designed and developed under the aegis of NAHEP Component-2 Project “Investments In ICAR Leadership In Agricultural Higher Education”
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Clouds can occur at any level of the atmosphere wherever there is sufficient moisture to allow condensation to take place. The layer of the atmosphere where almost all cloud exists is the troposphere, although the tops of some severe thunderstorms occasionally pierce the tropopause.

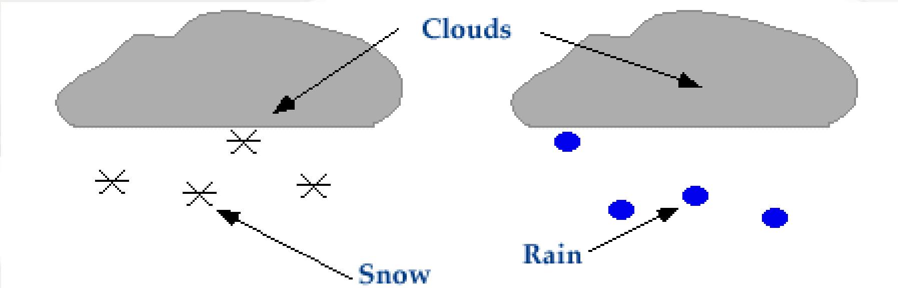
A cloud can be defined as hydrometeor consisting of minute particles of liquid water orice, or of both, suspended in the free air and usually not touching the ground. It may also include larger particles of liquid water or ice as well as non-aqueous or solid particles such as those present in fumes, smoke or dust.

2.1.Definition

Cloud is defined as “An aggregation of minute drops of water suspended in theair at higher altitudes”. The rising air currents tend to keep the clouds from falling tothe ground.

2.2. Development of clouds

Water is known to exist in three different states, as a solid, liquid or gas.Clouds, snow, and rain are all made of up of some form of water. A cloud is comprisedof tiny water droplets and/or ice crystals, a snowflake is an aggregate of many ice crystals, andrain is just liquid water.



All of these are made of some form of water.

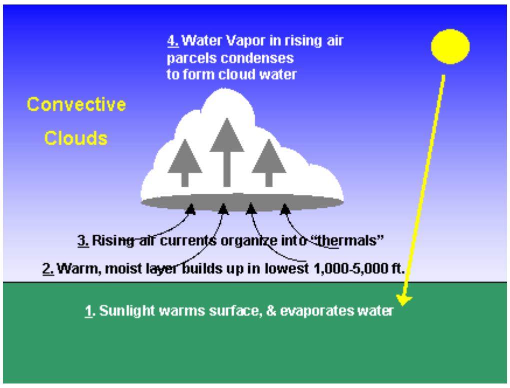
Water existing as a gas is called water vapor. When referring to the amount of moisturein the air, we are actually referring to the amount of water vapor. If the air is described as"moist", that means the air contains large amounts of water vapor. Moisture is a necessary ingredient for the production of clouds and precipitation

All clouds are a form of water. Clouds are condensed atmospheric moisture in the form of minute water droplets or ice crystals. The creation of a cloud begins at ground level. The sun heats the earth's surface, the warm ground heats the air, which rises. The air contains variable amounts of water, as vapor, that has evaporated from bodies of water and plants. Air at ground level is denser than air higher up, and as the warm air rises, it expands and becomes less dense.

Air rises for three main reasons

- Sunshine – heat from the sun or warm ground warms the air and makes it lighter. It therefore rises into the sky.
- The terrain – air may rise as it is forced upwards due to changes in the terrain(landscape). This often occurs when wind blows air either over mountains, or over cliffsonto land from the sea.
- A front – air can also rise at a weather front. At cold fronts, cold air is pushed underwarm air, forcing it upwards and at a warm front, warm moist air is forced up and overthe cold air.

Expansion cools the air and as the air cools, the water vapor that is present in the air,condenses into tiny microscopic droplets. Cloud formation depends on how much water is in theatmosphere, the temperature, the air current, and topography. If there is no water, no cloudscan form. If condensation occurs below the freezing point, the cloud is made of ice crystals.Warm and cold air fronts, as well as topography can control how air rises. Clouds that formduring vigorous uplift of air have a tall, stacked appearance and clouds formed by gentle uplift ofair currents have a flat or stratified appearance. One can make short-term forecasts byobserving clouds, as any change in the way a cloud looks indicates a change in the weather.



Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

After formation of cloud droplets or ice crystals, either they collide with each other and grow by joining together to such a large size that they fall to the ground as rain or snow, or they evaporate and change back into water vapor. It is estimated that, on average, about one-half of all cloud material eventually falls to the Earth as precipitation, while the other half re-evaporates back into water vapor.

2.3Drop size and cloud appearance

The smaller the drops in a cloud the brighter the tops appear (and the darker the bases).Smaller droplets scatter more sunlight, while large drops allow more sunlight to pass through. This explains why the heavily raining part of a shower cloud or thunderstorm is usually brighter than just the cloudy part. The cloud droplets have combined into large raindrops, which allow more sunlight to pass through them.

2.4 Cloud formation

When air rises due to increase in temperature the pressure being less it expands and cools until temperature is equalised. If the cooling proceeds further till the saturation point, the water vapour condenses and cloud is formed. Clouds are also formed when a current of warm air strikes the one that is cooler and when moist air from sea blows over a cold land.

2.5Cloud classification

2.5.1. A scheme of distinguishing and grouping clouds according to their appearance, and, where possible, to their process of formation.

The one in general use, based on a classification system introduced by Luke Howard in1803, is that adopted by the World Meteorological Organization and published in the International Cloud Atlas (1956). Classification is based on the determination:

2.5.1.1Genera - the main characteristic forms of clouds, the ten cloud genera are cirrus, cirrocumulus, cirrostratus, altocumulus, altostratus, nimbostratus, stratocumulus, stratus, cumulus, and cumulonimbus.

2.5.1.2 Species - the peculiarities in shape and differences in internal structure of clouds. The fourteen cloud species are fibratus, uncinus, spissatus, castellanus, floccus, stratiform, nebulosus, lenticularis, fractus, humilis, mediocris, congestus, calvus, and capillatus.

2.5.1.3 Varieties - special characteristics of arrangement and transparency of clouds. The nine cloud varieties are intortus, vertebratus, undulatus, radiatus, lacunosus, duplicatus, translucidus, perlucidus, and opacus.

2.5.1.4 Supplementary features and accessory clouds - appended and associated minor cloud forms and

2.5.1.5 Mother-clouds - the origin of clouds if formed from other clouds.

The nine supplementary features and accessory clouds are incus, mamma, virga, praecipitatio, arcus, tuba, pileus, velum, and pannus.

(Note: Although these are Latin words, it is proper convention to use only the singular endings, e.g., more than one cirrus cloud is cirrus, not cirri.)

2.6 A scheme of classifying clouds according to their usual altitudes

Three classes are distinguished: high, middle, and low.

High clouds include cirrus, cirrocumulus, cirrostratus, occasionally altostratus, and the tops of cumulonimbus.

The middle clouds are altocumulus, altostratus, nimbostratus and portions of cumulus and cumulonimbus.

The low clouds are stratocumulus, stratus and most cumulus and cumulonimbus bases, and sometimes nimbostratus.

2.7 A scheme of classifying clouds according to their particulate composition, namely, water clouds, ice-crystal clouds, and mixed clouds

The first are composed entirely of water droplets (ordinary and/or supercooled), thesecond entirely of ice crystals, and the third a combination of the first two. Of the cloud genera,only cirrostratus and cirrus are always ice-crystal clouds; cirrocumulus can also be mixed; andonly cumulonimbus is always mixed. Altostratus is nearly always mixed, but can occasionally be water. All the rest of the genera are usually water clouds, occasionally mixed; altocumulus, cumulus, nimbostratus, and stratocumulus.

2.8WMO cloud classification

The World Meteorological Organization (WMO) classified the clouds according to their height and appearance into 10 categories. From the height, clouds are grouped into 4categories (viz., family A, B, C and D) as stated below and there are sub- categories in each ofthese main categories.

The 4 clouds families, which are in different heights of the troposphere, are
Family A: High level clouds (altitudes of 5-13 km)
Family B: Medium level clouds (2-7 km)
Family C: Low level clouds (0-2 km) and
Family D: Clouds with large vertical extending (0-13 km)

2.8.1Family A

The clouds in this category are high. The mean lower level is 7 kilometers and the mean upper level is 12 kilometers in tropics and sub-tropics. In this family there are three subcategories.

2.8.1.1 Cirrus (Ci): In these clouds ice crystals are present, looks like wispy and feathery. Delicate, desist, white fibrous, and silky appearance. Sun rays pass through these clouds and sunshine without shadow. Does not produce precipitation.

2.8.1.2 Cirrocumulus (Cc): Like cirrus clouds ice crystals are present in these clouds also looks like rippled sand or waves of the sea shore. White globular masses, transparent with no shading effect. Meckerel sky.

2.8.1.3 Cirrostratus (Cs): Like the above two clouds ice crystals are present in these clouds also looks like whitish veil and covers the entire sky with milky white appearance. Produces “Halo”.

Cirrus and Cirrostratus

Cirrostratus represents clouds that are more widespread than cirrus but containing some similar features like cirrus, they are brilliant white and lack in contrast. Sunlight can pass through cirrostratus but this again depends on the varying thickness of the clouds.

Both cirrus and cirrostratus clouds vary in thickness. The sun can easily be observed through both types of clouds although the intensity of light that is observed depends on the thickness of their layers. In their thickest form, cirrus and cirrostratus will allow a similar intensity of light to pass through to that of thin altostratus. They do not only develop in one complete layer. It may be difficult to observe because of the lack of contrast but these clouds can consist of several thin layers.

Cirrus and cirrostratus tend to move in the direction of the wind at that level which differs to that at the surface. The most common direction of motion of these clouds is from a westerly direction. This varies with factors such as the latitude, weather conditions and time of the year. Their apparent velocities are relatively slow as compared to lower clouds. Both cirrus and cirrostratus can occur in conjunction with any of the other cloud types.

Obviously, all the lower and middle level clouds will obscure the view of the higher-level clouds, appear to move faster and appear less defined. They can only be observed above other clouds when breaks in the clouds occur. Any type of higher-level clouds can develop simultaneously.

Cirrus clouds tend to develop on days with fine weather and lighter winds at the surface cirrostratus can develop on days with light winds but normally increasing in strength. Although both cirrus and cirrostratus tend to develop in fine weather conditions, they also act as a sign of approaching changes in the weather conditions. Such changes could include any of the various types of cold front situations, thunderstorms or developing and advancing troughs of low pressure, normally with preceding cloud masses.

Except in the latter case, cirrus and cirrostratus will typically precede any other types of clouds as part of a cloud band. In fact cirrus normally precedes cirrostratus. Nevertheless, the higher level clouds will persist until the actual change in the weather occurs. The higher clouds can develop from a few hours up to a few days before an actual change in the weather conditions occurs. They may develop during one afternoon and dissipate but redevelop the next day and so on until the actual change occurs. If the amount of moisture in the lower layers of the atmosphere increases, other lower clouds may also develop changing the appearance of thecirrus or the cirrostratus clouds as well as partially or totally hiding them from view. The samesituation occurs in the case where cirrus develops ahead of thunderstorms. Cirrus normally precede cirrostratus which are then followed by the anvil of the approaching thunderstorm. Infact, cirrus and cirrostratus in this case are the remnants downwind of the weakening anvil.

Both cirrus and cirrostratus can develop and persist after a change has passed througha certain location. In this situation, cloud will decrease within a few hours up to a few days following the change. If it persists for longer periods, a jet stream cloud mass may be involved.

Another situation where cirrus and cirrostratus can be observed is when lower cloud breaks or clears during days with showers or rain. This case is far less common but can indicate a few situations. The higher clouds may be the remnants of the cloud mass that produced the actual wet weather. They can also be developing ahead of other cloud masses associated with another system, leading to the situation already discussed above. It all depends on the weather situation at that time but the observation of the movement of the higher-level clouds can be critical in determining what weather may follow.

Cirrus generally does not produce precipitation except when it results from dissipating thunderstorms. Precipitation from such cirrus usually consists of larger droplets and the cloud normally dissipates and vanishes completely. Cirrostratus does not produce precipitation.

Cirrus and cirrostratus can develop and persist at any time of the day despite the perception that it tends to occur during the day. This perception arises because it is much easier to observe cirrus during the day as compared to night time. The background darkness and the fact that the stars can easily be observed through cirrus and cirrostratus as thin layers allow them to camouflage from the view of the observer.

Cirrocumulus

Cirrocumulus is a higher level cloud that is brilliant white but with a spotty appearance created by the many small turrets. The turrets indicate vertical turbulence within the cloud. Despite this spotty appearance, cirrocumulus contains many features associated with cirrostratus discussed above. It moves in directions similar to that of the other higher clouds. This cloud can develop in conjunction with any other clouds as well as with cirrostratus clouds. The development of cirrocumulus sometimes occurs in conditions similar to those associated with the development lenticular altocumulus. cirrocumulus clouds do not produce precipitation and are normally associated with fine weather.

2.8.2Family B

The clouds in this category are middle clouds. Middle level clouds are those clouds that develop in the middle layers of the atmosphere. These clouds are brighter and less fragmented in appearance due to their distance from the ground and higher composition of ice crystals. Middle level clouds vary in thickness from relatively flat sheets of cloud to a more cumuli form appearance. In fact, the sun (and moon) can be observed through some thin middle level clouds. The mean lower level is 2.5 km and the mean upper level is 7 km in tropics and sub-tropics. Middle level clouds tend to have apparent speeds slower than the lower-level clouds. They move in the direction of the wind at that level which does not necessarily be the same of that at the surface.

In this family there are 2 sub-categories as details below:

2.8.2.1 Altocumulus (Ac): In these clouds ice water is present. Greyish or bluish globular masses. Looks like sheep back and also known as flock clouds or wool packed clouds.

2.8.2.2 Alto-stratus (As): In these clouds water and ice are present separately, looks like fibrous veil or sheet and grey or bluish in colour. Produces coronas and cast shadow. Rain occurs in middle and high latitudes.

Altocumulus

Altocumulus refers to the middle level cloud that exhibit to some extent the featuresnormally associated with cumulus. This includes cumuliform tops and bases that are usuallyrelatively darker than the tops. This cloud type can be widespread or patchy depending on theconditions. It can vary in appearance from broken to smooth, and vary in thickness.

Altocumulus can vary in its apparent movement (speed) depending on the wind and direction at that level. However, since altocumulus (like most other cloud types) represents an ever changing system, an observer must be careful in determining cloud motion. On some days, altocumulus continuously develops as it moves in the direction of the wind. Upstream, more altocumulus may develop giving the impression that the cloud is progressing slower than its actual speed. This process can occasionally create an illusion in terms of direction. Considering an example of altocumulus observed moving to the south east, because of development on the north and north-eastern side of the cloud band, the apparent direction may be more to the east.

Altocumulus can develop in more than one layer and also in conjunction with other cloud types. The lower layer will obscure part or the entire higher altocumulus cloud layer. This situation also applies to higher level clouds. Higher level clouds will be obscured by the altocumulus. Lower-level clouds, however, will obscure part or the entire altocumulus cloud layer.

Altostratus

Altostratus refers to middle level cloud that appears as a flat, smooth dark grey sheet. These clouds are most often observed as large sheets rather than isolated areas. However, in the process of development, altostratus may develop in smaller filaments and rapidly develop to larger sheets. These types of clouds in certain conditions normally indicate an approaching cloud mass associated with a cold front, a trough system or a jet stream.

Altostratus can develop into a thick or thin layer. As a thin layer, the sun can be observed through the cloud. In its thinner form, the developing altostratus can sometimes be confused with approaching cirrostratus. In its thicker form, the sun can only occasionally be observed through the thinner sections if not at all. Obviously, the thicker the altostratus, the darker it becomes. When observed closely, it becomes apparent that altostratus is not just one complete layer but a composition of several thin layers.

Altostratus can produce precipitation. It will normally develop and then thicken. The precipitation is observed as relatively thick dark sections since precipitation cascades are very difficult to observe with the same colour in the background. In this situation, rain will develop as a light shower and gradually increase to showers, light rain or moderate rain.

2.8.3Family C

The clouds in this category are lower clouds. The height of these clouds extends from ground to upper level of 2.5 kilometers in tropics and sub-tropics. Lower level clouds consist of those clouds in the lower layers of the atmosphere. Because of the relatively low temperatures at this level of the atmosphere, lower level clouds usually reflect lower amounts of light and therefore usually exhibit low contrast. The clouds at this level also appear not as well defined. When observed closely, it is easy to observe the turbulent motions and hence the ever-changing structure.

Being closer to the ground, lower-level clouds appear to move or progress faster than other clouds. The clouds generally move in the direction of the wind very similar to the direction of the wind on the ground. The most efficient method used to recognize lower clouds is when observed in conjunction with other clouds. The lower clouds will obscure part or all the view of the upper level clouds if they pass in between the observer's line of sight. In other words, all the observer can see is the lower clouds as well as parts of the higher level clouds through breaks of the lower clouds.

In this family, like high clouds, there are 3 sub-categories.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

2.8.3.1Stratocumulus (Sc): These clouds are composed of water. Looks soft and grey, large globular masses and darker than altocumuls. Long parallel rolls pushed together or broken masses. The air is smooth above these clouds but strong updrafts occur below.

2.8.3.2Stratus (St): These clouds are also composed of water. Looks like for as these clouds resemble grayish white sheet covering the entire portion of the sky (cloud near the ground).Mainly seen in winter season and occasional drizzle occurs.

2.8.3.3 Nimbostratus (Ns): These clouds are composed of water or ice crystals. Looks thick dark, grey and uniform layer which reduces the day light effectively. Gives steady precipitation. Sometimes looks like irregular, broken and shapeless sheet like.

Stratocumulus

Stratocumulus is low clouds that generally move faster than cumulus and are not as well defined in appearance (recall the techniques of observing clouds). They tend to spread more horizontally rather than vertically.

Depending on the weather conditions, stratocumulus can appear like cumulus since stratocumulus can develop from cumulus. They may also appear as large flat areas of low, grey cloud. Sometimes stratocumulus appear in the form of rolling patches of cloud aligned parallel to each other. Stratocumulus can also appear in the form of broken clouds or globules. The sun, moon and generally the sky can be observed through the breaks in broken stratocumulus clouds. Of course, this depends on how large the breaks are, how high the clouds rise and the angle of elevation of the breaks with respect to the observer. This generally applies to all clouds but is more notable with clouds in broken form.

Stratocumulus mostly develops in wind streams moving in the direction of the wind similar to the direction of the wind at the surface. The friction created by the earth causes turbulence in the form of eddies. With sufficient moisture, condensation will occur in the lower layers of the atmosphere visible as clouds. The amount of stratocumulus covering the sky depends on the amount of moisture concentrated at that level of the atmosphere. The speed that the cloud moves varies according to the wind

Stratus

Stratus is defined as low cloud that appears fragmented and thin. It can also occur in the form of a layer or sheet. The sun, moon and generally the sky can usually be observed through stratus clouds, especially at a steep angle of elevation. Stratus lacks the vertical growth of cumulus and stratocumulus, and therefore lacks the contrast. This is more evident when observed as one layer as compared to patchy stratus. Being closest to the ground, stratus clouds normally move fairly rapidly in the direction of the wind depending of course on the wind speed.

Like stratocumulus, stratus develops under several conditions or weather situations. Stratus mostly develops under the influence of wind streams where moisture condenses in the lower layers of the atmosphere. Wind changes during the summer months often lead to the development of stratus as the wind evaporates moisture from the ocean and condensing as turbulence mixes the surface air with the cooler air above. In these conditions, stratus develop in patches and gradually may become widespread forming into stratocumulus.

2.8.4Family D

These clouds form due to vertical development i.e., due to convection. The mean lowlevel is 0.5 and means upper level goes up to 16 kilometers.

In this family two sub-categories are present.

2.8.4.1. Cumulus (Cu): These clouds are composed of water with white majestic appearance with flat base. Irregular dome shaped and looks like cauliflower with wool pack and dark appearance below due to shadow. These clouds usually develop into cumulonimbus clouds with flat base.

2.8.4.2. Cumulonimbus (Cb): The upper levels of these clouds possess ice and water is present at the lower levels. These clouds have thunder head with towering envil top and develop vertically. These clouds produce violent winds, thunder storms, hails and lightening, during summer.

Cumulus

Cumulus is cauliflower-shaped low-level clouds with dark bases and bright tops. When observing cumulus, you are actually observing the condensation process of rising thermals or air bubbles at a certain level in the atmosphere known as the condensation level. The air rising above this level condenses and cloud is observed. Since the height of this level is fairly constant at any particular time, then the bases of cumulus are usually flat.

3. Drought

The term drought can be defined by several ways.

1. The condition under which crops fail to mature because of insufficient supply of water through rains.
2. The situation in which the amount of water required for transpiration and evaporation by crop plants in a defined area exceeds the amount of available moisture in the soil.
3. A situation of no precipitation in a rainy season for more than 15 days continuously. Such length of non-rainy days can also be called as dry spells.

3.1Classification of drought

Droughts are broadly divided into 3 categories based on the nature of impact andspatial extent.

3.1.1Meteorological Drought

If annual rainfall is significantly short of certain level (75 per cent) of the climatologically expected normal rainfall over a wide area, then the situation is called meteorological drought. In every state each region receives certain amount of normal rainfall. This is the basis for planning the cropping pattern of that region or area.

3.1.2Hydrological drought

This is a situation in which the hydrological resources like streams, rivers, reservoirs, lakes, wells, etc. dry up because of marked depletion of surface water. The ground water table also depletes. The industry, power generation and other income generating major sources are affected. If Meteorological drought is significantly prolonged, the hydrological drought sets in.

3.1.3Agricultural Drought

This is a situation, which is a result of inadequate rainfall and followed by soil moisture deficit. As a result, the soil moisture falls short to meet the demands of the crops during its growth. Since, the soil moisture available to a crop insufficient, it affects growth and finally results in the reduction of yield. This is further classified as early season drought, mid season drought and late season drought.

3.2Droughts and their influence on crop plants

1. The influence of drought can be observed not only on phenology but also on phenophases of crop plants. From seedling to ripening stage the water influence the crops particularly in case of cereals after the leaves are emerged from coleoptiles. The influence of drought is more pronounced at the time of maturity.
2. During flowering stage, any little stress of moisture by virtue of drought substantially reduces the size of inflorescence thereby affecting the final yield.
3. In the same way fertilization and grain filling are also markedly influenced and the final yield is substantially reduced.
4. When soil moisture stress increases, it limits water supply to all the plant parts, which result in wilting.
5. If drought occurs at the time of grain filling, it results in the decrease of yield considerably.

6. Cell division and enlargement are very sensitive to drought stress. During moisture drought stress cell enlargement is affected and is the primary cause of stunted growth plant is under field conditions.
7. Drought also affects nutrient absorption, carbohydrate and protein metabolism and translocation of ions and metabolites.
8. Protein breakdown injures the drought stressed plant due to the accumulation of toxic products of protein breakdown such as ammonia, rather than due to a protein deficiency.
9. Abscission of leaves, fruits and seeds can be induced by plant water deficit during droughts.
10. Plant respiration is drastically reduced.

3.3 Drought control and management practices at the time of drought

1. Modification of microclimate by use of shelter-belts and artificial barriers to reduce evapotranspiration and wind movement.
2. Maintaining optimum plant population.
3. Best possible seed-bed preparation to hold and absorb maximum moisture and better weed management.
4. Tillage practices to minimise runoff and evapotranspiration.
5. Crops that evade or endure periods of drought shall be sown.
6. Drought tolerant crops for which row spacing can be increased without affecting the final yield can be identified and practiced.
7. The dates of sowing shall be adjusted such that the reproductive stage of the crop shall not pass through the drought, in addition to other stages for critical crop growth.
8. Effective control of pests and diseases and use of recommended doses of fertilizers.
9. Correcting nutrient deficiencies and use of recommended doses of fertilizers.
10. Application of antitranspirants and use of mulches will reduce evapotranspiration.
11. Application of irrigation at appropriate stages of crop growth.

12. Weed control by keeping the land fallow has an added effect in conserving the moisture.
13. Ploughing of range lands with heavy disks or similar equipment to make a more rapid and complete infiltration.
14. Shaping of land so that the water stays where it falls or runoff from a slope to irrigate a level bench below the slope.

Glossary:

Agricultural Drought: This is a situation, which is a result of inadequate rainfall and followed by soil moisture deficit.

Clouds: An aggregation of minute drops of water suspended in the air at higher altitudes is called as cloud.

Hydrological drought: This is a situation in which the hydrological resources like streams, rivers, reservoirs, lakes, wells etc dry up because of marked depletion of surface water.

Meteorological Drought: If annual rainfall is significantly short of certain level (75 per cent) of the climatologically expected normal rainfall over a wide area, then the situation is called meteorological drought.

Stratus: Stratus is defined as low cloud that appears fragmented and thin.

Reference:

Alok Kumar Patra.(2020).Introduction to Agrometeorology and Climate Change. NIPA, New Delhi. ISBN. 9789387973619.

Lalitha,B.S., Kalyana Murthy,K.N., Jayadeva., H.M. and Prajwal Kumar, G.K. (2018). Introduction to Agricultural Meteorology & Climate Change. Agro India Publications, Allahabad. ISBN-10 : 9384188093ISBN-13 : 978-9384188092.

Mavi, H.S., 1996. Introduction to Agrometeorology, oxford and IBH Publishing Co., New Delhi.

Murthy, R.V. 2002. Basic Principles of Agricultural Meteorology. BS Publications, Hyderabad.

Course Name	Agro-meteorology and climate change
Lesson 6	Weather disasters and their management Objectives
Content Creator Name	Vallal Kannan Sankaralingam
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	Dr. Vijay Gopal More
University/College Name	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Lesson 6

Objectives:

- To understand about the types of weather disaster
- To empower skill on disaster management

1 Disaster

Disaster is a sudden, calamitous event bringing great damage, loss, destruction and devastation to life and property. The damage caused by disaster is immeasurable and varies with the geographical location, climate and the type of the earth surface. This influences the mental, socio-economic, political and cultural state of the affected area. Generally, disaster has the following effects in the concerned areas,

1. It completely disrupts the normal day to day life.
2. It negatively influences the emergency systems.
3. Normal needs and processes like food, shelter, health, etc. are affected and deteriorate depending on the intensity and severity of the disaster.

It may also be termed as "a serious disruption of the functioning of society, causing widespread human, material or environmental losses which exceed the ability of the affected society to cope using its own resources."

Disaster means a catastrophe, mishap, calamity or grave occurrence in any area, arising from natural or manmade causes, or by accident or negligence which results in substantial loss of life or human suffering or damage to, and destruction of, property, or damage to, or degradation of environment, and is of such a natural or magnitude as to be beyond the coping capacity of the community of the affected area.

1.1Types of Disaster

Generally, disasters are of two types – **Natural** and **Manmade**. Based on the devastation, these are further classified into major and minor natural disaster and major and minor manmade disasters.

- Major natural disasters are Flood, Cyclone, Droughtand Earthquake

- Minor natural disasters are Cold wave, Thunderstorm, Heat waves, Mud slides and Storm
- Man-made disasters are fire, accidents (road, rail or air), industrial accidents or epidemics.

1.2 Disaster Management

Disaster management means a continuous and integrated process of planning, organizing, coordinating and implementing measures which are necessary or expedient for

1) Prevention of danger or, threat of any disaster
2) Mitigation or reduction of risk of any disaster severity or consequences
3) Capacity-building
4) Preparedness to deal with any disaster
5) Prompt response to any threatening disaster situation or disaster
6) Assessing the severity or magnitude of effects of any disaster
7) Evacuation, rescue and relief
8) Rehabilitation and reconstruction

1.2.1. Disaster prevention, mitigation and preparedness

The first important steps towards reducing disaster impact are to correctly analyse the potential risk and identify measures that can prevent, mitigate or prepare for emergencies. Information and communication technology can play a significant role in highlighting risk areas, vulnerabilities and potentially affected populations by producing geographically referenced analysis through, for example, a geographic information system (GIS).

The importance of timely disaster warning in mitigating negative impacts can never be underestimated. For example, although damage to property cannot be avoided, developed countries have been able to reduce loss of life due to disasters much more effectively than their counterparts in the developing world. A key reason for this is the implementation of effective disaster warning systems and evacuation procedures used by the developed countries, and the absence of such measures in the developing world.

A warning can be defined as the communication of information about a hazard or threat to a population at risk, in order for them to take appropriate actions to mitigate any potentially negative impacts on themselves, those in their care and their property.The occurrence of a hazard does not necessarily result in a disaster. While hazards cannot be avoided, their negative impacts can be mitigated. The goal of early public warning is to ensure to the greatest extent possible that the hazard does not become a disaster. Such warnings must be unambiguous, communicate the risks succinctly and provide necessary guidance.

The success of a warning can be measured by the actions that it causes people to take, such as evacuation or avoiding at-risk areas. In a disaster situation, there is no doubt that timely warnings allow people to take actions that saves lives, reduce damage to property and minimize human suffering. To facilitate an effective warning system, there is a major need for better coordination among the early warning providers as well as those handling logistics and raising awareness about disaster preparedness and management.While disaster warnings are meant to be a public good, they are often most effectively delivered through privately-owned communication networks and devices. There are many new communication technologies that allow warning providers not only to reach the people at risk but also to personalize their warning message to a particular situation. Opportunities are available right now to significantly reduce loss of life and potential economic hardship if disaster warning systems can be improved.

It is important to note that disaster warning is indeed a system, not a singular technology, constituting the identification, detection and risk assessment of the hazard, the accurate identification of the vulnerability of a population at risk, and finally, the communication of information about the threat to the vulnerable population in sufficient time and clarity so that they can take action to avert negative consequences. This final component

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

underscores the importance of education and creating awareness in the population so that they may respond with the appropriate actions.

1.2.2Disaster management in India

The **National Disaster Management Authority** (NDMA), headed by the Prime Minister of India, is the apex body for disaster management in India. The setting up of the NDMA and the creation of an enabling environment for institutional mechanisms at the State and District levels is mandated by the Disaster Management Act, 2005. the Government of India enacted the Disaster Management Act, which envisaged the creation of the National Disaster Management Authority (NDMA), headed by the Prime Minister of India, and State Disaster Management Authorities (SDMAs) headed by respective Chief Ministers of the States, to spearhead and implement a holistic and integrated approach to disaster management in India.

Under this act National disaster management authority has following rights

1. Lay down policies on disaster management
2. Approve the National Plan
3. Approve plans develop by the Ministries or Department of the Government of India in accordance with the national plan
4. Lay down guidelines to be followed by State Authorities in drawing up the state plan
5. Lay down guidelines to be followed by the different Ministries or Department of the Government of India for the purpose of integrating the measures for prevention of disaster of the mitigation of its effect in their development plans and projects
6. Coordinate the enforcement and implementation of the policy and plan for disaster management
7. Recommended provision of funds for the purpose of mitigation
8. Provide such support to other countries affected by major disasters as may be determined by the Central Government

9. Take such other measures for the prevention of disaster or the mitigation, or preparedness and the capacity building for dealing with the threatening disaster situation or disaster as it may consider necessary
10. Lay down broad policies and guidelines for the functioning of National Institute of Disaster Management.

The national should include

1. Measures to be taken for prevention of disasters or the mitigation of their effects
2. Measures to be taken for the integration of mitigation measures in the development plans
3. Measures to be taken for preparedness and capacity building to effectively respond to any threatening disaster situation or disaster
4. Role and responsibilities of different Ministries or Departments of Government of India in respect of measures specified above.

The national plan should be revied and updated annually and appropriate provision should be made by Central Government for financing the measures to be carried out under national plan.

The National Authority should recommend guidelines for the minimum standard of relief to be provided to persons affected by disaster, which includes

1. The minimum requirements to be provided in the relief camps in relation to shelter, food, drinking water, medical cover and sanitation.
2. Ex gratia assistance on account of loss of life as also assistance on account of damage to houses and for restoration of means of livelihood and such other relief as may be necessary.

1.3Weather Disaster Management

1. Crops depend upon certain optimum weather conditions for their potentialproduction, although other variables such as fertilizers, insecticides., etc. interact to certain extent in an agricultural system

2. Daily, seasonal and long-term variations in any or all the climatic elements alter the efficiency of plant growth thereby the crop production.
3. The deviation of climatic factors considerably from their normal values is referred as "Adverse weather" or "Adverse climate" depending on duration of such impact.

The following are the adverse weather conditions and the possible management strategies.

1.3.1 Floods

A flood is caused by excess water in a location, usually due to rain from a storm or thunderstorm or the rapid melting of snow. A flood happens when an area of land, usually low-lying, is covered with water. The worst floods usually occur when a river overflows its banks. The flood is constituted not only of the overflowing water but also of all other waters that are unable to drain off into water channels.

1.3.1.1Causes of floods

- When snow on a mountain melt or when a river or a lake of some sort overflows
- Flooding from water displacement, such as in a landslide,
- The failure of a dam,
- An earthquake induced tsunami,
- A hurricane’s storm surge or melt water from volcanic activity.
- Flooding of Coastal areas by high tides or by tsunami waves caused by undersea earthquakes.
- A flood that rises and falls rapidly with little or no advance warning is called a flash flood. Flash floods usually result from intensive rainfall over a relatively small area.

1.3.1.2Elements at risk

- Buildings built of earth (mud), weak foundation and water-soluble material.
- Basement of buildings.
- Utilities such as sewerage, water supply.

- Agricultural equipment and crops, vehicles, fishing boats etc.

1.3.1.3Effects of flood

- **Physical damage**- structures such as buildings get damaged due to flood water. Landslides can also take place. Top soil gets washed away
- **Causalities** - people and livestock die due to drowning. It can also lead to epidemics and diseases.
- **Water supplies**- Contamination of water. Clean drinking water becomes scarce.
- **Crops and food supplies**- shortage of food crops can be caused due to loss of entire harvest.

1.3.1.4Flood management

Flood management involves the following activities:

- **Mapping**- of the flood prone area.
- **Land use control**- no major development should be permitted in the areas subjected to flooding.
- **Construction of engineered structures**- strong structures to withstand flood forces. Moreover, the buildings should be constructed on an elevated area and if necessary, should be built on stilts.
- **Flood control**- it aims to reduce flood damage. It includes,flood reduction, flood diversion and flood proofing

1.3.2Cyclone

Cyclone is meteorological phenomena in which an area of low pressure characterized by inward spiralling winds that rotate counter clockwise in the northern hemisphere and clockwise in the southern hemisphere of the earth. Near the places of their origin, they are only 80 Km in diameter, but well-developed cyclones have their diameter ranging from 300 to 1500 km. They move at faster rate over the oceans than over the land because the irregularities of the land surface retard their speed. The six main types of cyclones are polar cyclone, polar low, extra tropical, subtropical, tropical and mesoscale.

1.3.2.1 Polar cyclone

Polar or arctic cyclones are vast areas of low pressure. A polar cyclone is a low pressure weather system usually spanning 1,000-2000 km per hour, in which the air circulates in a counterclockwise fashion in the northern hemisphere.

1.3.2.2 Polar low

A polar low is a small-scale, short-lived atmosphere system (depression) that is found over the ocean areas in both the Northern and southern hemispheres. They are part of the larger class of meso scale weather systems. Polar lows can be difficult to detect using conventional weather reports and are a hazard to high latitude operations, such as shipping and gas and oil platforms. Polar lows have been referred to by many other terms, such as comma cloud, mesocyclone, polar meso scale vortex, Arctic hurricane, Arctic low and depression.

1.3.2.3 Extra-tropical

An extra tropical cyclone sometimes inaccurately called a cyclone is a synoptic scale low pressure weather system that has neither tropical nor polar characteristics. The "extra-tropical" refers to the fact that this type of cyclone generally occurs outside of the tropics, in the middle latitudes of the planet. These systems may also be described as "mid-latitude cyclones" or "post-tropical cyclones.

1.3.2.4 Sub-tropical

A sub-tropical cyclone is a weather system that has some characteristics of an extra-tropical cyclone. It can in a wide band of latitude, from the equator to 50°.

1.3.2.5 Tropical

A tropical cyclone is a low-pressure cyclonic storm system. It is caused by evaporated water which comes off the ocean and becomes a storm. Typical cyclones are the worst natural hazards in the tropics. They are large revolving vortices in the atmosphere extending horizontally from 150-1000 km and vertically from the surface from 12-14 km.

Strong winds spiralling anti-clockwise in the Northern Hemisphere blow around the cyclone centre at the low level. At the higher levels, the sense of rotation is just opposite to that at the lower level. They generally move 300-5000 km per day over the ocean. While moving over the ocean, they pick up energy from the warm water of the ocean and some of them grow into a devastating intensity. On an average, about 5-6 tropical cyclones form in the Bay of Bengal and the Arabian sea every year, out of which 2-3 may be severe.Depending on their location and strength, there are various terms by which tropical cyclones are known, such as hurricane, typhoon, tropical storm, cyclonic storm and tropical depression. They are all cyclonic storm systems that form over the oceans. Tropical cyclones can produce extremely strong winds, tornadoes, torrential rain, high waves, and storm surges. The heavy rains and storm surges can produce extensive flooding.

1.3.3 Mitigation strategies for cyclone

a) **Installation of Earth Warning Systems:** Such systems fitted along the coastlines can greatly assist forecasting techniques, thus helping in early evacuation of people in the storm surge areas.

b) **Developing communication infrastructure**:Community Radio has today emerged as second line unconventional communications systems and is an important tool for disaster mitigation.

c) **Developing shelter belts:** Shelter belts with plantations of trees can act as effective windand tidebreakers. Apart from acting as effective windbreakers and protecting soil crops from being damaged, they also prevent soil erosion.

d) **Developing community cyclone shelters**: Cyclone shelters at strategic locations can help in minimizing the loss of human life. In the normal course of life, these shelters can be used as public utility buildings.

e) **Construction of permanent houses**: There is a need to build appropriately-designed concrete houses that can withstand high winds and tidal waves.

f) **Training and education**: Public awareness programs that inform the population about their response to cyclone warnings and preparedness can go a long way in reducing causalities.

g) **Land use control and settlement planning**: Ideally, no residential and industrial units should be permitted in the coastal belt of 5 km from the sea, as it is the most vulnerable belt. No further growth of settlements in this region should be permitted. Major settlements and other important establishments should be located beyond 10 km from the sea.

1.3.4 Temperature

Temperature is essential for all plant physiological processes, gaseous exchange between plant and environment, stability of plant enzymatic reactions, etc. However, both cold and heat waves and abnormal soil temperatures are averse to crop growth and development.

1.3.4.1 Cold Waves: During winter (December - February), temperature decreases generally over the Indian subcontinent. It is lower in northernIndia and higher in southernIndia. This fall in temperature may cause damage to the crops. If the temperature drops on freezing or below, a frost may occur which causes severe damage to the crops/crop plants.

Threat of frost is danger to crops.

1. Frost is a form of condensation that forms on cold objects when the dew point isbelow freezing.
2. Frosts are of two types.
   a. Advection or air mass frost: Which results when the temperature at the surface in an air mass is below freezing.
   b. Radiation frost: Which occurs on clear nights with a temperature inversion.
3. There is a special case of frost caused by loss of heat by evaporation. This occurs when cold rain showers wet the leaves and are then followed by dry wind.

1.3.4.1.1Advection Frost

The usual effects of Advection frost are:

1. The injury and death caused by frost is due to the formation of ice crystals in and outside the plant cells.
2. During dormancy, plants can withstand lower temperatures upto 20^{o}C.
3. Once growth has commenced temperatures of few degrees below freezing point may be fatal.
4. The cell sap gets frozen below 0^{o}C, as also between cells.
5. Extra cellular ice formation occurs followed by withdrawal of water from the cell.
6. The protoplasm may become dehydrated and brittle, resulting in mechanical damage, or the cell may contract and damage the protoplasm.

Management of advection frost

For production of most field crops, the only satisfactory solution to the problem of advection freezing is to avoid it as far as possible by planting after incidence and by selecting varieties which will mature before the beginning of the hazard.

1.3.4.1.2 Radiation frost

The damage due to radiation frost differs from the above freeze damage in degree and its spotty occurrence.

1. This radiation frost damage is critical during critical stages of growth.
2. Young seedlings may be killed.
3. Flowering stage is most prone.
4. Crops like potato, tomato and melons are vulnerable right upto maturity.
5. For most field crops and orchard crops flowering stage is most critical for frost damage.
6. Frosty nights followed by warm sunny days produce a sunclad on orchard fruits, considerably reducing their production.

Management of radiation frost

The management of radiation frost can be grouped as follows

a. Passive methods: Clean cultivation, maintenance of soil moisture, wrapping plants with insulating material and enclosing the basal part of the plant. Proper site selection. Choice of growing season. Breeding of cold resistant varieties.

The above methods can be followed even for advection frost also. These passive methods do not involve any modification of environment.

b. Active methods: The active methods of frost protection are like use of heaters, wind machines and sprinkling water. Followweather forecast for better management of crops.

1.3.5 Heat Waves

These are very harmful during summer. These are experienced over Deccan and Central parts of India during March to May. The harmful effects include shedding of leaves, fruit drop, drying of water resources.

a) Loss of water by evaporation from irrigation channels.
b) Transpiration increases from plants beyond recouping levels
c) Plants tend to wilt and die owing to rapid desiccation.
d) Hot winds cause shriveling effect at milk stage of all agricultural crops.

Management of heat waves

Adoption of specific agronomic practices like, shelterbelts, choice of varieties, etc.

1.3.6Wind

Wind has its most important effects on crop production indirectly through the transport of moisture and heat. Vegetative growth at 'Zero' wind, as experienced in glass houses or under low glass cover is luxuriant. But there is typically a reduction in vegetative growth as the wind increases to small values, viz., 1 or 2 meters per second.

1.3.6.1 Beneficial effects of winds

1. Moderate turbulence promotes the consumption of carbon-dioxide by photosynthesis.
2. Prevent frost by disrupting a temperature inversion.

3. Wind dispersal of pollen and seeds is natural and necessary for certain agricultural crops and natural vegetation also.

1.3.6.2. Harmful effects of winds

1. At sustained high speeds (12-15 metres per second) at plant height, plants assume a low, dwarf like form, whilest the intermittent high wind speeds experienced in gales, hurricanes etc., results in gross physical damage to bushes and trees.
2. At higher wind speeds, the shape of the orchard tree alters giving rise to the characteristic wind shaping of trees in exposed positions.
3. Leaves become smaller and thicker.
4. Breakage occurs and bushes and trees subjected to natural (seasonal) pruning.
5. Direct mechanical effects are the breaking of plant structures, lodging of cereal crops, or shattering of seed from panicles.

Management of High Winds

It can be done by using wind breaks and shelter belts. The effects of wind on evaporation can be avoided by using proper method of irrigation. The damaging effect of wind can be reduced over a limited area by the use of shelter belts (rows of trees planted for wind protection) and wind breaks (any structure that reduce the wind speed).

1.3.7 Thunderstorms, dust storms and hail storms

These storms are known as local severe storms. As many as 44,000 thunder storms occur daily on earth.

1. These are formed in a situation where a great deal of the energy for their genesis and development comes from the release of the latent heat of condensation in rising humid air.
2. These local storms cause severe damage to the standing crop by causing mechanical injury to the plants.
3. In dust storms, the dust raised by the wind covers small plants, which may cause stomata closure and suffocation.
4. Hails cause direct damage to crops by lodging, shattering of seeds, etc., depending on their intensity.

Management of storms: Prevention of hails by hail suppression techniques.Follow the forecasts of weather and protect crops.Spraying of salt on harvested paddy, to prevent the germination / sprouting of harvested produce.

1.3.8 Excessive or defective insolation

Excessive solar radiation results in rise of soil and air temperatures. Defective insolation with consistently cloudy weather on one hand and consistently bright and high intensity sunshine on the other hand causes enormous damage to crop plants.

1 Cloudy weather retard growth, affect pollination and cause disease and pest incidence.

2High solar radiation intensity cause pollen burst or flower drop.

Management

Since, these are very rare, the location specific solutions like proper site selection, allowing air drainage,adequate water supply,pruning of orchard trees,spray of chemicals and plant hormones,covering plants with "hot caps" (covering plants with some standard and recommended material), etc. may prove beneficial.

1.3.9Tornado

This is a violent, destructive storm of small horizontal dimensions. A cumulonimbus cloud forms into a funnel shape with a vortex extending from the base of the storm to the surface. The Whirl-wind encircles a small dimension of about 500 meters. These are capable of causing severe structural and other damages. The violent winds associated with this abnormality are strong upward air currents. The tornados occurring on water are known as “Water spouts”.

Management: Warning in advance, precautions to protect the agricultural produce like transportation to safety places etc. and Quick removal of debris immediately after damage.

Glossary:

Disaster warning:A warning can be defined as the communication of information about a hazard or threat to a population at risk, in order for them to take appropriate actions to mitigate any potentially negative impacts on themselves, those in their care and their property.

Disaster: Disaster is a sudden, calamitous event bringing great damage, loss, destruction and devastation to life and property.It may also be termed as "a serious disruption of the functioning of society, causing widespread human, material or environmental losses which exceed the ability of the affected society to cope using its own resources."

Tornado: This is a violent, destructive storm of small horizontal dimensions

Water spouts:The tornados occurring on water are known as "Water spouts".

Mitigation: it means measures aimed at reducing the risk, impact or effects of a disaster or threatening disaster situation

Preparedness: It means the state of readiness to deal with a threatening disaster situation or disaster and the effects there of.

Reference:

Barry, R.G and R.J. Chorley.(2009).Atmosphere, weather and climate. Routledge Taylor and Francis group. UK.

IPCC, 2007: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 976pp.

Mahi, G.S. and Kingra, P.K. (2014), FUNDAMENTALS OF AGROMETEOROLOGY AND CLIMATE CHANGE. Kalyani publisher. New Delhi.

Mavi, H.S. and Tupper, G.J. (2004). Agro meteorology: Principle and Application of climate Studies in Agriculture. Haworth Press

The Gazette of India (2005),26th December,No.64 Pa

Course Name	Agro-meteorology and climate change
Lesson 7	Atmospheric pollution and role of meteorology-Basics of weather forecasting
Content Creator Name	Vallal Kannan Sankaralingam
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	Dr. Vijay Gopal More
University/College Name	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Lesson 7

Objectives:

- To understand atmospheric pollution and role of meteorology
- To understand basics of weather forecasting.

1 Atmospheric pollution and role of meteorologist

1.1 Pollution

Pollution is an undesirable change in the physical, chemical or biological characteristics of air, water and soil that may harmfully affect the life or create a potential health hazard of any living organism.

Pollution is thus direct or indirect changes in any component of the biosphere that is harmful to the living component (s), and in particular undesirable for man, affecting adversely the industrial progress, cultural and natural assets or general environment.

1.2. Pollutants

Any substance which causes pollution is called a pollutant. A pollutant may thus include any chemical or geochemical (dust, sediment, grit, etc.) substance, biotic component or its product, or physical factor (heat) that is released intentionally by man into the environment in such a concentration that may have adverse harmful or unpleasant effects.

1.3. Air pollution

Air pollution can be defined as an alteration of air quality that can be characterized by measurements of chemical, biological or physical pollutants in the air. Therefore, air pollution means the undesirable presence of impurities or the abnormal rise in the proportion of some constituents of the atmosphere. It can be classified as **visible** and **invisible** air pollution.

It is defined as the excessive concentration of foreign material in the atmosphere, which affects the health of individuals and also causes damage to the property.

Air pollution may be simply defined as the presence of certain substances in the air in high enough concentrations and for long enough duration to cause undesirable effects. "Certain substances" may be any gas, liquid or solid, although certain specific substances are considered significant pollutants because of very large emission rates are harmful and unwanted effects. "Long enough durations" can be anywhere from a few hours to several days or weeks; on a global scale, durations of months and years are of concern.

1.3.1. Causes for Air pollution

Air pollution is caused by the presence in the atmosphere of toxic substances, mainly produced by human activities, even though sometimes it can result from natural phenomena such as volcanic eruptions, dust storms and wildfires, also depleting the air quality.

Anthropogenic air pollution sources are:

1. Combustion of fossil fuels, like coal and oil for electricity and road transport, producing air pollutants like nitrogen and sulfur dioxide
2. Emissions from industries and factories, releasing large amount of carbon monoxide, hydrocarbon, chemicals and organic compounds into the air
3. Agricultural activities, due to the use of pesticides, insecticides, and fertilizers that emit harmful chemicals.
4. Waste production, mostly because of methane generation in landfills.

1.3.2. Effects of air pollution

Air pollution is known to have many adverse effects, including those on human health, building facades and other exposed materials, vegetation, agricultural crops, animals, aquatic and terrestrial ecosystems, and the climate of earth as a whole.

1.3.2.1 Environmental effects

Air pollution has a major impact on the process of plant evolution by preventing photosynthesis in many cases, with serious consequences for the purification of the air we breathe. It also contributes to the formation of acid rain, atmospheric precipitations in the form of rain, frost, snow or fog, which are released during the combustion of fossil fuels and transformed by contact with water steam in the atmosphere.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

1.3.2.2 Global warming

On top of that, air pollution is a major contributor to global warming and climate change. In fact, the abundance of carbon dioxide in the air is one of the causes of the greenhouse effect. Normally, the presence of greenhouse gases should be beneficial for the planet because they absorb the infra-red radiation produced by the surface of the earth. But the excessive concentration of these gases in the atmosphere is the cause of the recent climate change.

1.3.2.3 Health effects

Our continual exposure to air pollutants is responsible for the deterioration of human health.
Air pollution is indeed a significant risk factor for human health conditions, causing allergies, respiratory and cardiovascular diseases as well as lung damage.

Perhaps the most important effect of air pollution is the harm it causes to human health. Generally, air pollution is most harmful to the very old and the very young. Many elderly people may already suffer from some form of heart or lung disease, and their weakened condition can make them very susceptible to additional harm from air pollution. The sensitive lungs of new born infants are also susceptible to harm from dirty air. But it is not just the elderly or the very young who suffer; healthy people of all ages can be adversely affected by high levels of air pollutants. Major health effects are categorized as being acute, chronic, or temporary. There is much evidence linking lung cancer to air pollution, although the actual cause and effect relationship is still unknown. Typical effects of sulfur dioxide, oxides of nitrogen, and ozone include eye and throat irritation, coughing and chest pain. Nitrogen dioxide is known to cause pulmonary edema, an accumulation of excessive fluids in the lungs. Ozone, a highly irritating gas, produces pulmonary congestion, symptoms of ozone exposure may include dry throat, headache, disorientation, and altered breathing patterns.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

1.3.2.4 Effect on Materials

Every year, air pollutants cause damage worth billions of rupees. Air pollutants breakdown the exterior paint in cars and houses. Air pollutants have discolored irreplaceable monuments, historic buildings, marble statues and other heritage and natural beauty sites.

1.3.2.5 Effect on plants

Some gaseous pollutants enter leaf pores and damage the crop plants. Chronic exposure of leaves to air pollutants damages waxy coating, leads to damage from diseases, pests, drought and frost. Such exposure interferes with photosynthesis and plant growth, reduces nutrient uptake and causes leaves to turn yellow, brown or drop off. At higher concentrations of $SO_{2,}$ most of the flower buds become stiff and hard and fall off. Prolonged exposure to higher levels of air pollutants from Iron smelters, coal burning power plants and industries, vehicles can damage trees and plants.

1.3.2.6 Ozone Stratosphere

Ozone is continuously being created in the stratosphere by the absorption of short wavelength UV radiation, while at the same time it is continuously being removed by various chemical reactions that convert it back to molecular oxygen. The rates of creation and removal at any given time and location dictate the present concentration of ozone. The balance between creation and removal is being affected by increasing stratospheric concentrations of chlorine, nitrogen and bromine, which acts as catalysts, speeding up the removal process. CFCs are predominant.

1.3.3. Management of air pollution

For ages man has been dumping wastes into the atmosphere, and these pollutants have disappeared with the wind. We have seen that the main sources of air pollution are

(i) Motor vehicles,

(ii) Industries-particularly their chimney wastes,

(iii) fossil-fuel (coal) based plants, as thermal power plants.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Steps are to be taken to control pollution at source (prevention) as well as after the release so pollutants in the atmosphere. There is an urgent need to prevent the emissions from the above said major sources of air pollution. The control of emissions can be realized in number of ways.

1.3.3.1 Source correction

There are several approaches or strategies for air pollution control. The most effective control would be to prevent the pollution from occurring in the first place. Complete source shutdown would accomplish this, but shutdown is only practical under emergency conditions, and even then it causes economic loss. Nevertheless, state public health officials can force industries to stop operations and can curtain highway traffic if an air pollution episode is imminent or occurring.

An important approach for air pollution control is to encourage industries to make fuel substitutions or process changes. For example, making more use of solar, hydroelectric, and geothermal energy would eliminate much of the pollution caused by fossil fuel combustion at power generating plants. Nuclear power would do the same, but other problems related to high level radioactive waste disposal and safety remain to be solved. Fuel substitutions are also effective in reducing pollution from mobile sources. For example, the use of reformulated gasoline or alternative fuels such as liquefied petroleum gas, compressed natural gas, or methanol for highway vehicles would help to clear the air. The use of correct operation and maintenance practices is important for minimizing air pollution and should not be overlooked as an effective control strategy.

1.3.3.2 Collection of pollutants

Often the most serious problem in air pollution control is the collection of the pollutants so as to provide treatment. Automobiles are most dangerous, but only because the emissions cannot be readily collected. If we could channel the exhausts from automobiles to some central facilities, their treatment would be much more reasonable than controlling each individual car. One success in collecting pollutants has been the recycling of blow by gases in the internal combustion engine. By reigniting these gases and emitting them through the car's exhaust system, the need of installing a separate treatment device for the car can be eliminated.

1.3.3.3 Cooling

The exhaust gases to be treated are sometimes too hot for the control equipment and the gases must first be cooled. This can be done in three general ways: dilution, quenching, or heat exchange coils. Dilution is acceptable only if the total amount of hot exhaust is small. Quenching has the additional advantage of scrubbing out some of these gases and particulates. The cooling coils are perhaps the most widely used, and are especially appropriate when heat can be conserved.

1.3.3.4 Treatment

The selection of the correct treatment device requires the matching of the characteristics of pollutant and features of the control device. It is important to realize that the sizes of air pollutants range many orders of magnitude, and it is therefore not reasonable to expect one device to be effective for all pollutants. Although, any new devices may appear any day in the market, the following are the most widely used:

- **Setting chambers** are nothing more than large places in the flues, similar to settling tanks in water treatment. These chambers remove only the large particulates.
- **Cyclones** are widely used for removing large particulars. The dirty air is blasted into a conical cylinder, but off the centreline. This creates violent swirl within the cone, and the heavy solids migrate to the wall of the cylinder where they slow down due to friction and exit at the bottom of the cone. The clean air is in the middle of the cylinder and exits out the top. Cyclones are widely used as pre-cleaners to remove the heavy material before further treatment.
- **Bag filters** operate like the common vacuum cleaner. Fabric bags are used to collect the dust which must be periodically shaken out of the bags. The fabric removes nearly all particulates. Bag filters are widely

used in many industries, but are sensitive to high temperature and humidity.

- **Wet collectors** come in many shapes and styles. The simple spray tower is an effective method for removing large particulates. More efficient scrubbers promote the contact between air and water by violent action in a narrow throat section into which the water is introduced.
- **Electrostatic precipitators** are widely used in power plants. The particulate matter is removed by first being charged by electrons jumping from one high voltage electrode to the other, and then migrating to the positively charged electrode. The particulates will collect on the pipe and must be removed by banging the pipes with hammers. Electrostatic precipitators have no moving parts, require electricity, and are extremely effective in removing submicron particulates. They are expensive.
- **Gas scrubbers** are simply wet collectors as described above but are used for dissolving the gases.
- **Absorption** is the use of the material such as activated carbon to capture pollutants. Such adsorbers may be expensive to regenerate. Most of these work well for organics and have limited use for inorganic pollutants.
- **Incineration** is a method for removing gaseous pollutants by burning them to CO_2, H_2O and inert. This works only for combustible vapours.
- **Catalytic combustion** involves the use of a catalyst to adsorb or chemically change the pollutants.

2 Role of meteorology in air pollution

Atmospheric observation system forms the backbone of any meteorological service. Reliable and accurate measurement of upper air and surface Meteorological data is a basic requirement for defining current weather, weather forecasting, numerical weather prediction (NWP) and disaster management. Radiosonde provides the vertical profile of temperature and humidity at a place and this data is used for calibrating the satellite observations as well. High resolution data from improved radiosonde, wind profilers, wind lidars as well as measurements from aircraft through dropsondes lead to improved initial conditions of vertical profiles which in turn improve the forecast. The high quality upper air data and its sustenance is thus essential for improved performance not only at National level but at the International level as well since it provides input for global model. The long series of archived observational data also forms an integral part of the climate studies. The radiation measurements are undertaken to get the atmospheric radiation profile. This data along with ozone measurement data collected from all the stations are used for environmental monitoring and in the air pollution studies.

Environmental Monitoring is one of the major requirements to provide inputs on air quality. This would include black carbon, trace gases such as Ozone, SO_2, NO_2, CO_2, and physical and radioactive characteristics of aerosols. The measurement of various atmospheric parameters through surface, upper air, aircraft and satellite-based platforms is a prime requirement for weather forecasting.

2.1 The role of meteorology on observation in relation to air pollution involves

a. The identification of contaminants.
b. The identification of the source(s) of pollutants.
c. The prediction of air pollution events such as inversions and high pollutant concentration days.
d. The forecasting of pollution levels.
e. The determination of pollution trends in urban areas, monitoring and developing control measures.

When studying air quality, it is important to measure the following factors as they help us understand the chemical reactions that occur in the atmosphere:

2.2.1 Wind speed and direction

Wind data records can determine the general direction and area of the emissions. An anemometer measures wind speed, while a wind vane informs about its direction. Winds are usually summarized by classes of speeds and directions. Speed determines to some extent the dilution of the pollutants in the atmosphere, and direction gives the transport.

2.2.2 Temperature

Measuring temperature supports air quality assessment, air quality modeling and forecasting activities. Temperature and sunlight (solar radiation) performs a significant task in the chemical reactions that occur in the atmosphere to form photochemical smog from other pollutants. Favorable conditions can lead to increased concentrations of smog. The most common way of measuring temperature is the use of a thermometer (material with a resistance that changes with temperature, such as platinum wire). A sensor measures this change and converts it into a temperature reading. The vertical temperature variation plays a very important role in air pollution. The increase of temperature with height in the low level, known as ‘inversion’ is of much concern because such inversion, depending upon the level at which it occurs with respect to the stack height can act as a lid and not allow dispersion to take place resulting in an enormously high ground level concentrations. The spatial variation of surface temperature also plays a role in air pollution studies. Surface temperature in the cities is usually higher compared to nearby rural areas due to urbanization also known as ‘urban heat island’ (UHI). The UHI influences the dispersion of the pollutants.

Stability is another important parameter which governs the dispersal of pollutants. Highly unstable conditions result in thorough mixing and dilution and a consequent reduction in the ground level concentration. Stable conditions on the other hand are characterized by low mixing and cannot disperse the pollutants resulting in the build-up of pollutants.

2.2.3 Humidity

Water vapour plays an important role in many thermal and photochemical reactions in the atmosphere. As water molecules are small and highly polar, they can bind strongly to many substances. If attached to particles suspended in the air they can significantly increase the amount of light scattered by the particles (measuring visibility). If the water molecules attach to corrosive gases, such as sulfur dioxide, the gas will dissolve in the water and form an acid solution that can damage health and property. Water vapour content of air is reported as a percentage of the saturation vapour pressure of water at a given temperature. This is the relative humidity. The amount of water vapour in the atmosphere is highly variable and it depends on geographic location, how close water bodies are, wind direction and air temperature. Relative humidity is generally higher during summer when temperature and rainfall are also at their highest. Measuring humidity uses the absorption properties of a polymer film. The film either absorbs or loses water vapour as the relative humidity of the ambient air changes. A sensor measures these changes and converts them into a humidity reading.

2.2.4 Rainfall

Rain has a 'scavenging' effect when it washes particulate matter out of the atmosphere and dissolves gaseous pollutants. Removing particles improves visibility. Where there is frequent high rainfall, air quality is generally better. If the rain dissolves gaseous pollutants, such as sulfur dioxide, it can form acid rain resulting in potential damage to materials or vegetation. A common method to measure rainfall is to use a rain gauge.

2.2.5 Solar radiation

It is important to monitor solar radiation for use in modeling photochemical smog events, as the intensity of sunlight has an important influence on the rate of the chemical reactions that produces smog. The cloudiness of the sky, time of day and geographic location all affect sunlight intensity. An instrument called a pyranometer measures solar radiation from the output of a type of silicon cell sensor.

3 Basics of weather forecasting

The task of predicting the weather that will be observed at a future time is called weather forecasting. As one of the primary objectives of the science of meteorology, weather forecasting has depended critically on the scientific and technological advances in meteorology that have taken place since the latter half of the 19th century.

3.1 Historical background

Throughout most of history, forecasting efforts at any given site depended solely on observations that could be made at that site. Observations of sky, wind, and temperature conditions and knowledge of local climate history permitted a limited predictive ability. Weather lore was also accumulated in an effort to codify apparent patterns in the behavior of the atmosphere.

With the development of the telegraph in the mid-1800s, weather forecasters were able to obtain observations from many distant locations within a few hours of the collection of such data. These data could then be organized into so called synoptic weather charts, synoptic meaning the display of weather data occurring at the same time over an area. These were the predecessors of the synoptic weather maps produced today. The physical bases of atmospheric motions were not yet understood, however, so prediction depended on various empirical rules. The most fundamental rules developed in that period were that weather systems move and that precipitation typically is associated with regions of low atmospheric pressure.

Weather forecasting was revolutionized in the 1920s by the work of a group of Norwegian scientists led by Vilhelm Bjerknes. Bjerknes, who introduced the polar front theory to account for the large-scale movement of air masses, His group provided a consistent and empirically based description of atmospheric circulation systems such as cyclones and anticyclones and of the formation of precipitation.

By the 1930s, radio technology had provided forecasters with an important new tool, the radiosonde. Radiosondes are balloon-borne automated packages of meteorological instruments that relay back observations while ascending through the atmosphere. Such devices extended and refined the forecasting concepts of polar-front theory by revealing major upper-atmosphere features such as the jet stream.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Current weather-forecasting techniques were initiated by the theoretical work of American meteorologist Jule Charney in developing numerical weather prediction. That is, weather phenomena are predicted by solving the equations that govern the behavior of the atmosphere. Experimental numerical forecasts in 1950 proved so fruitful that they were soon adopted on a practical basis. Since then, computerized systems based on numerical models have become a central part of weather forecasting.

3.2 The forecasting process

Weather forecasting involves three steps 1. Observation and analysis, 2. Extrapolation to find the future state of the atmosphere, and 3. Prediction of particular variables. One qualitative extrapolation technique is to assume that weather features will continue to move as they have been moving. In some cases the third step (prediction) simply consists of noting the results of extrapolation, but actual prediction usually involves efforts beyond this.

The tools that meteorologists can use for forecasting depend on the intended range of the forecast, or how far into the future the forecast is supposed to extend. Short-range forecasts, sometimes called "now casts," extend up to 12 hours ahead. Daily-range forecasts are valid for 1 to 2 days ahead; this is the range in which numerical forecasting techniques have made their greatest contribution. In the 1980s, however, the techniques also became useful in the development of medium-range forecasts, which extend from three to seven days ahead. Extended-range forecasts, which extend more than a week ahead, depend on a combination of numerical and statistical forecast guidance. Finally, short-term climate forecasts, such as the one-month and three-month average forecasts issued by the Climate Prediction Center of the National Weather Service (NWS), depend mostly on statistical guidance.

The decreasing usefulness of numerical forecasts with increasing range reflects imperfections in current numerical models, but it also reflects the extreme complexity of the atmosphere. Theoretical results show that "perfect" forecasting schemes should become useless for describing daily weather at a range of two to three weeks, although skill remains for forecasting monthly averages in certain cases.

3.2.1 Observation and analysis

Meteorological observations taken around the world include reports from surface stations, radiosondes, ships at sea, aircraft, radar, and meteorological satellites. Although data-access policies vary among countries, many of these reports are transmitted on the Global Telecommunications System (GTS) of the World Meteorological Organization (WMO) to regional and global centers. There the data are collated, redistributed back across the GTS, and used in various numerical forecast models. Typically, these numerical models start out with data observed at 0000 and 1200 Universal Coordinated Time (7 A.M. and 7 P.M. Eastern Standard Time, respectively). Accordingly, special efforts are made to collect as much meteorological data as possible at those times of day.

The data are printed, plotted, and graphed in a wide variety of forms to assist the forecaster. In addition, as the data enter a given forecast model, certain "initialization" routines slightly modify the data just for use in that model. This is done in order to provide the most consistent picture of the atmosphere within the model's limitations. In short-range forecasting a major effort is made toward providing flexible access to the most current observations. Interactive computer systems are very important for helping the forecaster to use the huge mass of data available.

3.2.2 Extrapolation

Whenever possible, meteorologists rely on numerical models to extrapolate the state of the atmosphere into the future, since these models are based on the actual equations that describe the behavior of the atmosphere. Different models, however, have widely varying levels of approximation to the equations. The more exact the approximation, the more expensive the model is to use, because more computer time is required to do the work.

The **India Meteorological Department** (**IMD**) is an agency of the Ministry of Earth Sciences of the Government of India. It is the principal agency responsible for meteorological observations, weather forecasting and seismology. IMD is headquartered in Delhi and operates hundreds of observation stations across India and Antarctica. Regional offices are at Chennai, Mumbai, Kolkata, Nagpur, Guwahati and New Delhi.

IMD is also one of the six Regional Specialized Meteorological Centers of the World Meteorological Organization. It has the responsibility for forecasting, naming and distribution of warnings for tropical cyclones in the Northern Indian Ocean region, including the Malacca Straits, the Bay of Bengal, the Arabian Sea and the Persian Gulf.

The foundation for commissioning of a dynamic coupled forecasting system for Indian summer monsoon rainfall prediction at seasonal and sub-seasonal scale was led by an implementing agreement through a memorandum of understanding (MoU) between National Oceanic and Atmospheric Administration (NOAA) and Ministry of Earth Sciences (MoES) in year 2008 (NOAA and MoES MoU, 2008). This leads to the evolution of the Indian Institute of Tropical Meteorology Earth System Model (IITM-ESM2.0), considered as one of major backbone for monsoon and climate forecasting system in the country. Further, this model is transforming through continuous up gradation and rigorous validation in terms of incorporating accurate prognostic dynamical and physical processes (sea surface temperature, aerosol, land surface, sea ice, cloud parameterization, etc.), horizontal resolution, coupling strategies with an aim towards improving its forecast skills across multiple scales, i.e., short range, extended range, seasonal and climate with special emphasize on Indian summer monsoon (ISM) rainfall. It is noteworthy to mention that, one of the major challenges in monsoon rainfall forecast is to accurately replicate El-Nino Southern Oscillation (ENSO)-Monsoon teleconnection mechanism, which is being realistically simulated by the IITMESM2.0. In addition, this is for the first time that this model will be contributing to the Inter-Governmental Panel of Climate Change (IPCC) 6th phase of coupled modelling Inter-comparison project (CMIP6).

MoES-National Centre for Medium Range Weather Forecasting (NCMRWF) has implemented a high resolution unified model based global forecasting system adopted from United Kingdom Met office (UKMET). The NCMRWF Unified model (NCUM) is a step towards developing a seamless forecasting platform for multiple applications at different temporal and spatial resolutions (horizontal and vertical) through a single window modeling framework. The NCUM a coupled system model, is providing operational forecasts for wide varieties of weather and climate systems such as monsoon, tropical cyclones, dust storms and visibility. This model is also a nucleus to the NCMRWF global ensemble prediction system (NEPS) operationally running at 12 km resolution. The NCUM is modular in nature and can be adjusted from regional to global scale starting from 1.5 km to 25 km grid resolution and 50 to 85 vertical levels at different lead times up to 168 hr (Rajagopal *et al*., 2012, 2014; Sharma *et al*., 2018).

3.2.3 Prediction

High resolution spatio-temporal observation data is one of the major challenges for the weather and climate researchers for accurate understanding of the physical processes, validation of model results and to provide an authenticate representation of climate change scenario over the Indian region. Therefore, reliable long term observation data is key for the progress of weather and climate science in India. Rajeevan *et al*. (2006) has developed a gridded daily rainfall data at 1° × 1° horizontal resolution taking surface observations from 1803 stations across the country. These data is considered as one of the benchmark data sets for rainfall observations over India and extensively used by the research community and operational agencies across the globe for various purpose. This effort has been augmented by Pai *et al*. (2013, 2014) by bringing out high resolution daily rainfall data at a spatial resolution of 0.25° × 0.25° over Indian main land. They have considered about 6955 rain gauge station for developing these data sets. This data set is now extremely popular and authenticated by several researchers in terms of its representativeness and accuracy. Further, Mitra *et al*. (2009, 2013) had developed a moderate resolution (1° × 1°) daily rainfall data sets through merging of satellite rainfall dataset [e.g., Tropical Rainfall Measuring Mission (TRMM), Global Precipitation Measurement (GPM)] along with estimates from IMD rain gauge. This data is immensely popular among research community across India and the globe due to additional information of local gauge rainfall data and rainfall estimates are available over the oceanic regions. In this segment, the high resolution outgoing long wave radiation (OLR) data developed at 0.25° × 0.25° resolution by Mahakur *et al*. (2013) has potential to provide information about cloud types causing rainfall and facilitate in unraveling convective cloud organization from mesoscale to synoptic scale over the Indian region. Apart from these specific data sets, plethora of different atmospheric and ocean data sets were obtained from observation campaign, satellites and remote sensing instruments are readily available in IMD, Meteorological and Oceanographic Satellite Data Archival Centre (MOSDAC), Indian Space Research Organization (ISRO), IITM Pune and Indian National Centre for Ocean Information Services (INCOIS) for researchers for carrying out research and development activities. Indian research community has taken lead in initiating several targeted observational campaigns with specific scientific questions relevant to the country in recent years. To name a few, Cloud-Aerosol Interactions and Precipitation Enhancement Experiment (CAIPEEX), Interaction of Convective Organization and Monsoon Precipitation, Atmosphere, Surface and Sea (INCOMPASS), South West Asian Aerosol - Monsoon Interactions (SWAAMI), Forecast Demonstration Project on Cyclone (Raj *et al*., 2010), Pre-monsoon SAARC Severe Thunderstorm observation and regional modelling (STORM) project (Ray *et al*., 2015), Continental Tropical Convergence Zone (CTCZ) (DST, 2008). These massive observation campaigns under the national monsoon mission program will surely prove to be a milestone in achieving desired objectives of the outstanding scientific challenges in weather and climate sciences in coming years through enriching scientific community with rare and valuable observation and modeling data sets. Each of these observation campaigns has been oriented towards specific scientific questions, region/duration of observations, deployment of observation equipment and modeling framework. Successful completion of these observation campaigns, has highlighted the point that India has developed indigenous capabilities and authorities to take up these emerging challenges in future with an aim to understand and unravel finer details of many intriguing science questions related to monsoon and other important weather systems over the region. This vital information in terms of observations can be subsequently used in terms of data assimilation, accurate representation of physical processes, validations of the models with aim to improve their forecast skills at different spatio-temporal resolution for diverse weather and climate systems over the Indian region.

3.2.4 Severe Weather Events

The Indian region is frequently affected by a variety of hydro-meteorological disasters such as heavy rains, tropical cyclones, storm surges, severe local storms like thunderstorms, hailstorms, cloudburst, tornadoes, floods, heat and cold waves, etc. almost every year. These disasters cause huge loss of lives and properties worth several thousand cores of rupees every year. While the natural disasters cannot be prevented or controlled, the loss of lives and damage to property can be substantially minimized by issuing accurate forecast/advisories of the impending impact of these disasters. Accurate and advanced advisories will greatly help the disaster managers getting sufficient lead time to initiate all necessary preparedness and mitigation actions which would help reducing risk due to these disasters.

Tropical cyclone is one of the major natural disasters impacting India. Even though the North Indian Ocean (NIO) basins generate only 7 per cent of the world cyclones but often they are very severe storms making landfall on the coastline of India. They are responsible for large scale destructions of properties, loss of livelihood and deaths of the citizens particularly residing in vulnerable coastal areas. Das *et al*. (2015) tested Hurricane Weather Research and Forecasting (HWRF) model, which is operationalized at IMD for real time forecast for NIO basin. They found that the average track error of the model varies between 83 km with lead time 12 hours to 319 km at 72 hours. The model showed an improvement of track up to 27 per cent and 15 per cent at the lead time of 48 and 72 hour respectively, however the improvement in the intensity forecast is marginal (5-8%) compared to IMD operational forecast.

Bhomia *et al*. (2017) compared four forecast models from global operational forecasting agencies to evaluate their skills up to 72 hours for landfall of tropical cyclones over NIO. They found that though the models able to capture the track forecast reasonably well, however, none of the models are able to replicate the rainfall characteristics of the storm within 600 km radius from the centre. Routray *et al*. (2018) using operational NCUM found that, the model able to reproduce skilful track prediction when initialized at the severe cyclone stage rather cyclonic stage or lower. Further, they have concluded that the model able to predict landfall location with better accuracy compared to landfall time and the model has eastward bias in the tropical cyclone track compared to best track observations over the NIO basins. The best ensemble prediction for tropical cyclone was provided by the cloud microphysics ensemble suggesting that inclusion of all different hydrometeors are essential for accurate tropical cyclone forecast for Bay of Bengal. These results highlighting the importance, challenges and complexity of forecast of the tropical cyclone particularly with respect to its genesis, intensity and rainfall for NIO basins.

3.2.5 Forecasting Research

New numerical models continue to be developed as supercomputers become more powerful. It is not simply a matter of doing more and more computations, however. Some approximations in such models depend on other parts of the solution being sufficiently simple to make the resulting approximation satisfactory. For example, the treatment of incoming solar radiation is relatively unimportant for models that are no longer useful after two days. However, some scheme for solar radiation must be included for models that are still useful for up to seven or eight days.

The thrust must be on developing and adapting state of art tools, models and emerging techniques such as artificial intelligence, machine learning, augmented and virtual reality and other digital framework not only to generate forecast but also to customized and disseminate region specific information for different kind of weather systems over the targeted area.

3.3 Weather forecast

The prediction of weather for the next few days to follow. The Figure below depicts different weather forecasting services normally practiced in a country.

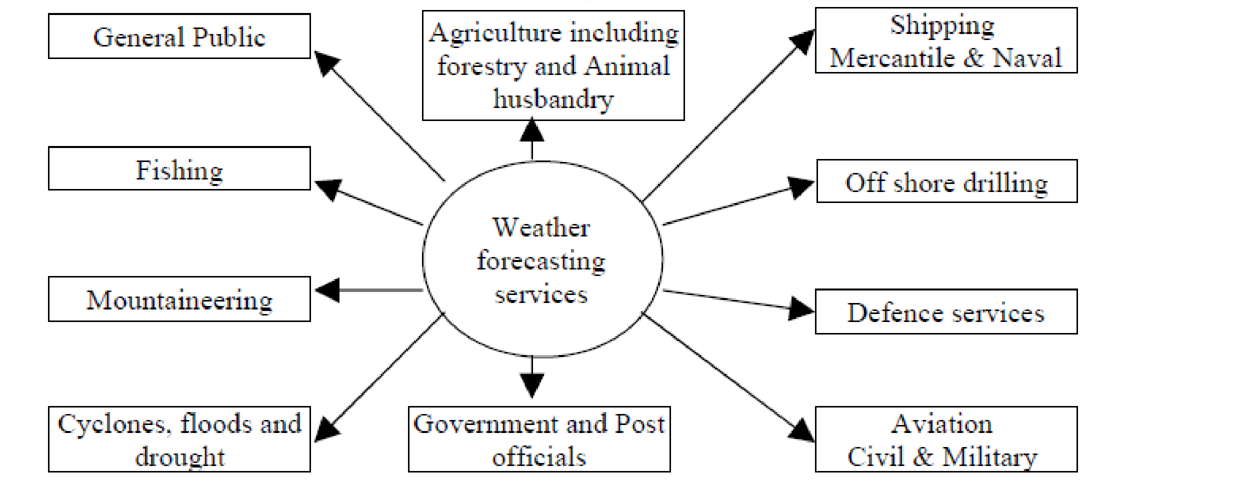


Table-1: Type of weather forecast

Types of forecast	Validity period	Main users	Predictions
1. Short range a) Now casting	Up to 72 hours 0-2 hours	Farmers marine Agencies, general public	Rainfall distribution, heavy rainfall, heat and cold wave conditions, thunder storms etc
b) Very short range	0-12 hours		

Medium range	Beyond 3 days and upto 10 days	Farmers	Occurrence of rainfall, temperature.
Long range	Beyond 10 days upto a month and a season.	Planners	This forecasting is provided for Indian monsoon rainfall. The out looks are usually expressed in the form of expected deviation from normal condition\

3.4 Need and importance of forecast

- Basically weather has many social and economic impacts in a place.
- Among different factors that influence crop production, weather plays a decisive role as aberrations in it alone explains up to 50 per cent variations in crop production
- The rainfall is the most important among the required forecast, which decides the crop production in a region and ultimately the country’s economy.
- The planning for moisture conservation under weak monsoon condition and for flood relief under strong monsoon condition is important in a region.

- A reliable weather forecasting when disseminated appropriately will pave way for the effective sustainability.
- One can minimize the damage, which may be caused directly or indirectly by unfavourable weather.
- The recurring crop losses can be minimized if reliable forecast on incidence of pest and diseases is given timely based on weather variables.
- Help in holding the food grain prices in check through buffer stock operations. This means that in good monsoon years when prices fall, the government may step in and buy and in bad years when price tend to rise, it may unload a part of what it had purchased.
- Judicious use of water can be planned in a region depending up on the forecast.

3.5. Synoptic charts

An enormous volume of meteorological data is being collected from all over the world continuously round the clock through various telecommunication channels. To assess, assimilate and analyse the vast data, it has to be suitably presented. For this purpose, the observations are plotted on maps in standard weather codes. These maps are called 'Synoptic maps or charts'. Synoptic charts display the weather conditions at a specified time over a large geographical area. The surface synoptic charts plotted for different synoptic hours (00, 03, 06, 09, 12, 15, 18, 21 UTC) depict the distribution of pressure, temperature, dew point, clouds, winds, present and past weather. In place of GMT, UTC (Universal Time Co-ordinate) is used. The upper air charts are also prepared at the standard pressure levels of the atmosphere (different heights) of the atmosphere wherein the pressure, wind and temperature are plotted. The surface charts together with the upper air charts provide a composite three-dimensional weather picture pertaining to a given time. Thus it gives a bird's eye view of the state of atmosphere at a time over a large area and is an important tool used by operational meteorologists and scientists. The surface synoptic charts are the most used charts. It contains the maximum number of observations with the largest number of parameters plotted and often forms the base on which the pressure level charts are built up. The pattern of the pressure distribution is brought out by drawing isobars, troughs, ridges, lows, highs, depressions, cyclones, cols, fronts and discontinuities. These systems are clearly marked and labelled using appropriate symbols and colours.

Glossary:

Air pollution: Air pollution may be simply defined as the presence of certain substances in the air in high enough concentrations and for long enough duration to cause undesirable effects.

Pollutants: Any substance which causes pollution is called a pollutant. A pollutant may thus include any chemical or geochemical (dust, sediment, grit etc.) substance, biotic component or its product, or physical factor (heat) that is released intentionally by man into the environment in such a concentration that may have adverse harmful or unpleasant effects.

P**ollution:** Pollution is an undesirable change in the physical, chemical or biological characteristics of air, water and soil that may harmfully affect the life or create a potential health hazard of any living organism.

Weather forecasting: The task of predicting the weather that will be observed at a future time is called weather forecasting.

Climatic normals: The climatic normals are the average value of 30 years of a particular weather element. The period may be week, month and year. The crop distribution, production and productivity depend on the climatic normals of a place. If the crops are selected for cultivation based on the optimum climatic requirements it is likely that the crop production can be maximized.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Reference

Bhomia, S., Jaiswal, N. and Kishtawal, C. M. (2017). "Accuracy assessment of rainfall prediction by global models during the landfallof tropical cyclones in the North Indian Ocean", Meteorological Applications, 24, 503-511. Das, A. K., Rama Rao, Y. V., Tallapragada, Vijay, Zhang, Zhan, Roy Bhowmik, S. K. and Sharma, Arun, 2015, "Evaluation of the Hurricane Weather Research and Forecasting (HWRF) model for tropical cyclone forecasts over the North Indian Ocean (NIO)", Nat. Hazards, 75, 1205-1221.

G S L H V. Prasada Rao. (2008). Agricultural Meteorology, Prentice Hall India Learning Private Limited.

Mahakur, M., Prabhu, A., Sharma, A. K., Rao, V. R., Senroy, S., Singh, Randhir and Goswami, B. N. (2013). "A high-resolution outgoing longwave radiation dataset from Kalpana-1 satellite during 2004-2012", Current Science, 105, 8, 1124-1133.

Mahi, G.S. and Kingra, P.K. (2014). FUNDAMENTALS OF AGROMETEOROLOGY AND CLIMATE CHANGE. Kalyani publisher. New Delhi.

Mavi H. S. and Tupper G. J. (2004). Agrometeorology: Principle and Application of climate Studies in Agriculture. Haworth Press

Mitra, A. K., Bohra, A. K., Rajeevan, M. N. and Krishnamurti, T. N. (2009). "Daily Indian precipitation analyses formed from a merged of rain-gauge with TRMM TMPA satellite derived rainfall estimates", Journal of the Meteorological Society of Japan, 87A, 265-279.

Mitra, A. K., Momin, I. M., Rajagopal, E. N., Basu, S., Rajeevan, M. N. and Krishnamurti, T. N. (2013). "Gridded daily Indian monsoon rainfall for 14 seasons: Merged TRMM and IMD gauge analyzed values", J. Earth Syst. Sci., 122, 5, 1173-1182.

Pai, D. S., Sridhar, L., Rajeevan, M., Sreejith, O. P., Satbhai, N. S. and Mukhopadhyay, B. (2013). "Development and analysis of a new high spatial resolution (0.25° × 0.25°) long period (1901-2010) daily gridded rainfall data set over India Rep.", National Climate Centre, India Meteorological Department, Pune, India. Pai, D. S., Sridhar, L., Rajeevan, M., Sreejith, O. P., Satbhai, N. S. and Mukhopadhyay, B., 2014, "Analysis of daily rainfall events over India using a new long period (1901-2010) high resolution (0.25° × 0.25°) gridded rainfall data set", Mausam, 65, 1, 1-18.

PATTNAIK SANDEEP. (2019). Weather forecasting in India: Recent developments. MAUSAM, 70(3): 453-464

Raj, Y. E. A., Balachandran, S., Ramanathan, R. M. A. N., Geetha, B., Ramesh, K., Selvam, N., Guhan, M. V. and Rajanbabu, D. (2010). "Forecast Demonstration Project (cyclone)-2010", IMD Report, http://www.imdchennai.gov.in/wxSummFinal.pdf.

Rajagopal, E. N., Iyengar, G. R., George, John P., Gupta, Das, Munmun, Saji, Mohandas, Siddharth, Renu, Gupta, Anjari, Chourasia, Manjusha, Prasad, V. S., Sharma, Aditi, Kuldeep Sharma and Amit, Ashish. (2012). "Implementation of Unified Model based Analysis-Forecast System at NCMRWF", NCMRWF Technical Report, NMRF/TR/2/2012.

Rajagopal, E. N., Iyengar, G. R., Mitra, A. K., Prasad, V. S., Gupta, M. Das, George, John P., Kumar, Preveen D., Saji, Mohandas, Ashrit, R. and Dube, A. (2014). "Recent Advances in Numerical Weather Prediction", Vayu Mandal, 19-31, imetsociety.org/wpcontent/pdf/vayumandal/2014/2014_2.pdf.

Rajeevan, M., Bhate, J., Kale, J. D. and Lal, B. (2006). "High resolution daily gridded rainfall data for the Indian region: Analysis of break and active monsoon spells", Curr. Sci., 91, 3, 296-30.

Ray, K. Bandopadhyay, B. K., Sen, B., Sharma, P., Warsi, A. H., Mohapatra, M., Yadav, B. P., Debnath, G. C., Stella, S., Das. S., Duraisamy, M., Rajeev, V. K., Barapatre, V., Paul, S., Shukla, P., Madan, R., Goyal, S., Das, A. K., Bhan, S. C., Chakravarthy, K. and Rathore, L. S. (2015). "Pre-monsoon thunderstorms 2015", No. ESSO/IMD/SAARC STORM PROJECT2015/(01)(2015)/4.

Course Name	Agro-meteorology and climate change
Lesson 8	Climate Change-Causes-Global Warming-Causes and Remote Sensing
Content Creator Name	Vallal Kannan Sankaralingam
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	Dr. Vijay Gopal More
University/College Name	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Lesson 8

Objectives:

- To understand about the climate change and their effect.
- To understand about the Global warming and their causes
- To study about remote sensing principles and their applications

1. Climate change

Any permanent change in weather phenomena from the normal or a long period average is referred as climate change. E. g. The global temperature has increased by 2.0to 3.0^oC and increase in CO_2 from 180ppm to 350ppm.The phrases climate change and global warming and more recently global cooling are now part of our life. Climate change has come upon us in a relatively short space of time and is accelerating with alarming speed. It is perhaps the most serious problem that the civilized world has to face. It is the subject of major international cooperation through the Intergovernmental Panel on Climate Change (IPCC) which was set up in 1988 by the World Meteorological Organization and the United Nations Environment Programme.

The Earth's climate has always changed in response to changes in the cryosphere, hydrosphere, biosphere, and other atmospheric and interacting factors. It is widely accepted that human activities are now increasingly influencing changes in the global climate. Since 1750, global emissions of radiatively active gases, including CO_2, have increased rapidly, a trend that is likely to accelerate if increase in global emissions cannot be curbed effectively.

Man-made increase in CO_2 emissions has come from industry, particularly as a result of the use of carbon-based fuels. Over the last 100 years, the global mean temperature has increased by 0.74°C and atmospheric CO_2 concentration has increased from 280ppm in 1750 to 410 ppm in 2019.(WMO, 2019)Temperature is projected to increase by 3.4°C and CO_2 concentration to increase to 1250 ppm by 2095 under the A2 scenario, accompanied by much greater variability in climate and more extreme weather-related events. Underlying these trends is much spatial and temporal heterogeneity, with projections of climate change impacts differing among various regions on the globe.

2 Climate variability

The temporal changes in weather phenomena which are part of general circulation of atmosphere and occur on a yearly basis on a global scale. Climate change and climate variability are the concern of human kind in recent decades all over the world.

The recurrent drought and desertification seriously threaten the livelihood of over 1-2billion people who depend on the land for most of their needs. The weather-related disasters viz. drought and floods, ice storms, dust storms, landslides, thunder clouds associated with lightening and forest fires are uncommon over one or another region of the world.

2.1Causes of climatic variability

A. Astronomical factors (External)

i) Solar output: An increase in solar output by 0.3 per cent when compared to 1650 -1700ADdata.

ii) Orbital variation:

1. Earth orbit varies from almost a complete circle to marked ellipse (orbital eccentricity).
2. Wobble of earth's axis (Precession of equinox)
3. Tilt of the earth's axis of rotation relative to the plane of the orbit varies between 21.8^{o} and 24.4 ^{o}.

B.Geographical factor (Internal)

i) Changes in the atmospheric composition. Change in the greenhouse gases especiallyCO_2

ii) Land surface changes particularly the afforestation and deforestation

iii) The internal dynamics of southern oscillation – changes in the sea surface temperature in western tropical Pacific (El-Nino/La-Nina) coupled with Southern Oscillation Index, the Tahiti minus Darwin normalized pressure index leading to the ENSO phenomena

iv) Anthropogenic causes of climate variation in greenhouse gases and aerosols.

3. Causes for Climate change

The Earth's climate is in a continuous state of change and it is inherent in the dynamic nature of our planet. Changes in the basic components that influence the state of the Earth's climatic system can occur externally (from extra-terrestrial systems) or internally(from oceans, atmosphere, and land systems) through any one of the described components. For example, an external change may involve a variation in the sun's output which would externally vary the amount of solar radiation received by the Earth's atmosphere and surface. Internal variations in the Earth's climatic system may be caused by changes in the concentrations of atmospheric gases, mountain building, volcanic activity, and changes in surface or atmospheric albedo. These forces will continue to have a major influence on our future climate.

The emerging consensus is that the threshold for dangerous climate change is on the order of 2°C above preindustrial levels. The fact that the Earth's mean surface temperature has risen over the past century is not disputed. However, there are some (climate change skeptics) who dispute that, anthropogenic emissions have been the main cause of the observed warming. It is indeed true that the Earth's mean surface temperature can vary considerably over time due to natural cycles, both long term(over millennia) and short term (over several years or decades). Nevertheless, the scientific consensus concludes with very high confidence that these factors alone could not account for the rapid increase in temperatures observed over the past 50years. A key issue is the global warming debate is determining the anthropogenic contribution to warming, given that natural factors are known to cause significant variations in global mean temperatures.

Milankovitch cycles can cause global mean temperatures to vary as much as 5°Cbetween glacial and interglacial periods. However, these cycles take many centuries to cause perceptible changes to global temperatures. The Earth's orbit around the sun is subject to long-term variations. There are three principal effects on incoming solar radiation 1. the eccentricity (or stretch) of the orbit, with periods of approximately 95,000 years and 4,10,000 years; 2. the tilt of the Earth's axis (approximately 41,000 years); and 3. a wobblein the Earth's axis of rotation, which causes changes in the timing of perihelion. Mean global temperatures can also vary up and down over periods ranging from several years to several decades as a result of regular climatic cycles and variations in the amount of solar radiation reaching the Earth's surface. The resulting changes to global mean temperatures are generally small and do not have a lasting impact on longer term global average temperatures. For example, variations in the amount of solar energy reaching the Earth over the past century have added an estimated 0.12 Wm^{-2} to atmospheric radiative forcing compared with the estimated 2.64 Wm^{-2} increase attributable to human activities. Although subject to long-term changes, it is their susceptibility to short-term anthropogenic influences that makes them of particular climatic interest.

Most notable are the concentrations of carbon dioxide and methane, both of which are stored in large quantities in peat, tundra, and ocean sediments in colder climates, and are released into the atmosphere in warmer climates. Any warming due to orbital changes results in more carbon dioxide and methane being released into the atmosphere, leading to greater warming. Carbon dioxide (CO_2) and certain other trace gases, including methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons(CFCs), and tropospheric ozone (O_3), are accumulating in the atmosphereas a result of human activities too. All of these are greenhouse gases, or gases that absorb radiated heat from the sun, thereby increasing the temperature of the atmosphere.

Additional, but minor greenhouse gases include carbon tetrachloride, methylchloroform, chlorodifluoromethane (HCFC-22), sulfur hexafluoride, trifluoromethylsulfur pentafluoride, fluoroform (HCF-23), and perfluoroethane. Becausethese gases absorb infrared radiationradiated heat from the sun and higher green house gas concentrations lead to warming and global climate change. This occurs

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

because the absorption of heat slows its eventual reradiation into space thereby warming the lower atmosphere. However, as human activities increase theatmospheric concentration of greenhouse gases, the atmosphere and ocean will continue to warm, and the overall global temperature will rise. Carbon dioxide accounts for 60 per cent of the increased radiative forcing and heat retention caused by green house gases. A climate sensitivity (global warming for a stabilized doubling of carbondioxide concentrations) in the upper part of the range adopted by the Intergovernmental Panel on Climate Change (IPCC) in its 2007report, remains 1.5to 4.5°C.

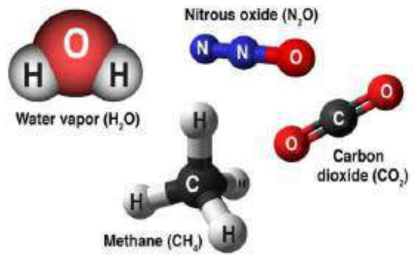
Increase in aerosols due to emission of greenhouse gases including black carbon and chlorofluorocarbons (CFCS), ozone depletion, UV-B filtered radiation, cold and heat waves, global cooling and warming and “human hand” in the form of deforestation and loss of wetlands in the process of imbalanced development for betterment of human kind may be caused factors for climate variability and climate change.

3.2. Greenhouse gases

Certain gases in the atmosphere block heat from escaping. Long-lived gases that remain semi-permanently in the atmosphere and do not respond physically or chemically to changes in temperature are described as "forcing" climate change. Gases, such as water vapor, which respond physically or chemically to changes in temperature, are seen as "feedbacks."

Gases that contribute to the greenhouse effect include some gases in the Earth's atmosphere act a bit like the glass in a greenhouse, trapping the sun's heat and stopping it from leaking back into space. Many of these gases occur naturally, but human activity is increasing the concentrations of some of them in the atmosphere, in particularcarbon dioxide (CO_2), methane, nitrous oxide and fluorinated gases.

CO_2 is the greenhouse gas most commonly produced by human activities and it is **responsible for 64 per cent of man-made global warming**. Its concentration in the atmosphere is currently 47 per cent higher than it was when industrialization began. **Other greenhouse gases** are emitted in smaller quantities, but they trap heat far more effectively than CO_2, and in some cases are thousands of times stronger. **Methane** is responsible for 17 per cent of man-made global warming, **nitrous oxide** for 6 per cent.



3.2.1Water vapor: The most abundant greenhouse gas, but importantly, it acts as a feedback to the climate. Water vapor increases as the Earth's atmosphere warms, but so does the possibility of clouds and precipitation, making these some of the most important feedback mechanisms to the greenhouse effect.

3.2.2Carbon dioxide (CO_2): A minor but very important component of the atmosphere, carbon dioxide is released through natural processes such as respiration and volcano eruptions and through human activities such as deforestation, land use changes, and burning fossil fuels. Humans have increased atmospheric CO_2 concentration by 47 per cent since the industrial revolution began. This is the most important long-lived "forcing" of climate change.

3.2.3Methane: A hydrocarbon gas produced both through natural sources and human activities, including the decomposition of wastes in landfills, agriculture, and especially rice cultivation, as well as ruminant digestion and manure management associated with domestic livestock. On a molecule for molecule basis, methane is a far more active greenhouse gas than carbon dioxide, but also one which is much less abundant in the atmosphere.

3.2.4Nitrous oxide: A powerful greenhouse gas produced by soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning.

3.2.5Chlorofluorocarbons (CFCs): Synthetic compounds entirely of industrial origin used in a number of applications, but now largely regulated in production and release to the atmosphere by international agreement for their ability to contribute to destruction of the ozone layer. They are also greenhouse gases.

3.3Volcanism

Volcanic activity is an important natural cause of climate variations because tracer constituents of volcanic origin affect the atmospheric chemical composition and optical properties. A weak volcanic activity results in gas and particle effusions in the troposphere (lower part of atmosphere), which constitute, on an average, the larger portion of volcanic mass flux into the atmosphere. However, the products of tropospheric volcanic emissions are short-lived and contribute only moderately to the emissions from large anthropogenic and natural tropospheric sources. Strong volcanic eruptions with a volcanic explosivity index equal to or greater than 4 could inject ash and sulphur rich gases into the clean lower stratosphere at an altitude about 25–30 km, increasing their concentration thereby two to three orders of magnitude in comparison with the background level.

Chemical transformation and gastoparticle conversion of volcanic tracers from a volcanic aerosol layer that remains in the stratosphere for two to three years after an eruption, there by affects the Earth's climate because volcanic aerosols cool the surface and the absorbing thermal IR and solar near IR radiation .

3.4Human activities

On Earth, human activities are changing the natural greenhouse. Over the last century the burning of fossil fuels like coal and oil has increased the concentration of atmospheric carbon dioxide (CO_2). This happens because the coal or oil burning process combines carbon with oxygen in the air to make CO_2. To a lesser extent, the clearing of land for agriculture, industry, and other human activities has increased concentrations of greenhouse gases.

The industrial activities that our modern civilization depends upon have raised atmospheric carbon dioxide levels from 280 parts per million to 414 parts per million in the last 150 years. The panel also concluded there's a better than 95 percent probability that human-produced greenhouse gases such as carbon dioxide, methane and nitrous oxide have caused much of the observed increase in Earth's temperatures over the past 50 years.

- **Burning coal, oil and gas** produces carbon dioxide and nitrous oxide.
- **Cutting down forests (deforestation):** Trees help to regulate the climate by absorbing CO_2 from the atmosphere. So, when they are cut down, that beneficial effect is lost and the carbon stored in the trees is released into the atmosphere, adding to the greenhouse effect.
- **Increasing livestock farming:** Cows and sheep produce large amounts of methane when they digest their food.
- **Fertilisers containing nitrogen** produce nitrous oxide emissions.
- **Fluorinated gases** produce a very strong warming effect, up to 23,000 times greater than CO_2.

4. Effects of greenhouse gases:

The consequences of changing the natural atmospheric greenhouse are difficult to predict, but some effects seem likely:

- On average, Earth will become warmer. Some regions may welcome warmer temperatures, but others may not.
- Warmer conditions will probably lead to more evaporation and precipitation overall, but individual regions will vary, some becoming wetter and others dryer.
- A stronger greenhouse effect will warm the ocean and partially melt glaciers and ice sheets, increasing sea level. Ocean water also will expand if it warms, contributing further to sea level rise.

- Outside of a greenhouse, higher atmospheric carbon dioxide (CO_2) levels can have both positive and negative effects on crop yields. Some laboratory experiments suggest that elevated CO_2 levels can increase plant growth. However, other factors, such as changing temperatures, ozone, and water and nutrient constraints, may more than counteract anypotential increase in yield. If optimal temperature ranges for some crops are exceeded, earlier possible gains in yield may be reduced or reversed altogether.
- Climate extremes, such as droughts, floods and extreme temperatures, can lead to crop losses and threaten the livelihoods of agricultural producers and the food security of communities worldwide.
- Depending on the crop and ecosystem, weeds, pests, and fungi can also thrive under warmer temperatures, wetter climates, and increased CO_2 levels, and climate change will likely increase weeds and pests.

5. Effects of climate change

1. The increase concentration of CO_2 and other greenhouse gases are expected toincrease the temperature of the earth.
2. Crop production is weather dependent and any change will have major effects on cropproduction and productivity.
3. Elevated CO_2 and temperature affects the biological process like respiration,photosynthesis, plant growth, reproduction, water use, etc. Depending on the latitude theCO_2 may either offer beneficial effect or may behave otherwise also.

El-Nino and La-Nina

El-Nino is a Spanish word meaning “the boy child” (‘Child Christ’) because El-Nino occurs around Christmas time each year when the waters off the Peruvian coast warm slightly. In every three to six years, the waters become unusually warm. 'El Nino' is now used more widely to refer to this abnormal warming of the ocean and the resulting effects on weather. 'El Nino' is often coupled with 'Southern Oscillation' as the acronym ENSO. 'La Nino' is used popularly to signify the opposite of El Nino occurring when the waters of the eastern Pacific are abnormally cold. La Nino episodes are associated with more rainfall over eastern Australia, and continuing drought in Peru. Peruvian meteorologists have objected to term La Nino (the Girl Child) because Christ is not known to have had a sister and the term anti-ENSO is sometimes preferred. The El-Nino event is due to decrease in atmospheric pressure over the South East Pacific Ocean. At the same time, the atmospheric pressure over Indonesia and North Australia increases. Once the El-Nino event is over, the atmospheric pressure over the above regions swings back. This sea-saw pattern of atmospheric pressure is called Southern Oscillation. Since El-Nino and Southern Oscillation are linked they often termed as ENSO. It is most important one, which represents a tendency for high atmospheric pressure over the Pacific Ocean, represents to be associated with low pressure over the Indian Ocean and vice-versa. A measure of the monsoon low pressure is the Southern Oscillation Index (SOI) represented by the difference in sea level pressure over Tahiti, an Island in South central pacific and Darwin in North Australia, which represents the northern part of the Indian Ocean. The positive SOI denotes high pressure over the central pacific and low over Indonesia, North Australia and Northern Indian Ocean. Above average rainfall is expected over India, Indonesia and North Australia if the SOI is positive. Drought or deficit rainfall is expected in the above countries if the SOI is negative, indicating high atmospheric pressure over Indonesia and low in the central pacific.

6. Global warming and its impacts

The current global average temperature is 0.85ºC higher than it was in the late 19thcentury. Each of the past three decades has been warmer than any preceding decade since records began in 1850.The world's leading climate scientists think human activities are almost certainly the main cause of the warming observed since the middle of the 20th century.An increase of 2°C compared to the temperature in pre-industrial times is seen by scientists as the threshold beyond which there is a much higher risk that dangerous and possibly catastrophic changes in the global environment will occur. For this reason, the international community has recognized the need to keep warming below 2°C.

Climate change is any significant long-term change in the expected patterns of average weather of a region (or the whole Earth) over a significant period of time. It is about abnormal variations to the climate and the effects of these variations on other parts of the earth. These changes may take tens, hundreds or perhaps millions of years. But increased anthropogenic activities such as industrialisation, urbanisation, deforestation, agriculture, and change in land use pattern, etc., lead to emission of greenhouse gases due to which the rate of climate change is much faster. Climate change scenarios include higher temperatures, changes in precipitation and higher atmospheric CO_2 concentrations.

There are three ways in which the "Greenhouse Effect" may be important for agriculture. First, increased atmospheric CO_2 concentrations can have a direct effect on the growth rate of crops. Secondly, CO_2induced changes of climate may alter levels of temperature, rainfall and sunshine that can influence plant and animal productivity. Finally, rises in sea level may lead to loss of farmland by inundation and increasing salinity of groundwater in coastal areas.

6.1India's agriculture

From ancient times India's agriculture has been dependent on monsoons. Any change in monsoon trends drastically affects agriculture. Even the increasing temperature is affecting Indian agriculture. In the Indo-Gangetic plain, these pre-monsoon changes will primarily affect the wheat crop. In the states of Jharkhand, Odisha and Chhattisgarh alone, rice production losses during severe droughts (about one year in five) average about 40 percent of total production, with an estimated value of $800 million.

Increase in CO_2 to 550 ppm increases yields of rice, wheat, legumes and oilseeds by 10 to 20 percent. A 1^{o}C increase in temperature may reduce yields of wheat, soybeans, mustards, groundnuts and potatoes by 3 to 7 percent. There would be higher losses at higher temperatures.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Productivity of most crops decreases only marginally by 2020 but by 10 to 40 percent by 2100 due to increases in temperature, rainfall variability and decreases in irrigation water.The major impacts of climate change will be on rain fed or un-irrigated crops, which are cultivated on nearly 60 percent of cropland. A rise by 0.5°C in winter temperature is projected to reduce rain fed wheat yield by 0.45 tonnes per hectare. Possibly there might be some improvement in yields of chickpeas, rabi maize, sorghum and millets and coconut on the west coast and less loss in potatoes, mustard and vegetables in north-western India due to reduced frost damage. Increased droughts and floods are likely to increase production variability. Agriculture will be affected in the coastal regions of Gujarat and Maharashtra, as fertile areas are vulnerable to inundation and salinization.

6.2Food security

Food security is both directly and indirectly linked with climate change. Any alteration in the climatic parameters such as temperature and humidity which govern crop growth will have a direct impact on quantity of food produced. Indirect linkage pertains to catastrophic events such as floods and droughts which are projected to multiply as a consequence of climate change leading to huge crop loss and leaving large patches of arable land unfit for cultivation which hence threatens food security. The net impact of food security will depend on the exposure to global environmental change and the capacity to cope with and recover from global environmental changes. On a global level, increasingly unpredictable weather patterns will lead to a fall in agricultural production and higher food prices, leading to food insecurity. Food insecurity could be an indicator for assessing vulnerability to extreme events and slow-onset changes. This impact of global warming has significant consequences for agricultural production and trade of developing countries as well as an increased risk of hunger. The number of people suffering from chronic hunger has increased from under 800 million in 1996 to over 1 billion recently. United Nations population data and projections show the global population reaching 9.1 billion by 2050, an increase of 32 percent from

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

2010.The world's population is expected to grow by 2.2 billion in the next 40 years and a significant portion of the additional population will be in countries that have difficulties feeding themselves. Preliminary estimates for the period up to 2080 suggest a decline of some 15 to 30 percent of agricultural productivity in the most climate change exposed developing country regions, Africa and South Asia. Rice and wheat have an important share in total food grain production in India. Any change in rice and wheat yields may have a significant impact on food security of the country.

"Global Warming" has now started showing its impacts worldwide. Climate is the primary determinant of agricultural productivity which directly impacts food production across the globe. The agriculture sector is the most sensitive sector to climate changes because the climate of a region/country determines the nature and characteristics of vegetation and crops. Increase in the mean seasonal temperature can reduce the duration of many crops and hence reduce final yield. Food production systems are extremely sensitive to climate changes like changes in temperature and precipitation, which may lead to outbreaks of pests and diseases thereby reducing harvest ultimately affecting the food security of the country.The net impact of food security will depend on the exposure to global environmental change and the capacity to cope with and recover from global environmental change. Coping with the impact of climate change on agriculture will require careful management of resources like soil, water and biodiversity. To cope with the impact of climate change on agriculture and food production, India will need to act at the global, regional, national and local level.

6.3 Effect of CO_2 concentration

Carbon dioxide (CO_2) is fundamental to crop carbohydrate production (important for crop productivity and yield) and overall plant metabolism. It also plays an important role in climate change. Atmospheric CO_2 concentrations have risen dramatically over the past 200 years and may reach 450–1,000 µmol by the end of this century (IPCC, 2007). Rising CO_2 levels will likely boost the overall productivity of many crops, although important tropical grasses like maize, sugarcane and sorghum and some cellulosic bio-fuels crops, don't respond as well to elevated CO_2 levels. Increases in productivity could be offset, though, by pressures such as insect and fungal pests, ozone, and more variable precipitation, although the degree to which this occurs will depend on the physiology and biochemistry of each crop.

Crop adaptation will be critical to ensure that crops can maintain or even increase, productivity within a CO_2enriched environment. Crops with C_3 photosynthesis (soybean, rice, and wheat) respond more positively to increasing CO_2 than C_4 crops (maize, sugar cane, and bio-fuel grasses).Crops also respond differently to temperature and water availability, e.g. C_3 crops are more susceptible to increases in temperature. Given that environmental factors like CO_2 concentration, temperature and water availability will likely change simultaneously (as well as impact biotic factors), it is therefore difficult to make accurate predictions about crop production under elevated concentrations of CO_2.

6.4 Impacts of CO_2 on crop quality and nutrition

Research shows that increased CO_2 can reduce grain protein by 4 to 13 per cent in wheat and 11 to 13 per cent in barley, while increasing the carbohydrates in grain. Depending on the crop, micronutrients also appear to be somewhat diluted by an increase in carbohydrate in the grain. These effects are difficult to explain and more difficult to separate from whole plant physiological changes. However, they suggest that increased emphasis on research evaluating crop composition, as well as yield, will be needed in the coming decades.

6.5 Ozone(O_3)

Ozone (O_3)an important greenhouse gas and agricultural pollutant, continues to increase because of fossil fuel combustion. While levels of CO_2 will rise rather uniformly around the globe, O_3 concentrations will vary regionally and exist to a greater extent around industrialized. Crops take ozone into their leaves during photosynthesis, where the gas lowers photosynthetic rates and accelerates leaf death, affecting crop maturity and productivity. The rate at which crops take up O_3 depends on the O_3 concentration in the air as well as the opening and closing of the stomata or leaf pores. Present day global yield losses due to ozone are estimated at approximately 10 per cent for wheat and soybean, and 3–5 per cent for rice and maize. Modern tools of crop breeding will help to inform scientists about different approaches for developing crops that can thrive despite exposure to increasing concentrations of O_3.

7REMOTE SENSING

Remote sensing is defined as the art and science of gathering information about objects or areas from a distance without having physical contact with objects area being investigated.

Remote sensing techniques are used in agricultural and allied fields.

1. Collection of basic data for monitoring of crop growth
2. Estimating the cropped area
3. Forecasting the crop production
4. Mapping of wastelands
5. Drought monitoring and its assessment
6. Flood mapping and damage assessment
7. Land use/cover mapping and area under forest coverage
8. Soil mapping
9. Assessing soil moisture condition, irrigation, drainage
10. Assessing outbreak of pest and disease
11. Ground water exploration

7.1Remote Sensing platforms

Three platforms are generally used for remote sensing techniques. They are ground based, air based and satellite based. Infrared thermometer, Spectral radiometer, Pilot-Balloons and Radars are some of the ground based remote sensing tools, while aircrafts are air based remote sensing tools. Since the ground based and air based platforms are very costly and have limited use, space based satellite technology has become handy for wider application of remote sensing techniques. The digital image processing, using powerful computers, is the key tool for analyzing and interpretation of remotely sensed data. The advantages of satellite remote sensing are synoptic view i. e. wide area can be covered by a single image/photo (one scene of Indian Remote Sensing Satellite IRS series cover about 148 x 178 sqkm area), receptivity i. e. can get the data of any area repeatedly (IRS series cover the same area every 16-22 days) and coverage i. e. inaccessible areas like mountains, swampy areas and thick forests are easily covered. Space based remote sensing is the process of obtaining information about the earth from the instruments mounted on the Earth Observation Satellites. The satellites are subdivided into two classes and the types of satellite are as follows

7.1.1Polar orbiting satellites

These satellites operate at an altitude between 550 and 1,600 km along an inclined circular plane over the poles. These satellites are used for remote sensing purposes. LANDSAT (USA), SPOT (France), and IRS (India) are some of the Remote Sensing Satellites.

7.1.2Geostationary satellite

These have orbits around the equator at an altitude of 36,000 km and move with the same speed as the earth so as to view the same area on the earth continuously. They are used for telecommunication and weather forecasting purposes. INSAT series are launched from India for the above purposes. All these satellites have sensors onboard operating in the visible and near infrared regions of the electromagnetic spectrum. GOES 18 was launched on 1st March, 2022.

7.2Role of Remote Sensing in agriculture

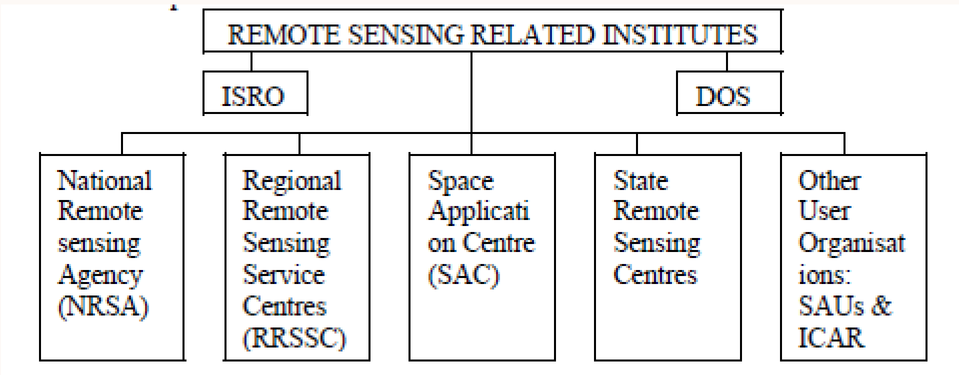
Agricultural resources are important renewable dynamic natural resources. In India, agriculture sector alone sustains the livelihood of around 70 percent of the population and contributes nearly 35 percent of the net national product. Increasing agricultural productivity has been the main concern since scope for increasing area under agriculture is rather limited. This demands judicious and optimal management of both land and water resources. Hence, comprehensive and reliable information on land

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

use/cover, forest area, soils, geological information, extent of wastelands, agricultural crops, water resources both surface and underground and hazards/natural calamities like drought and floods is required. Season wise information on crops, their acreage, vigour and production enable the country to adopt suitable measures to meet shortages, if any, and implement proper support and procurement policies. Remote Sensing systems, having capability of providing regular, synoptic, multi-temporal and multi-spectral coverage of the country, are playing an important role in providing such information. A large number of experiments have been carried out in developing techniques for extracting agriculture related information from ground borne, air borne and space borne data.

7.3Indianremote sensing programme

India, with the experience gained from its experimental remote sensing satellite missions BHASKARA-I and II, has now established satellite based operational remote sensing system in the country with the launch of Indian Remote Sensing Satellite IRS-IA in 1988, followed by IRS-IB (1992), IRS-IC (1995) and IRS-ID (1997). The Department of Space (DoS) / Indian Space Research Organization (ISRO) as the nodal agency for establishing an operation remote sensing system in the country, initiated efforts in the early 1970s for assessing the potentials of remotely sensed data through several means. In order to meet the user requirement of remote sensing data analysis and interpretation, ISRO/DoS has set up a system to launch remote sensing satellites once in three or four years to maintain the continuity in data collection. The remote sensing and some of its related institutes are depicted as follows.



7.4 Applications for generation of agricultural statistics using remote sensing

Crop production statistics are of vital importance to a country such as India, where the agricultural production is highly susceptible to the vagaries of monsoon. These statistics consist of two major components: (i) acreage under the crop and (ii) crop yield per unit area. The traditional approach of crop estimation in India involves a complete enumeration (except a few states where sample surveys are employed) for estimating crop acreages and the yield surveys based on crop cutting experiments for estimating crop yield. The crop production estimates are obtained by taking product of crop acreage estimates and the corresponding crop yield estimates.

7.4.1Crop acreage estimation

Currently, the use of remotely sensed (RS) data is being investigated for crop production forecasting all over the world. The intrinsic ability of spectral reflectance data to identify crops and distinguish one from another is very helpful in estimating crop acreages.

7.4.2Cropyield estimation

Various yield models have been discussed in literature to establish relationship between yields and weather, soil or biometrical characters of the plants, several studies have been taken up to establish the relationships between spectral reflectance and the crop yield. The basic approach in the past has been to develop a transformation of the multi-band spectral response as a measure of vegetation vigor and relate it to some agronomic quantity such as leaf area index, wet or dry biomass or grain yield. Several vegetation indices have been developed and shown to be well correlated with these agronomic variables.

7.4.3Crop Yield Modeling

Reliable and timely forecast of crop production is of crucial economic importance. The advent of remote sensing technology during seventies provided an immense potential to improve upon the existing pre-harvest forecasting models. The fact that spectral reflectance data can be timely available for the entire crop growth period with almost equal accuracy can be effectively utilized in the development of better yields forecasting models.

7.4.4Integrated resource management for sustainable agriculture production

Adoption of appropriate strategies for achieving integrated sustainable development of land and water resources is the only answer to improve agricultural productivity in a rational manner. The integrated sustainable development is defined as growth oriented development to meet the needs of the present as well as the needs of the future generations without causing any degradation to the ecology and environment. Sustainable agricultural production could be achieved only through an understanding of the mutual interdependencies of land and water resources (both renewable and non-renewable) and identification of the constraints/ecological problems at the micro level.

The synoptic view provided by satellite remote sensing offers a technologically appropriate method for integrating the land and water resources information and for identifying agro-climatically coherent zones. Once such zones are identified, location specific prescriptions could be arrived at through the effective use of space based remote sensing data merged with other collateral socio-economic data by use of geographic information systems.

It is in this context the Indian experience of using satellite remote sensing for integrated resources development at micro level become relevant. It involves stock taking of land and water resources through a series of surveys, carried out in phases, using a combination of conventional and remote sensing techniques. The first phase consists of collection of conventional data and their evaluation. The second stage involves preparation of a set of resource maps using remotely sensed data on (i) surface water bodies (ii) ground water potential zones, (iii) potential zones for ground water recharge, (iv) existing land use and distribution of wastelands and (vi) an integrated land and water resource map giving high priority areas for development of agriculture, fuel and fodder, soil conservation and afforestation. The final stage is to develop a package of appropriate strategies to address the local resource management and environment problems.

7.4.4.1 Sustainable agricultural development/ sustainable increase in crop production could be achieved by adopting a variety of agricultural technologies, which may be summed up as:

• Improved crop management technology through the use of high yielding, input responsive and soil, climatic and biotic stresses - tolerant crop varieties.

• Suitable cropping systems for different agro-ecological regions based on soil, terrain and climatic suitability.

• Integrated nutrient management for improving soil productivity and minimization of the risk of pollution of soil, water and environment.

• Integrated pest management for effective pests control as well as to reduce the adverse effects of pesticides on environment.

• Soil and water conservation for controlling soil degradation and improving moisture availability.

• Input use efficiency maximization in terms of economic return with minimal input.

7.4.4.2 Applications of Remote Sensing and GIS Technology in Sustainable Agricultural Management and Development (Case examples from India)

Remote sensing and GIS technology are being effectively utilized in India in several areas for sustainable agricultural development and management. The areas of sustainable agricultural development/

management include cropping system analysis, agro-ecological zonation, quantitative assessment of soil carbon dynamics and land productivity, soil erosion inventory, integrated agricultural drought assessment and management and Integrated Mission for Sustainable Development (IMSD). Use of Remote Sensing and GIS technology in these areas of sustainable agricultural management and development are discussed for Indian conditions.

7.4.4.2.1 Cropping system analysis

Information on existing cropping systems in a region with respect to areal extent of crops, crop vigours/ yield and yearly crop rotation / sequence practices is important for finding out agricultural areas with low to medium crop productivity where sustainable increase in crop production can be achieved by adoption of suitable agronomic management packages including, introduction of new crops, etc. GIS technology can play a vital role in cropping system analysis of an area by spatially integrating temporal crop inventory information of various crop seasons of that area.

7.4.4.2.2 Agro-ecological zone based land use planning

Agro-ecological zoning (AEZ) is an important basis of sustainable agricultural land use planning of a region. AEZ encompasses the delineation of landscapes into regions or zones that are broadly homogeneous with respect to agro-climate, soils and terrain characteristics and are also relatively uniform with respect to crop production possibilities. GIS technology is very useful for automated logical integration of bio-climate, terrain and soil resource information which are required for delineating AEZ in a region.

7.4.4.2.3 Soil Erosion Inventory

The information on soil erosion such as quantification of erosional soil loss and soil conservation prioritization of watersheds/ sub watersheds provides vital inputs for sustainable agricultural management with respect to soil conservation. Remote Sensing and GIS techniques are being effectively used in India for preparation of soil erosion inventories by integration of physiography, soils, land use/ land cover, slope map layers and use of ancillary data of agro-met and soil physicochemical properties .

7.4.4.2.4 Soil carbon dynamics and land productivity assessment

By studying the carbon dynamics of agro-ecosystems it is possible to quantify fixation and release of carbon in the soil-crop-plant system. This knowledge is essential for assessing organic matter depletion of soil, long-term soil fertility and sustained productivity of agro-ecosystems. An integrated Remote Sensing and GIS based methodology was developed for studying carbon dynamics such as annual crop Net Primary Productivity (NPP), soil organic matter decomposition and the annual soil carbon balance using models such as the Osnabruck - Biosphere and Century models.

7.4.4.2.5Integrated agricultural drought mitigation

An integrated method for agricultural drought mitigation, the National Agricultural Drought Assessment and Monitoring system (NADAMS) operationally used in India forms one of the strategies for sustainable agriculture development. NADAMS integrates NOAA satellite derived temporal spectral vegetation index(VI) and land use/ land cover data and ground meteorological station observed rainfall and aridity anomaly with ancillary crop cultural information through GIS, to provide a realistic assessment of agricultural droughts.

7.4.4.2.6 Remote sensing application for precision farming

Precision farming aims to improve crop performance and environmental quality. It is defined as the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production. In other words, precision farming is the matching of resource application and agronomic practices with soil attributes and crop requirements as they vary across a field. Thus, the concepts of precision farming include:

(i) Variations occur in crop or soil properties within a field

(ii) These variations are noted, and often mapped

(iii) Management actions are taken as a consequence of the spatial variability within the field.

Though, the 20th century agriculture had been characterized by the increase in land and labor productivity, the use of external inputs, an increase in efficiency and efficacy of external inputs, it has also been associated with the stimulation of uniformity in agricultural production areas and the negative side-effects of agriculture. These techniques, by appreciating the variability within the field and adopting management practices to cater the variability, are serving the dual purpose of enhancing productivity and reducing ecological degradation. The real value from precision farming is that the farmer can perform more timely tillage, adjust seeding rates, fertilizer application according to soil conditions, plan more crop protection programs with more precision, and know the yield variation within a field. These benefits can enhance the overall cost effectiveness of crop production. Many technological developments, which occurred in 20thcentury contributed to the development of the concept of precision farming which includes GPS, GIS and high-resolution remote sensing satellite data.

Glossary:

Climate change: Any permanent change in weather phenomena from the normals of a long period average is referred as climate change.

Climate variability: The temporal changes in weather phenomena which is part of general circulation of atmosphere and occurs on a yearly basis on a global scale.

Precision farming: It is defined as the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production.

REMOTE SENSING: Remote sensing is defined as the art and science of gathering information about objects or areas from a distance without having physical contact with objects area being investigated.

KEPLER'S FIRST LAW DESCRIBES THE SHAPE OF AN ORBIT

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

The orbit of a planet around the Sun (or of a satellite around a planet) is not a perfect circle. It is an ellipse—a “flattened” circle. The Sun (or the center of the planet) occupies one focus of the ellipse. A **focus** is one of the two internal points that help determine the shape of an ellipse. The distance from one focus to any point on the ellipse and then back to the second focus is always the same.

KEPLER’S SECOND LAW DESCRIBES THE WAY AN OBJECT’S SPEED VARIES ALONG ITS ORBIT

A planet’s orbital speed changes, depending on how far it is from the Sun. The closer a planet is to the Sun, the stronger the Sun’s gravitational pull on it, and the faster the planet moves. The farther it is from the Sun, the weaker the Sun’s gravitational pull, and the slower it moves in its orbit.

KEPLER’S THIRD LAW COMPARES THE MOTION OF OBJECTS IN ORBITS OF DIFFERENT SIZES

A planet farther from the Sun not only has a longer path than a closer planet, but it also travels slower, since the Sun’s gravitational pull on it is weaker. Therefore, the larger a planet’s orbit, the longer the planet takes to complete it.

Precession of the equinoxes : One particular wobble in Earth's rotation has perplexed scientists since observations began in 1899. Every six to 14 years, the spin axis wobbles about 20 to 60 inches (0.5 to 1.5 meters) either east or west of its general direction of drift.

Orbital eccentricity: The Earth’s orbit varies from almost a complete circle to a marked ellipse. A complete cycle from near circular through a marked ellipse back to near circular takes between 90,000 to 100000 years.

Volcanic explosivity index:

The Volcanic Explosivity Index (VEI) is a scale that describes the size of explosive volcanic eruptions based on magnitude and intensity. The numerical scale (from 0 to 8) is a logarithmic scale, and is generally analogous to the Richter and other magnitude scales for the size of earthquakes.

Course Name	Agro-meteorology and climate change
Lesson 9	Effect of climate change on horticulture Past and future changes in greenhouse gases within the atmosphere sources and sinks for greenhouse gases
Content Creator Name	Vallal Kannan Sankaralingam
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	Dr. Vijay Gopal More
University/College Name	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Lesson 9

Objectives:

- To understand the effect of climate change on horticultural crops
- To empower knowledge on changes in greenhouse gases and source and sinks.

1. Effect of climate change on horticulture

India with diverse soil and climate comprising several agro-ecological regions provides ample opportunity to grow a variety of horticultural crops which form a significant part of total agricultural produce in the country comprising of fruits, vegetables, root and tuber crops, flowers and other ornamentals, medicinal and aromatic plants, spices, condiments, plantation crops and mushrooms. The sensitivity of individual crop to temperature depends on inherent tolerance and growing habits. Indeterminate crops are less sensitive to heat stress conditions due to extended flowering compared to determinate crops. The temperature rise may not be evenly distributed between day and night and between different seasons. Horticultural crops play a unique role in India's economy by improving the income of the rural people. Fruits and vegetables are also rich source of vitamins, minerals, proteins, carbohydrates, etc., which are essential in human nutrition. Hence, these are referred to as protective foods and assumed great importance in nutritional security of the people. Thus, cultivation of horticultural crops plays a vital role in the prosperity of a nation and is directly linked with the health and happiness of the people. India with more than 28.2 million tonnes of fruits and 66 million tonnes of vegetables is the second largest producer of fruits and vegetables in the world next only to Brazil and China. However, per capita consumption of fruits and vegetables in India is only around 46 g and 130 g against a minimum of about 92 g and 300 g, respectively recommended by Indian Council of Medical Research and National Institute of Nutrition, Hyderabad.

The knowledge about the impact of climate change on horticultural crops compared to annual food crops. The issues of climate change and solution to the problems arising out of it requires thorough analysis, advance planning and improved management. The crop productivity is subjected to number of stresses and potential yields are seldom achieved with stress. Climate change is predicted to cause an increase in average air temperature of between 1.4^{0}C and 5.8^{0}C, increases in atmospheric CO_2 concentration, and significant changes in rainfall pattern. Vegetable production is threatened by increasing soil salinity particularly in irrigated croplands which provide 40 per cent of the world's food. Fruits, vegetables, flowers, medicinal plants and tubers are grown from tropical to temperate, some horticultural crops like spices and plantation crops are location specific. It is vital to develop packages to manage abiotic stresses in order to sustain horticultural production with present day challenges. The nature and magnitudes of stress vary. Climate change poses serious challenges to human and places unprecedented pressure on the development of horticultural crops that withstand stress will be can the single most important step we may take to adapt the changes we have faced today and will face in the future.

1.1 Impact of climatic condition

- Higher temperatures increasing potential evaporation and duration of heat waves.
- Significant decline in winter rainfall leading to severe water scarcity during early summer months.
- More intense droughts over large areas adversely affecting crop production. The per capita availability of freshwater in India is expected to drop from around 1900 cubic meters currently to 1000 cubic meters by 2025 due to a combination of population growth and climate change.
- More intense floods, especially in the flood plains of the eastern Himalayan Rivers, their major tributaries, and the delta regions.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

- Coastal flooding and salinity intrusion from sea level rise in combination with the amplification of storm surges from more intense tropical cyclones in the Bay of Bengal.
- Rapid melting of Himalayan glaciers, leading initially to greater river flow and hence sedimentation and subsequent reduced flow, especially in the drier months.
- Serious health impacts due to heat-related stress and vector borne diseases.
- Climate change will intensify other environmental pressures and impinge on sustainable development.

2. Impact of climatic condition on horticultural crops

2.1 Impact on fruit crops: The extreme weather events of hot and cold wave conditions have been reported to cause considerable damage to many fruit crops. In perennial crops like mango and guava, temperature is reported to have influence on flowering. Mango has vegetative bias, and this becomes stronger with increase in temperature, thus influencing the flowering phrenology. The percentage of hermaphrodite flowers was greater in late emerging panicles, which coincided with higher temperatures.

India is the second largest producer of Fruits after China, with a production of 82.04 million tonnes of fruits from an area of 6.72 million hectares. A large variety of fruits are grown in India, of which mango, banana, citrus, guava, grape, pineapple and apple are the major ones. Due to rise in temperature, crops will develop more rapidly and mature earlier, e. g. Citrus, grapes, melons, etc. Delay in monsoon, dry spells during rains and untimely dry spells during rains and untimely rains during water stress period, supra-optimal temperatures during flowering and fruit growth, hailstorms are some of the most commonly encountered climatic conditions experienced by the citrus growers over the past decade or so. The hailstorms are some of the most commonly encountered during flowering and fruit growth. Temperature has a big influence on the rate of fruit growth, thus use of bunch covers, which are though, to warm the fruit, increased the growth rate. Higher temperature (31-32^{0}C), in general increase the rate of plant maturity in banana, thus shortening the bunch development period. Higher air temperature (>38^{0}C) and brighter temperatures (above 38^{0}C) and drought delay in monsoon, dry spells of rains, and untimely rains during water stress period, supra-optimal temperatures during flowering and fruit growth and hailstorms are some of the most commonly encountered climatic conditions experienced by the citrus growers over the past decade or so. The climate change increases the atmospheric temperature and change in rainfall pattern, as a result, banana cultivation may suffer from high temperature, soil moisture stress or flooding or water logging. In mango flooding simultaneously reduced net CO_2 assimilation and stomata conductance after 2-3 days. However, flooding did not affect leaf water potential, shoot extension growth, or shoot dry weight, but stem radial growth and root dry weight were reduced. Mortality of flooded trees ranged from 0 to 45 per cent. Hypertrophied lenticels were observed on trees that survived flooding but not on trees that died.

The studies conducted in apple showed that, the productivity was continue to decline up to 1500 m msl to the tune of 40-50 per cent due to warmer climate and lack of chilling requirement during winter and warmer summers in lower elevations resulting into shifting of apple production to higher elevation (2700 m msl). Winter snowfall affects flowering. In spring, low fluctuating temperatures during bloom results in poor fruit set while warm temperatures result in desiccation of floral parts.

Mild winter temperatures followed by warmer springs advanced bud burst and exposing buds to frost damage in almond and apricot. The changes in climate in the form of erratic precipitation, increase in temperature, lesser days serving as the chilling period have started affecting the mountain agricultural production systems and ultimately the food security of the people.

Fruits crops classified on the basis of severity of damage into four groups viz. severely affected which included crops such as aonla, phalsa, moringa, ber, ficus sp. etc. It was also observed that few crops such as pomegranate was moderately affected, sapota and bael less affected and crops such as date palm was unaffected by the frost

2.3 Impact on vegetable crops: The current production level is over 136 MT and the total area under vegetable cultivation is around 9.2 million hectares which is about 5 per cent of the total area under cultivation in the country. Environmental stress is the primary cause of crop losses worldwide, reducing average yields for most major crops by more than 50 per cent (I.P.C.C. 2007). Climatic changes will influence the severity of environmental stress imposed on vegetable crops. The response of plants to environmental stresses depends on the plant developmental stage and the length and severity of the stress. Plants may respond similarly to avoid one or more stresses through morphological or biochemical mechanisms. Indian climate is dominated by the monsoon, responsible for most of the region's precipitation, poses excess and limited water stress conditions. Vegetables being succulent are generally sensitive to environmental extremes and high temperature, limited and excess moisture stresses are the major causes of low yields.

Soil water stress at early stages of onion crop growth caused 26 per cent yield loss. Water stress accompanied by temperature above 28^{0}C induced about 30-45 per cent flower drop in different cultivars of tomato. Chilli also suffers drought stress, leading to yield loss up to 50-60 per cent. Most vegetables are sensitive to excess moisture stress conditions due to reduction in oxygen in the root zone. Tomato plants under flooding conditions accumulate endogenous ethylene, leading to rapid epinastic leaf response. Onion is also sensitive to flooding during bulb development with yield loss up to 30-40 per cent.

Under climate change scenario the impact of these stresses would be compounded. These stresses are the primary cause of yield losses worldwide by more than 50 per cent. The response of plants to environmental stresses depends on the developmental stage and the length and severity of the stresses. In tomato high temperatures can cause significant losses in productivity due to reduced fruit set, smaller size and low quality fruits. Pre anthesis temperature stress is associated with developmental changes in the anthers, particularly irregularities in the epidermis and endothelium, lack of opening of stromium and poor pollen formation. Optimum daily mean temperature for fruit set in tomato has been reported to be 21- 24^{0}C. The pre-anthesis stage is more sensitive in tomato.

Post pollination exposure to high temperature inhibits fruit set in pepper, indicating sensitivity of fertilization process. Such as bud drop, abnormal flower development, poor pollen development, dehiscence and viability, ovule abortion and poor viability and other reproductive abnormalities.

In cucumber sex expression is affected by temperature. Low temperatures favours female flower production, which is desirable and high temperatures lead to production of more male flowers.

The duration of onion gets shortened due to high temperature leading to reduced yields. Cauliflower performs well in the temperature range of 15-25^{0}C with high humidity. Though some varieties have adapted to temperatures over 30^{0}C, most varieties are sensitive to higher temperatures and delayed curd initiation is observed

2.4 Impact on plantation crops: Studies conducted on “Impact of climate change in cashew” at Directorate of Cashew Research, Puttur, India indicated that the rainfed cashew crop is highly sensitive to changes in climate and weather vagaries, particularly during reproductive phase. Cashew requires relatively dry atmosphere and mild winter (15-20^{0}C) coupled with moderate dew during night for profuse flowering. High temperature (>34.4 ^{0}C) and low relative humidity (<20 %) during afternoon, causes drying of flowers resulting in yield reduction. Unseasonal rains and heavy dew during flowering and fruiting period aggravated the incidence of pests and diseases. All these situations resulted in reduction yield up to 50 to 65 per cent. Unseasonal rains at ripening stage leads to blackening of nuts as well as rotting of apples on trees. Cashew experiences severe moisture stress from January to May, which adversely affects its flowering and fruit set. In order to harvest the rainwater and to make it available to the cashew plant during the critical period, in situ soil and water conservation and rainwater harvesting are very important

2.5 Impact on flower crops: Plant species requiring high humidity and water may find them under difficult conditions for survival. Plains of India will also have similar kind of problems and will be affected either by drought or excessive rains, floods and seasonal variations. Commercial production of flowers particularly grown under open field conditions will be severely affected leading to poor flowering, improper floral development and colour. Chrysanthemum is a short day plant and flowering round the year in open field condition is not possible. Low temperatures shut down flowering in Jasmine (<19^{0}C) and lead to reduction in flower size. Flowers do not open up fully in tropical orchids wherever temperatures below 15^{0}C. High temperature leads to flower bud drop and unmarketable spikes in tropical orchids when temperature remains >35^{0}C.

3. **Past and future changes in greenhouse gases within the atmosphere-source sink**

- Global atmospheric concentrations of carbon dioxide, methane, nitrous oxide, and certain manufactured greenhouse gases have risen significantly over the last few hundred years
- Historical measurements showed that the current global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide are unprecedented compared with the past 800,000 years

3.1 Carbon dioxide: CO_2 concentrations have increased substantially since the beginning of the industrial era, rising from an annual average of 280 ppm in the late 1700s to 412 ppm in 2019 (47 % increase) (Alan,2019) Almost all of this increase is due to human activities.

Carbon is constantly moving between the three active reservoirs (the atmosphere, the terrestrial (land) system, and the oceans), and these exchanges are called carbon fluxes. In total around 41,000 billion tons of carbon (C) are available for exchange between the three principal reservoirs. The major reservoir of carbon is the ocean, which is estimated to contain around 38,000 GtC, or 93 per cent of all exchangeable carbon. The ocean can be further subdivided into the surface ocean (down to 100 m), which contains around 1000 GtC, and the deep ocean, which contains the remaining 37,000 GtC. The land carbon reservoir is estimated to contain just over 2000 GtC, about 5 per cent of exchangeable carbon. Of this, approximately 30 per cent is stored in vegetation and other living organisms and the remainder in the soil and detritus. The atmosphere is the smallest of the three active reservoirs and is estimated, at present, to contain around 800 GtC, roughly 2 per cent of exchangeable carbon. There is also a vast reservoir of geological carbon (20,000,000 Gt) stored in the Earth's crust, mainly as carbonate rocks. Of this, a small fraction (about 5000 Gt) is stored as fossil fuels (coal, oil, and natural gas) and methane hydrates (5000–10,000 Gt).

Natural annual carbon fluxes into and out of the geological reservoir are tiny (less than 0.1 % of the cycled carbon), so geological carbon is not generally considered part of the active carbon cycle. The ocean and land reservoirs both emit and absorb large quantities of CO_2. The difference between these opposing fluxes, plus emissions from human activities, determines the net annual addition of carbon (in the form of C_2) to the atmosphere. As CO_2 is responsible for 61 per cent of global warming, a doubling of the atmospheric CO_2 and a rise in other so-called greenhouse gases (methane, nitrous oxide, chlorofluorocarbons) would increase the mean global temperature, possibly as much as 4.5 to 6 °C. In addition, shifts in regional precipitation patterns as a result of rising atmosphere CO_2 will probably result in decreased soil water availability in many areas of the world.

Atmospheric CO_2 is an essential compound for life on Earth. Through photosynthesis plants obtain carbon for their growth and provide sustenance for other living things including humans. In photosynthesis, solar energy is absorbed by a system of pigments, and inorganic atmospheric CO_2 is fixed and reduced into organic compounds. Reduction of carbon is a major function of photosynthesis and is quantified by realizing that plant organic matter is about 45 per cent carbon on a dry weight basis.

3.2 Methane: The concentration of methane in the atmosphere has more than doubled since preindustrial times, reaching approximately 1,800 ppb in recent years. This increase is predominantly due to agriculture and fossil fuel use. The 20 year global warming potential of methane is 84. That is, over a 20 year period, it traps 84 times more heat per mass unit than carbon dioxide (CO_2) and 32 times the effect when accounting for aerosol interactions. Global methane concentrations rose from 722 parts per billion (ppb) in pre-industrial times to 1866 ppb by 2019, an increase by a factor of 2.5 and the highest value in at least 8,00,000 years. Its concentration is higher in the Northern Hemisphere since most sources (both natural and human) are located on land and the Northern Hemisphere has more land mass. The concentrations vary seasonally, with, for example, a minimum in the northern tropics during April−May mainly due to removal by the hydroxyl radical. It remains in the atmosphere for 12 years.

3.2.1 Global trends in methane levels: Long term atmospheric measurements of methane by NOAA (National Oceanic and Atmospheric Administration) showed that the build up of methane levelled off during the decade prior to 2006, after nearly tripling since pre-industrial times. Although scientists have yet to determine what caused this reduction in the rate of accumulation of atmospheric methane, it appears it could be due to reduced industrial emissions and drought in wetland areas. Exceptions to this drop in growth rate occurred in 1991 and 1998 when growth rates increased suddenly to 14-15 nmol mol^{-1} year^{-1} for those years, nearly double the growth rates of the years before. The 1991 spike is understood to be due to the volcanic eruption of Mt. Pinatubo in June of that year. Volcanoes affect atmospheric methane emissions when they erupt, releasing ash and sulfur dioxide into the air. As a result, photochemistry of plants is affected and the removal of methane via the tropospheric hydroxyl radical is reduced. However, growth rates quickly fell due to lower temperatures and global reduction in rainfall. The cause of the 1998 spike is unresolved, but scientists are currently attributing it to a combination of increased wetland and rice field emissions as well as an increased amount of biomass burning. 1998 was also the warmest year since surface temperatures were first recorded, suggesting that anomalously high temperatures can induce elevated methane emission.

Data from 2007 suggested methane concentrations were beginning to rise again. This was confirmed in 2010 when a study showed methane levels were on the rise for the 3 years 2007 to 2009. After a decade of near-zero growth in methane levels, "globally averaged atmospheric methane increased by approximately by 7 nmol mol^{-1} $year^{-1}$ during 2007 and 2008. During the first half of 2009, globally averaged atmospheric CH_4 was approximately 7 nmol mol^{-1} greater than it was in 2008, suggesting that the increase will continue in 2009. From 2015 to 2019 sharp rises in levels of atmospheric methane have been recorded. Methane emissions levels vary greatly depending on the local geography. For both natural and anthropogenic sources, higher temperatures and higher water levels result in the anaerobic environment that is necessary for methane production.

3.3 Nitrous oxide: Over the past 800,000 years, concentrations of nitrous oxide in the atmosphere rarely exceeded 280 ppb. Levels have risen since the 1920s, however, reaching a new high of 328 ppb in 2015.This increase is primarily due to agriculture.

3.4 Halogenated gases: Concentrations of many of the halogenated gases were essentially zero a few decades ago but have increased rapidly as they have been incorporated into industrial products and processes. Some of these chemicals have been or are currently being phased out of use because they are ozone depleting substances, meaning they also cause harm to the Earth’s protective ozone layer. As a result, concentrations of

Designed and developed under the aegis of NAHEP Component-2 Project “Investments In ICAR Leadership In Agricultural Higher Education”
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

many major ozone depleting gases have begun to stabilize or decline Concentrations of other halogenated gases have continued to rise, however, especially where the gases have emerged as substitutes for ozone depleting chemicals

3.5 Ozone: Overall, the total amount of ozone in the atmosphere decreased by about 3 percent between 1979 and 2014. All of the decrease happened in the stratosphere, with most of the decrease occurring between 1979 and 1994. Changes in stratospheric ozone reflect the effect of ozone depleting substances. These chemicals have been released into the air for many years, but recently, international efforts have reduced emissions and phased out their use. Globally, the amount of ozone in the troposphere increased by about 3 percent between 1979 and 2014

4 Sources and sinks for greenhouse gases

The most important individual GHG is carbon dioxide (CO_2), but substantial contributions to global warming are made by trace gases, in particular methane (CH_4) and nitrous oxide (N_2O), both of which come in part from soil emissions. Together, these gases account for around 87 per cent of the radiative forcing of the atmosphere.

Water vapor traps more infra-red radiation than CO_2, but its concentration in the troposphere is quite variable and is highly dependent on temperature, since warm air holds more water vapor than cold air.

Other contributors to radiative forcing are tropospheric ozone (O_3), produced by light catalyzed reactions involving nitric oxide (NO) (a product emitted during combustion processes as well as from soils) and organic compounds emitted by vegetation, and the halogenated trace gases (substances containing fluorine, chlorine, and bromine) which are primarily products of industrial activities.

4.1 Carbon Dioxide (CO_2)

Carbon dioxide is the most important GHG, contributing about 64 per cent of the total radiative forcing and comprising 82 per cent of GHG emissions. The natural carbon (C) cycle circulates C between the atmosphere, ocean and terrestrial biosphere reservoirs on timescales from

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

days to millennia. Carbon dioxide is removed from the atmosphere by photosynthesis in plants and is returned by the natural processes of respiration and microbial decay of plant litter and organic matter (OM). Before the start of the Industrial Era, these opposing flows were in balance, but since then anthropogenic CO_2 emissions from burning fossil fuels and vegetation, and from cultivating virgin soils, have increased the concentration of CO_2 in the atmosphere from 277 parts per million (ppm) to 412 ppm in 2019, with a recent rate of increase of approximately 3 per cent annually. From 1750 to 2011, it is estimated that burning fossil fuels has released 365 Gt C to the atmosphere while deforestation and other LUC have released another 180 Gt C. Of these emissions, 240 Gt C has accumulated in the atmosphere, while 155 Gt C of the remainder is estimated to have been taken up by the oceans and the other 150 Gt C by natural terrestrial ecosystems.

Carbon dioxide is generally well mixed in the atmosphere, with mean annual differences of only 1–2 ppm between high northerly and southerly latitudes but there are seasonal fluctuations due to summer-time photosynthesis, especially by northern forests. Recently, it has been shown that the annual amplitude of the fluctuations in CO_2 concentration is increasing, with more rapid draw-down rates in the spring, possibly reflecting fast CO_2 fixation by northern forests in response to what is termed as the CO_2 fertilization effect.

The global soil organic carbon (SOC) inventory is estimated to be 1500 PgC, which is thrice the amount of C stored in vegetation and twice the amount in the atmosphere. Soil OC levels are determined by the balance of net OM inputs (e.g., crop residues, organic amendments) and net losses of C from the soil through OM decomposition, as dissolved OC and loss through erosion. Carbon inputs to the soil are largely determined by the land use and the conversion of native ecosystems to agriculture almost invariably results in a net loss of SOC. Humans have drastically altered the global C cycle, CO_2 emissions from fossil fuel combustion have been the dominant source of anthropogenic emissions to the atmosphere.

Other sources include industrial processes such as cement production, deforestation, and other human driven LUC as well as chemical oxidation of reactive C-containing gases from sources other than fossil fuels (e.g., biogenic emissions from changes in vegetation, fires, and wetlands) adds primarily CH_4, CO_2 and volatile organic compounds such as isoprene and terpene. Net emissions of CO_2 from established agriculture are relatively small, although land-use change (for example conversion of forested land to new cropland) can make very large contributions to emissions. It is estimated that since preindustrial times, around one third of CO_2 emissions to the atmosphere have originated from land-use change. Over this period, soils used in agricultural production have lost soil organic carbon (SOC), a natural constituent, and one which is important in contributing to soil fertility. The land-use sector is, however, unusual in that apart from releasing CO_2, it is able to remove it from the atmosphere, in this regard, afforestation and appropriate soil management to sequester carbon are both important.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

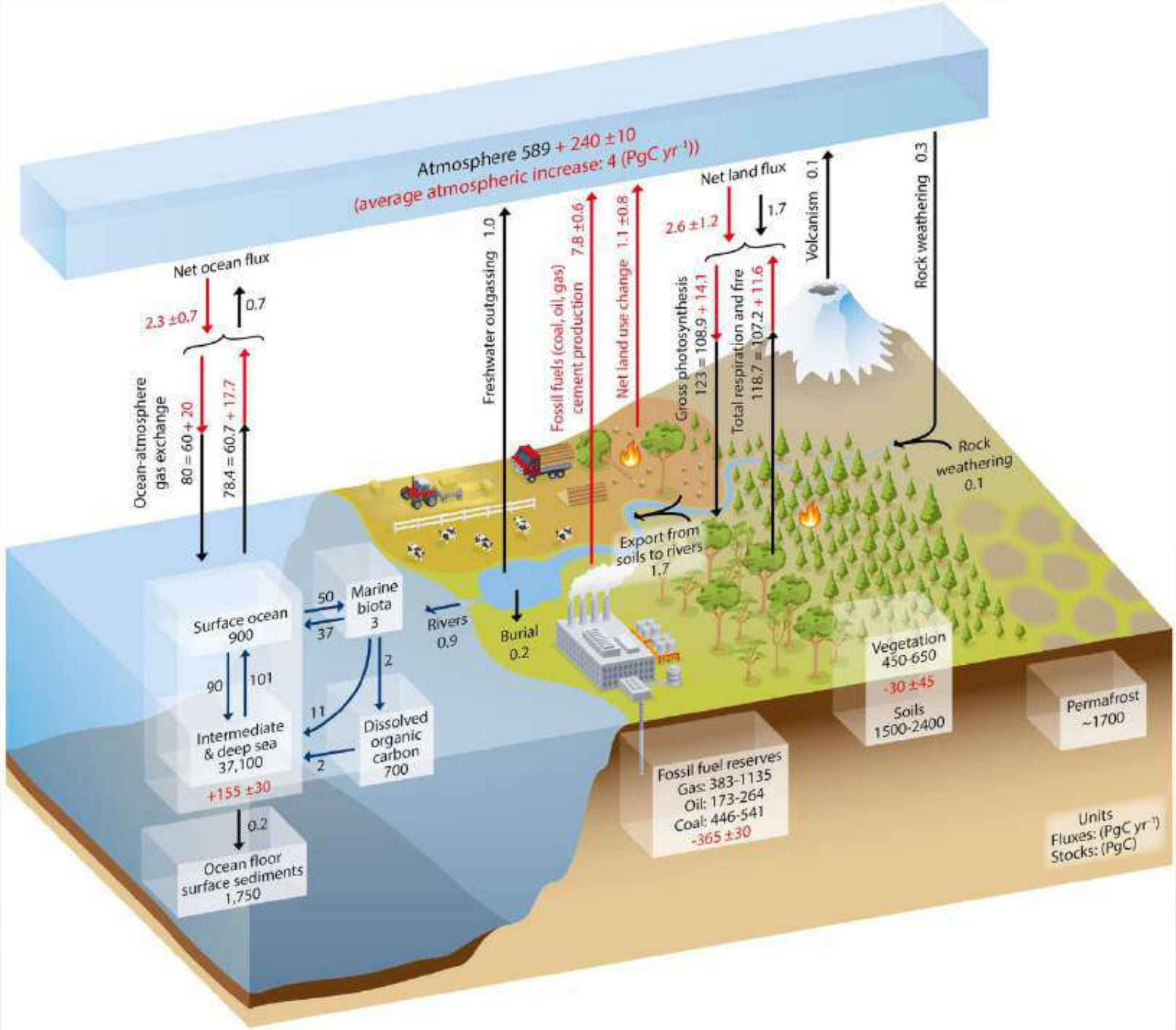


Fig. 1 Simplified global carbon (C) cycle diagram.

4.2 Methane (CH_4)

The concentration of CH_4 in the atmosphere has more than doubled since the preindustrial era, from approximately 0.7 ppm to about 1.8 ppm today (Northern Hemisphere c.1.85 ppm and Southern Hemisphere c. 1.75 ppm). Methane originates from a wide range of sources and approximately 60 per cent of its global emissions are derived from human activity. There are six major natural and anthropogenic sources of CH_4.

(i) Natural wetlands,

(ii) Paddy fields,

(iii) Emissions from livestock production systems (including enteric fermentation and animal waste),

(iv) Biomass burning (including forest fires, charcoal combustion and wood burning),

(v) Anaerobic decomposition of organic waste in landfills, and

(vi) Fugitive emissions during extraction and transport of fossil fuels.

Human agricultural activities and fossil fuel extraction and transport account for 230 Tg CH_4 year^{-1}, which represents two thirds of all anthropogenic CH_4 emissions. Wetlands, especially tropical wetlands, are the dominant natural sources of methane (150–180 Tg CH_4 year^{-1}) though other methanogenic ecosystems include riverbanks, lake sediments, and termites.

Most CH_4 is produced as a result of methanogenesis i.e. the microbial breakdown of organic compounds in strictly anaerobic conditions. The underlying microbiology is the same, whether in wetlands, the gut of ruminant livestock, manure stores, or landfill sites. Agriculture is responsible for approximately 37 per cent of net anthropogenic CH_4 emissions. Emissions from livestock (ruminants and manure management) and rice cultivation are the principal sources in the agricultural sector. Ruminants (e.g., cows, sheep, and goats) degrade fibrous carbohydrate compounds in grass or conserved fodder with the aid of symbiotic microorganisms in the rumen. In addition, ruminants may receive a proportion of their diets as grain and high-protein feed from oilseed. Feed type, its nutritive value, and level of intake will indirectly determine the amount of CH_4 produced by influencing microorganisms in the gut.

The lifetime of CH_4 in the atmosphere is quite short, 9.1 years, and the main removal pathway or sink is through oxidation by UV-created hydroxyl radicals (OH) in the atmosphere, while 5 per cent is oxidized by soil microorganisms. In well-drained and therefore well-aerated soils, in the absence of termites, any CH_4 present is largely that which has diffused in from the atmosphere. This CH_4 is oxidized to CO_2 by methanotrophic bacteria that are adapted to living on this very low concentration of substrate. It has been estimated that average removal rates of CH_4 from the atmosphere are around 400 Tg year^{-1}.

Observed seasonal variations in the concentrations of CH_4 in the atmosphere at different latitudes can now be simulated reasonably well by models and generally these models predict that more than 50 per cent of global wetland emissions are of tropical origin. Research also suggests that CH_4 production from northern wetlands may be changing and that a significant fraction of the observed atmospheric CH_4 concentration increase could have been caused by warming at high latitudes. Changing rates of atmospheric consumption are considered unlikely to be responsible and it has been suggested therefore that various emission sources may be decreasing.

4.3 Nitrous Oxide (N_2O)

The concentration of N_2O in the atmosphere during the preindustrial era was approximately 275 parts per billion (ppb), but this has increased to about 330 ppb today. Approximately 65 per cent of all atmospheric emissions of N_2O are from soils. Nitrous oxide is mostly produced by the microbially mediated soil processes of nitrification and denitrification. These are a natural part of the N cycle and essential for life on Earth. Nitrification is a step in the mineralization of organic N to nitrate and a key process in the life cycle of all organisms (life, death, decay, and decomposition i.e. release of basic nutrients and new life).

The main cause for the increase in atmospheric N_2O has been anthropogenic emissions from reactive N compounds. Reactive N compounds are introduced into the natural terrestrial environment primarily by biological nitrogen fixation (BNF) in forests and grasslands, particularly in the tropics.

Human activity has now roughly doubled the N supply to the biosphere through synthetic N fertilizers, together with a smaller amount through BNF by leguminous crops, and also inadvertently as NOx from fossil fuel combustion. The estimated amount of N fertilizer to have been used worldwide in 2016 is 116 Tg N. Anthropogenic emissions from agriculture are principally due to the use of N fertilizers, livestock manures, urine deposited by grazing livestock, BNF, mineralized SOM from cultivating old pasture or forest and biomass burning. In spite of a decline in industrial emissions through improved processing techniques, the agriculture sector is still responsible for more than three quarters of total global N_2O emissions. The soils of humid tropical forests are the largest natural terrestrial source of N_2O emissions to the atmosphere estimated at 3 Tg of N_2O-N per year. In these soils, N is more rapidly cycled between organic forms and mineral (NH_4 and NO_3) forms than in temperate or boreal soils, because of the elevated temperatures and moist conditions. Thus, the essential substrates for nitrification and denitrification are in more plentiful supply and the emissions are correspondingly higher. However, emissions from temperate forests, temperate grasslands and tropical dry savannas are not negligible. Each is believed to contribute to the order of 1 Tg year^{-1}. A global total of 6.6 Tg N_2O-N year^{-1} from all natural soils.

Nitrous oxide is one of the stable GHGs, with an atmospheric lifetime of approximately 120 years. This has the consequence that emissions from current natural and anthropogenic activities will have long-term implications even if immediate action is taken to curb emissions. In contrast to ammonia (NH_3) and nitric oxide (NO), very little of the N_2O that evolved from sea or land is thought to return to the Earth's surface in combined form. Though N_2O is chemically inert in the troposphere, as it slowly diffuses into the stratosphere it participates in photochemical reactions, which contribute to the destruction of the earth-protecting O_3 layer. This process is the dominant sink for N_2O but an additional small soil sink (uptake of N_2O in soil).

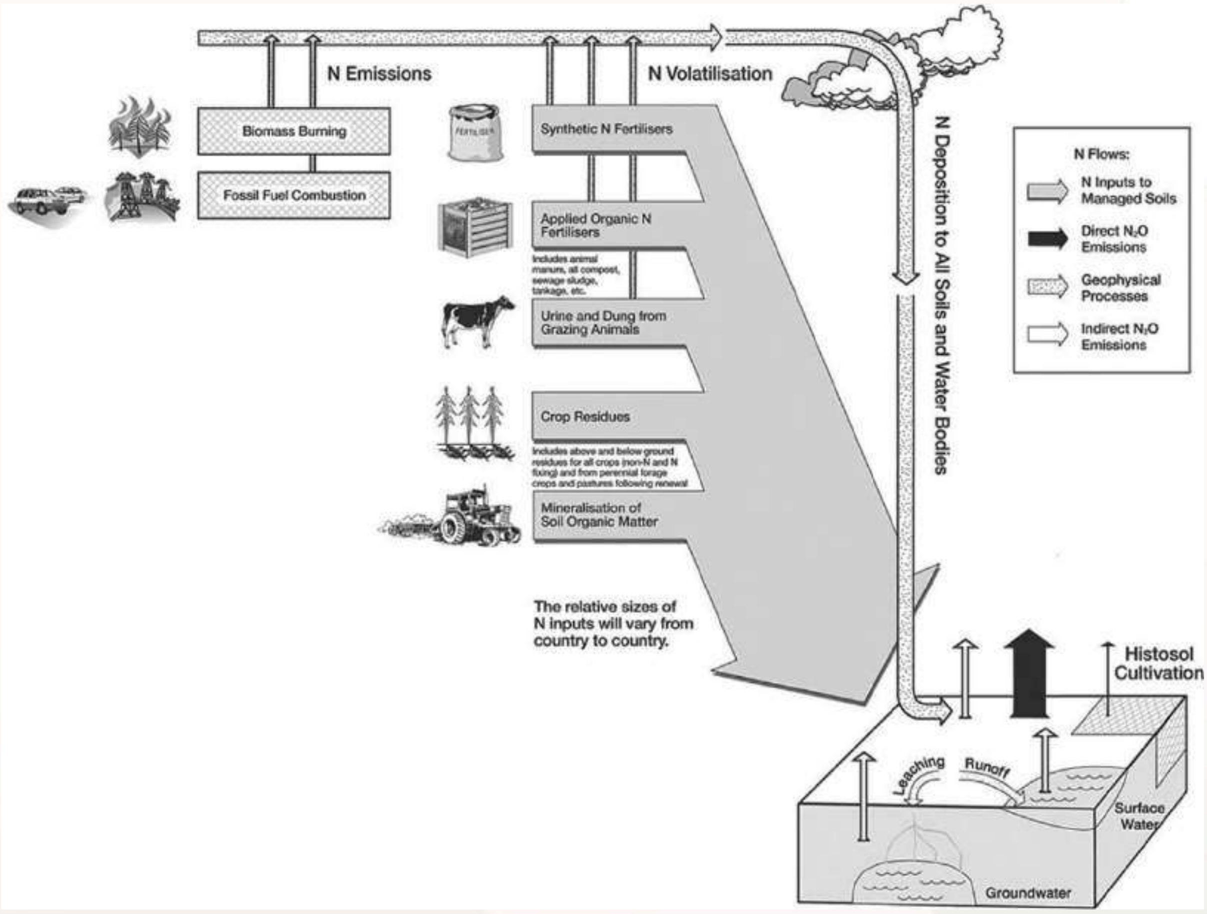


Fig:2. Sources and pathways of reactive nitrogen compounds

Glossary

Hypertrophied lenticels are enlarged cells that allow for increased oxygen diffusion along the stem.

Podzols: Soils in the boreal forest are typically podzols (from the Russian word for "ash"), gray soils that are thin, acidic, and poor in nutrients.

References

Alan Buis.(2019). The Atmosphere: Getting a Handle on Carbon Dioxide. *Sizing Up Humanity's Impacts on Earth's Changing Atmosphere: A Five-Part Series. News, October,9.*

Cloy, J. M and Smith, K.A.(2017).Greenhouse Gas Sources and Sinks. In book: Reference Module in Earth Systems and Environmental Sciences. DOI: 10.1016/B978-0-12-409548-9.09961-9

Course Name	Agro-meteorology and climate change
Lesson 10	Atmospheric chemistry. Plants sense and respond to changes in CO2 concentration. Measurement of short-term effects and mechanisms underlying the observed responses in C3 and C4 species
Content Creator Name	Vallal Kannan Sankaralingam
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	Dr. Vijay Gopal More
University/College Name	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Lesson 10

Objectives:

- To understand the atmospheric chemistry and their effect.
- To understand the effects and mechanisms involved in C_3 and C_4 species for changes in CO_2 concentration

1. Atmospheric chemistry

Atmospheric chemistry is the branch of atmospheric science focused on chemical processes within the Earth's atmosphere, including photochemistry of gas compounds; the formation and properties of airborne aerosol particles; gas–particle interactions; cloud processes; emission, transport, and dispersion of chemical tracers; and biogeochemical cycles (i.e., interaction with the underlying surface).

1.1. Atmospheric Gases:

The major gas molecules that comprise the Earth's atmosphere are nitrogen (N_2) and oxygen (O_2) (nearly 99% ofthe atmosphere by mass), hundreds of gas-phase species have been detected in the atmosphere.The concentration and environmentalimportance of these low abundance gases vary in space and time. However, it is these trace species that drive much of thechemistry of the atmosphere.

1.1.1. Hydroxyl radical:

Hydroxyl radical (OH) is responsible for a large fraction of all oxidation reactionsin the atmosphere (and hence is often referred to as the 'atmosphere's detergent'). However, it is typically present at concentrationsbelow $1x10^5$ molecules per cm^3 (i.e., typically fewer than four in one quadrillion (10^{15}) gas molecules in the lower atmosphereare OH).

Gas molecules in the atmosphere are subject to physical removal processes (e.g., inclusion in cloud droplets and removal inprecipitation), removal by contact with the surface (dry deposition), and/or chemical removal processes.

Virtually, every gas that isemitted into the atmosphere will be chemically altered – either by photochemical processes (where sunlight strikes the moleculeand has sufficient energy to break apart bonds within the molecule) or by interaction with another gas molecule and/or an aerosolparticle.

The likelihood of these interactions and the dominance of physical versus chemical removal are a function of the specificgas under consideration. Equally, the rate of removal of gases from the atmosphere to the Earth's land surface or oceans by physicalprocesses is determined by properties such as the bonding structure of the gas molecule and the solubility. Hence, the atmosphericlifetime (residence time) of different gas molecules in the atmosphere ranges from fractions of a second to many thousands ofyears.

The average atmospheric residence time for a given gas and/or aerosol particle of a given size is inversely related to removalrates and, in conjunction with the spatiotemporal variability and intensity of emission sources, determines the variability of theconcentration of that atmospheric species in space and time.

Gases with very low reactivity and solubility may becomealmost uniformly mixed throughout the Earth's atmosphere and even mix from the troposphere into the stratosphere (e.g.,chlorofluorocarbons).

The environmental consequences of elevated concentrations of a particular gas are determined by factors such as atmosphericresidence time, reactivity, toxicity, and the degree to which it interacts with radiation.

1.1.2. Methane:

Methane (CH_4) is the mos tabundant hydrocarbon (any compound that contains hydrogen and carbon atoms) in the Earth's atmosphere and is an important 'greenhouse gas' (i.e., a gas responsible for warming of Earth's atmosphere). Methane is responsible for anthropogenic (human origin) radiative forcing of about 0.48-0.05 $Wm^{-2}$and carbon dioxide radiative forcing (which is 200 times more abundant) is 1.82- 0.19 Wm^{-2}
The large contribution of CH_4 to anthropogenic 'global warming' is due to

(i) its high radioactive efficiency (i.e., the amount of radiation absorbed per unit mass of the gas), (ii) its relatively long atmospheric lifetime, and (iii) the rapid increase of atmospheric concentrations – from pre-industrial concentrations of 722.25 ppb to over 1879 ppb in 2020 (ppb, parts per billion; 1 ppb is equal to one in 109 molecules) an increase by a factor of 2.5 and the highest value in at least 800,000 years..

Methane has a relatively long atmospheric lifetime, because it does not dissolve in water contained in clouds, rivers, and oceans (it is a non-polarmolecule), does not photo-chemically decompose, and has strong (saturated) chemical bonds that render it comparatively un-reactive.

Gases such as CH_4 are referred to as ‘greenhouse gases’ because they absorb passing infrared photons and convert that energy into an excited vibrational state, thus trapping that energy in the atmosphere. A photon can only be absorbed by a molecule if the interaction between the radiation and the molecule leads to a transition from the molecule’s original state to one ofits other allowed states. Because of its molecular structure, CH_4 absorbs radiation at multiple wavelengths including 7.6 mm –which is a wavelength at which the Earth’s surface emits a substantial amount of energy and that virtually no other atmospheric constituent absorbs. For this and other reasons, methane has a disproportionate impact on the climate of the Earth.

1.1.3 Atmospheric Aerosol Particles

Atmospheric aerosol particles are defined as any solid or liquid droplets suspended in the atmosphere. The size of aerosol particles ranges from diameters (Dp) of a few nanometers to diameters of several tens of micrometers, and hundreds of chemical compounds have been found in aerosol particles.

Atmospheric aerosol particles, of both natural and anthropogenic origins, play akey role in the Earth’s climate and human health impacts of decreased air quality. They are classified as being of primary origin if they are directly emitted into the atmosphere from either natural sources (e.g., volcano eruptions, sea spray, and erosion mechanisms) or anthropogenic processes (e.g., fuel combustion and industrial processes).

Secondary natural aerosol particles are typically dominated by sulphate produced from reactions of dimethyl sulfide and other sulfur gases emitted by the oceans or volcanic sulfurdioxide (SO_2) oxidation and organic aerosol compounds formed from oxidation products of biogenic volatile organic compounds.

Primary anthropogenic aerosol particles derive principally from combustion processes and are mostly black (elemental) carbon, whereas secondary anthropogenic aerosol particles tend to be dominated by sulfate and nitrate produced by oxidation of SO_2 and oxides of nitrogen(NOx) emitted by human activities (often found in association with ammonium) and secondary organic components.

The organic components comprise hundreds of different compounds formed when organic gases undergo reactions that typically lead to anincrease in oxidation state and the products of which can partition to the aerosol particle phase depending on their volatility. Most measurements indicate that sulfate, nitrate, and organic carbon constitute the majority of mass in both remote and urban areas.

Depending on their composition and size, aerosol particles alter the radiation balance of the Earth and thus its temperature, primarily by either scattering or absorbing the incoming radiation from the Sun (direct effect) and regulating cloud formation and properties by acting as cloud condensation nuclei (CCNs) (indirect effect).

Generally, aerosol particles tend to be more efficient atscattering incoming sunlight (leading to an increase in the global albedo and cooling) than in absorbing radiation. An exception tot his is black (or elemental) carbon aerosol particles that tend to have a larger absorption cross section than scattering cross section and hence generally act to absorb radiation and warm the atmosphere.

Some aerosol particles will ultimately reach a size (or will be emitted at a size) where they become climate-relevant. Aerosol particles become

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

active in indirect climate forcing (by acting as CCN) at diameters (Dp) of about 100 nm.

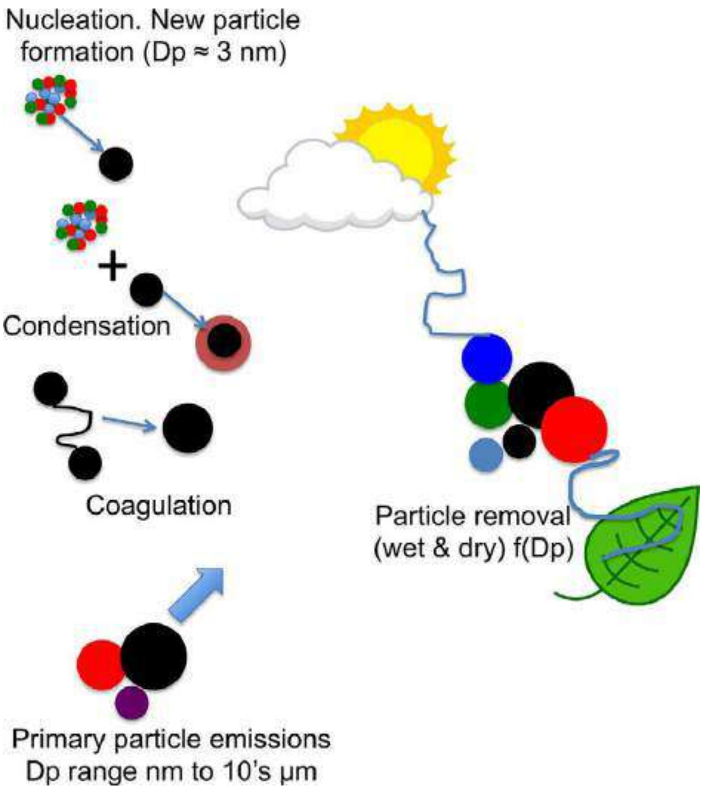


Figure 1.An overview of aerosol particle dynamics (left) and an example aerosol particle size distribution

Aerosol particles with diameters approximately equal to the dominant wavelengths of incoming solar radiation (400–700 nm) are most relevant for direct climate forcing. Thus, accumulation mode particles are most important to the direct climate effect – although the precise composition and mixing state of the aerosol particles will determine the actual radiative properties of any given aerosol particle ensemble. Further, the 'mixing state' of the aerosol particles is extremely important to the ability of aerosol particles to act as CCN and thus to participate in the indirect climate forcing effect

1.2.Composition of atmosphere

The following all the different gases that are present in percentage by volume approximately.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

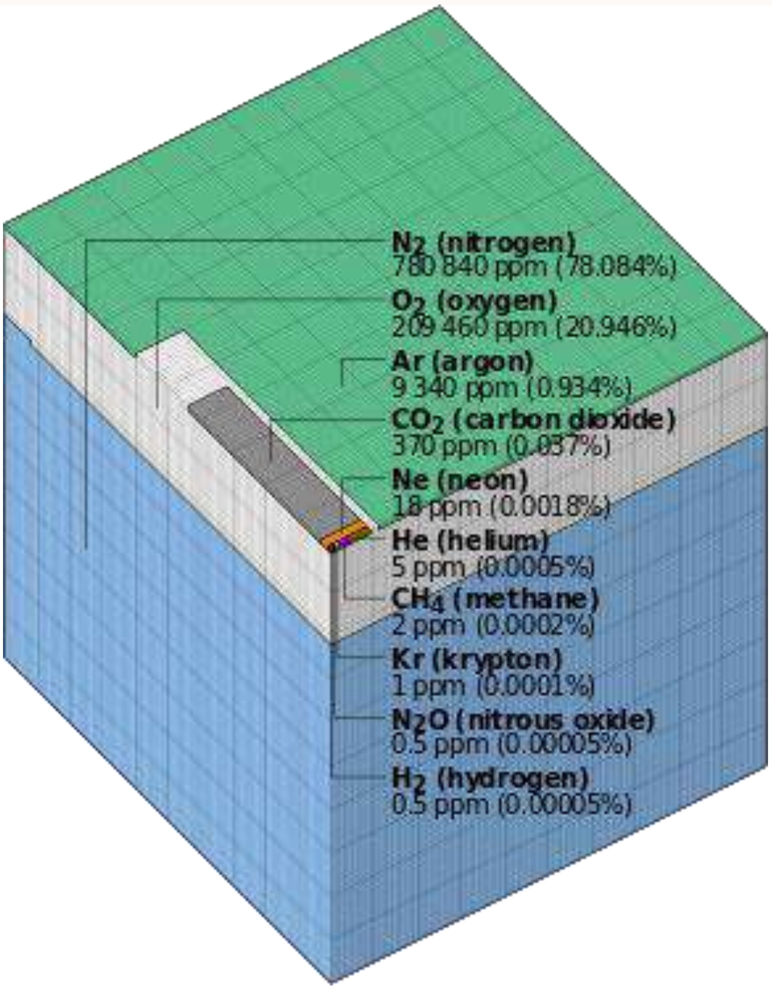


Table-1: Composition of dry clean air near sea level according to standard ISO 2533 - 1975

Gas	Content of volume %
Nitrogen, N_2	78.084
Oxygen, O_2	20.9476
Argon, Ar	0.934
Carbon dioxide, CO_2	0.0314 *
Neon, Ne	1.818×10^{-3}
Helium, He	524×10^{-6}

Krypton, Kr	114×10^{-6}
Xenon, Xe	8.7×10^{-6}
Hydrogen, H_2	50×10^{-6}
Nitrous oxide, N_2O	50×10^{-6}
Methane, CH_4	0.2×10^{-3}
Ozone, O_3, in summer	up to 7.0×10^{-6} *
Ozone, O_3, in winter	up to 2.0×10^{-6} *
Sulphur dioxide, SO_2	up to 0.1×10^{-3} *
Nitrogen dioxide, NO_2	up to 2.0×10^{-6} *
Iodine, I_2	1.0×10^{-6}*
* The content of the gas may undergo significant variations from time to time or from place to place.	

2. Plants sense and respond to changes in CO_2 concentration

Increased in CO_2, since the beginning of the 18th century has been postulated to influence climate causing a rise in atmospheric temperature and increased frequency of droughts around the world this phenomena may have a significant effect on plant growth and species distribution around the world.

Plant tissue (including wood) is composed of about half carbon, all of which comes from carbon dioxide (CO_2) in the atmosphere. Photosynthesis rates tend to increase as CO_2 levels raise, leading to an increase in dry weight, or biomass of plants grown under elevated carbon dioxide levels.

Compared to plants grown at existing carbon dioxide levels, plants "fertilized" by elevated levels of atmospheric carbon dioxide increase their photosynthesis rates. In addition, carbon dioxide-fertilized plants respond with increased biomass (dry weight), improved water use efficiency and an increased tolerance of low light levels.

An important consideration in relation to climate change is that carbon dioxide fertilization raises the optimum temperature for photosynthesis. It also increases the water use efficiency of plants. However, other factors, such as deficient nitrogen or absence of moisture, can limit plant response even with increased CO_2 levels.

Various plant species and genotypes express differences in their degree of responses to CO_2 fertilization. Although most experiments have considered the effect of carbon dioxide fertilization on individual species and not interactions among species, woody species, such as trees and shrubs, appear to be more responsive to carbon dioxide fertilization than some grasses and crops. For instance, forest ecosystems tend to have a more pronounced response to CO_2 fertilization than grassland ecosystems.

Woody Plants vs. Grasses

Carbon dioxide fertilization in recent decades could be contributing to the biomass increase. Response to CO_2 fertilization may influence competition between species, including woody species versus grasses, and native grasses versus invasive species.

Plants using the C_4 photosynthetic pathway already boost their internal concentration of CO_2, so they tend to be less affected by external increases than C_3 plants. Therefore, C_3 plants, which include all trees and shrubs as well as some cool-season invasive grasses like bromes (*Bromus* spp.) and cheat grass (*Bromustectorum*), may be more responsive to CO_2 fertilization than C_4 plants, which include most warm-season grasses and invasives, like love grass (*Eragrostis* spp.) and buffel grass (*Pennisetumciliare*).

Deserts vs. Forests

Carbon dioxide fertilization increases plant water use efficiency, which may help explain why the desert ecosystems responded more dramatically than other ecosystems. In comparing all the ecosystems, net primary productivity rose by an average of 12 per cent in ecosystems exposed to elevated levels of CO_2 compared to controls (typically 550 parts per million compared to ambient levels of 380 parts per million or below, depending on the year of the experiment).

2.1 Response of C_3 and C_4 plants to changes in CO_2 concentration

The response of C_3 species to increased CO_2 may be more positive than that of C_4 species because photosynthetic rate of C_3 species increases by approximately 58 per cent due to doubled CO_2. However, in C_4 species, the photosynthesis is nearly saturated under recent ambient CO_2level.On the other hand, in conditions of higher temperature and drought, C_4 species have been predicted to be more favoured than C_3 species due to CO_2 concentrating mechanism (CCM) in C_4 species enables the plants to maintain CO_2 assimilation rate when stomatal conductance is lower in limited water availability.

2.1.1 Water use efficiency

Increased CO_2 will increase water use efficiency (WUE) of C_3 species, because it causes a reduction in transpiration rate and an increase in CO_2 assimilation rate of the plants. In C_4 species, the positive effect of increased CO_2 on photosynthesis may be pronounced under drought conditions. Elevated CO_2 has increased the growth of several C_4 grasses even under well watered conditions.

The fertilizer effects of elevated CO_2

CO_2 enrichment increased leaf photosynthetic assimilation rate(*Pn*)and reduced transpiration rate may cause an increase in photosynthetic assimilation rate(*Pn*)of C4 species by increasing leaf temperature.Increased CO_2 has also been predicted to have a positive effect on plants grown under drought stress because CO_2 enrichment may result in an increase of osmotic adjustment(OA).Increase of photosynthesis due to elevated CO_2 especially during the beginning of drought may improve solute accumulation such as sugars and organic acids required for osmotic adjustment.

2.1.2 Effect of increased CO_2 and drought stress on stomatal conductance, net CO_2assimilation and intercellular CO_2concentration.

2.1.2.1 Drought

The effect of CO_2 concentration and drought stress on gas exchange parameters varies between species.In well-watered conditions double CO_2reduced stomatal conductance (*Gs*).In C_3 species, *Gs* decreased rapidly from the beginning until moderate drought, where*Gs*of plants grown in both ambient and elevated CO_2 showed similar values. Thereafter, *Gs* reduction continued more slowly until the end of the drought.

In the C_4 species, *Gs* reduction was almost linear from the beginning until the end of the drought, where the stomata remained open and *Gs* was approximately 60 mmol m^{-2} s^{-1}.

In severe drought *Gs* of all species grown in double CO_2 was similar to that of the plants grown in ambient CO_2.

2.1.2.2 CO_2assimilation

Photosynthetic assimilation rate (*Pn*) of the C_3 and C_4 species responded differently to CO_2. When well-watered, *Pn*of the C_3 species increased by approximately 15-25 per cent due to doubled CO_2, but there was no increase in the C_4 species. During drought, *Pn* reduction in C_3 species occurred soon after the drought progressed, while in C_4 species it occurred later after development of moderate stress. Intercellular CO_2 concentration (*Ci*) differed between species under both ambient and elevated CO_2 concentration. In ambient CO_2, *Ci* of well-watered C_3 species was approximately 250 µmol mol^{-1} while in the C_4 species *Ci*was between 150- 200 µmol mol^{-1}.Doubled CO_2increased *Ci*of C_3 species to 500-520 µmol mol-1, and of C4 species to 440-500 µmol mol-1. The response of relative net CO_2 assimilation rate, R*Pn*, to reduced WP was different between C_3 and C_4 species and growth. Phospho enol pyruvate carboxylase(PEPCase) in C_4 photosynthesis is saturated at a much lower CO_2 concentration than Ribulose-1,5-bisphosphate carboxylase oxygenase (Rubisco), Any decrease in *Gs* will decrease *Pn*in a C_3 species, whereas in C_4 species it will only affect *Pn*if intercellular CO_2 is lowered below 100-150 µmol mol-1

Increased CO_2 was only able to delay *Pn* reduction due to the drought, not remove it completely. Under severe drought the positive effect of doubled CO_2 on *Pn*of C_3 species disappeared. During moderate drought, *Gs*of the C_3 species in both CO_2 treatments were similar. The disappearance of positive effects of increased CO_2 under severe drought suggested that metabolic effects limited photosynthesis.

2.1.2.3 Response of stomatal conductance and photosynthesis to plant water status.

Stomatal conductance (*Gs*) of well-watered plants either under present ambient or double CO_2 was lower in C_4 species which have lower *Gs* than C_3 species under the same atmospheric conditions. Drought stress caused a dramatic reduction of *Gs* in the C_3 species especially during the beginning of the drought while in the C_4 species *Gs* decreased gradually with progressive drought and this was also evident from the response curves of *Gs* to WP. Clearly reduced stomatal conductance during the early stages of drought caused higher *Pn* reduction inC_3 than C_4 species, which is consistent with the concept of the CO_2 concentrating mechanism (CCM) of C_4 species which enables the plant to maintain photosynthetic capacity under environmental stresses such as drought.

2.1.3 Different response of photosynthetic gas exchange to drought stress between C_3 and C_4 Species

Drought stress caused a substantial reduction of *Pn* and at the end of the drought cycle *Pn* of the C_3 species grown in either ambient or doubled CO_2 was almost zero. Reduced *Pn* during mild drought stress was associated with a decrease of intercellular CO_2 concentration, *Ci* suggesting that stomatal closure limits photosynthesis in the C_3 species. However, when drought became severe the reduced *Pn* was not related to low *Ci* because *Ci* even increased more than that of well watered plants indicating that there were non-stomatal effects on photosynthesis.

In the C_4 species *Pn* was sustained until moderate drought (9 days after drought began) even though the *Gs* of these species had reduced 6 days after drought began. In addition, the response curve of *Pn* to WP was different between the C_3 and C_4 species with the C_3 species showing very much higher gradient than the C_4.

3. Short-term effects and mechanisms underlying the observed responses in C_3 and C_4 species.

3.1 Short-term response of photosynthesis to CO_2 enrichment

The effect of the short-termCO_2 enrichment during a period of seconds to hours on the rate of photosynthesis was described in this section.

3.1.1 CO_2diffusion :CO_2 flows from the atmosphere to intercellular air spaces through the stomatal pore, and diffuses across the wall, plasma lemma, cytosol and the chloroplast envelope, and to the stroma. The partial pressure of CO_2 in the intercellular air spaces *(pCl)* is controlled by stomatal opening. Generally, as ambient CO_2 partial pressures *(pCa)* increase, stomata tend to close.

A mechanism controlling CO_2 diffusion from the intercellular airspaces to the chloroplast stroma has not been identified, but this seems be related to the chloroplast movement. The chloroplast movement may occur by act in filaments.

In leaves with high photosynthetic capacity, chloroplasts avoid the membranes of the cells attached to the neighbouring cells and adhere effectively to the membranes which are exposed to air spaces. Probably, such a chloroplast movement within the cells may also regulate the partial pressure of CO_2 in the chloroplast stroma(*pCc*).

3.1.2 CO_2 and Rubiscokinetics: The fixation of CO_2 intophotosynthetic metabolism is catalysed by ribulose-1,5-bisphosphate (RuBP) carboxylase/oxygenase. This enzyme also catalyse competitively, the production of 2-phosphoglycolate in the photo respiratory pathway with O_2 as another substrate.

The ratio of these two reactions by Rubisco (carboxylationand oxygenation of RuBP) depends on the ratio of the partial pressure of CO_2 to that of O_2. Since the respective Km(CO_2) and Km(O_2)values at 25°C of Rubisco from higher plants are close to the partial pressures of CO_2 andO_2 in the atmospheric air, elevating CO_2 levels in air stimulate the carboxylation and suppress the oxygenation.

However, the increase in the photosynthetic rate observed above the present atmospheric CO_2 level is generally smaller than that predicted from the Rubisco kinetics. For example, whereas an elevation of *pCa* from 36 Pa to 72 Pa(20 Pa to 50 Pa at *pCc)* at 25°C enhances the carboxylation rate by about two times according to the Rubisco kinetics,the actual increase of photosynthesis observed lies in therange of 25 to 60 per cent. This means that photosynthesis under conditions of CO_2 enrichment is limited by other components limiting photosynthesis.

3.1.3 CO_2 and limitation of photosynthesis: The response of C_3-photosynthesis to CO_2 was theoretically modelled by Farquhar's group. According to their model, the photosynthetic rate is limited by either Rubisco capacity or the capacity of the thylakoid reactions to regenerate RuBP.

In their model, the rate of electron transport reflects the capacity of RuBP regeneration.

Sharkey (1985) modified this model and added a limitation by the availability of Pi in the chloroplast for ATP synthesis to RuBP-regeneration limitation.

3.2 Mechanism underlying the observed responses in C_3 and C_4 species.

All plants use photosynthetic carbon reduction (PCR- Calcin Benson) cycle for CO_2 fixation in which Ribulose-1,5- biphosphate carboxylase/oxygenase(Rubisco) catalyses the first step producing a three carbon compound, Phosphoglycerate(3-PGA).A major problem with the C_3 cycle is that the enzyme Rubisco catalyses two competing reactions, carboxylation and oxygenation. The oxygenation reaction directs the flow of carbon through the photo respiratory pathway, and this can result in losses of between 25and 30 per cent of the carbon fixed. Environmental variables such as high temperature and drought can result in an increase in the oxygenase reaction. Therefore, reducing the Rubisco oxygenase reaction has the potential to increase carbon assimilation significantly and would represent a step change in photosynthesis (up to 100%) depending on temperature. The C_4 photosynthesis is an adaptation of the C_3 pathway

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

that overcomes the limitation of the photorespiration, improving photosynthetic efficiency and minimizing the water loss in hot, dry environments. Generally, C_4 species originate from warmer climates than C_3 species. Most C_4 plants are native to the tropics and warm temperate zones with high light intensity and high temperature. Under these conditions, C_4 plants exhibit higher photosynthetic and growth rates due to gains in the water, carbon and nitrogen efficiency uses. Indeed, the highest known productivity in natural vegetation is for a C_4 perennial grass in the central Amazon, which achieves a net production of 100 t (dry matter) ha^{-1} year-^{1}. Some of the world´s most productive crops and pasture, such as maize (*Zea mays*), sugar cane (*Saccharumofficinarum*), sorghum (*Sorghum bicolor*), amaranth, paspalums *(Paspalumnotatum* and *P. urvillei),* bermudagrass (*Cynodondactylon*), blue grama (*Boutelouagracilis)* and rhodes grass (*Chlorisgayana)* are C_4 plants. In addition, the most troublesome weeds like nutgrass, crabgrass and barnyard, are also C_4 species. In C_4 plants, the photorespiration is suppressed by elevating the CO_2 concentration at the site of Rubisco though suppressing the oxygenase activity of the enzyme. This is achieved by a biochemical CO_2 pump and relies on a spatial separation of the CO_2 fixation and assimilation. In general, these species have a particular anatomy (Kranz anatomy), where mesophyll and bundle sheath cells cooperate to fix CO_2 (Figure 2). Differentiation of these two cell types is essential for the operation of C_4 photosynthesis, although special cases for the operation of the C_4 cycle within only one type of photosynthetic cell have been found.

Basically, carboxylation of phosphoenolpyruvate (PEP) by the phosphoenolpyruvate carboxylase (PEP-carboxylase) produces four-carbon organic acids in the cytosol of mesophyll cells. This so-called C_4 compounds are transported to the bundle sheath cells and decarboxylated to yield CO_2 which is assimilated by Rubisco in the Photosynthetic Carbon Reduction (PCR) cycle (Hatch, 1987). The decarboxylation reaction also produces three-carbon organic acids (C_3)

that return to the mesophyll cells to regenerate PEP in a reaction catalyzed by the enzyme pyruvate orthophosphate dikinase (PPDK). This process called *Hatch-Slack pathway*, after the first scientists that postulated the metabolic pathway. However, they used the name C_4 *dicarboxylic acid pathway of photosynthesis.* Due to current use, the name has been shortened to C_4 *photosynthesis*, C_4 *pathway*, C_4 *syndrome* or C_4 *metabolism*. The plants that perform this type of photosynthesis are then called C_4 *plants*.

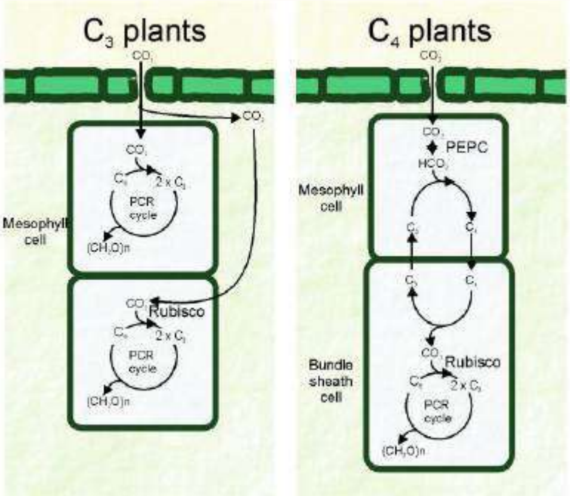


Figure 2. Simplified scheme of carbon fixation pathways operating in C_3 and C_4 plants.(Abbreviations: C_3, three-carbon organic acids; C_4, four-carbon organic acids; C5, ribulose-1,5-bisphosphate; PCR, Photosynthetic Carbon Reduction Cycle; PEPC, phosphoenolpyruvate carboxylase; Rubisco, Ribulose-1,5-bisphosphate carboxylase/oxygenase).

This general scheme is common among the C_4 species; however, there are variations to this basic pathway that include diverse decarboxylation enzymes as well as different transported metabolites. Thus, the decarboxylation process occurs in three diverse ways, mainly using one of the following enzymes: NADP-malic enzyme (NADP-ME), NAD-malic enzyme (NAD-ME) or phosphoenolpyruvatecarboxykinase (PEP-CK). Therefore, C_4 plants have been traditionally grouped into three biochemical subtypes depending on the majordecarboxylase used (C_4-NADP-ME subtype; C_4-NAD-ME subtype or C_4-PEP-CK subtype). Each

C_4 subgroup possesses particular structural features, biochemistry and physiology, and also differences in the mechanism used to regenerate phosphoenolpyruvate (PEP), the substrate of PEP-carboxylase in mesophyll cells. Nevertheless, it is now becoming apparent that, in several cases, more than one decarboxylase operates at the same time.

3.3. C_3 vs C_4 species

C_4 species have evolved in a high CO_2 environment. This increases both their nitrogen and water use efficiency compared to C_3 species. C_4 plants have greater rates of CO_2 assimilation than C_3 species for a given leaf nitrogen when both parameters are expressed either on a mass or an area basis. Although the range in leaf nitrogen content per unit areas is less in C_4 compared to C_3 plants, the range in leaf nitrogen concentration per unit dry mass is similar for both C_4 and C_3 species. Even though leaf nitrogen is invested into photosynthetic components into the same fraction in both C_3 and C_4 species, C_4 plants allocate less nitrogen to Rubisco protein and more to other soluble protein and thylakoids components. In C_3 plants, the photosynthetic enzyme Rubisco accounts for up to 30 per cent of the leaf nitrogen content, but accounts for only 4 to 21per cent of leaf nitrogen in C_4 species. The lower nitrogen requirement of C_4 plants results from their CO_2concentrating mechanism, which raises the bundle sheath CO_2 concentration led to saturating Rubisco in normal air and almost eliminating photorespiration. Without this mechanism, Rubisco in the C_3 photosynthetic pathway operates at only 25 per cent of its capacity and loses about 25per cent of fixed carbon to photorespiration. To attain comparable photosynthetic rates to those in C_4 plants, C_3 leaves must therefore invest more heavily in Rubisco and have a greater nitrogen requirement. Because the Rubisco specificity for CO_2 decreases with increasing temperature, this difference between the C_3 and C_4 photosynthetic nitrogen-use efficiency is greatest at high temperatures. The high photosynthetic nitrogen-use efficiency of C_4 plants is partially offset by the nitrogen-requirement for CO_2-concentrating mechanism enzymes, but the high maximum catalytic rate of PEP-carboxylase means that these account for only about 5per cent of leaf nitrogen. Improved leaf and plant water use efficiency in C_4 plants is due to both higher photosynthetic rates per unit leaf area and lower stomatal conductance, with the greater CO_2 assimilation contributing to a major extent.

The advantages of greater nitrogen use efficiency and water use efficiency of C_4 relative to C_3 photosynthesis are fully realized at high light and temperature, where oxygenase reaction of Rubisco is greatly increased. It is worth noting, although in C_4 plants energy loss due to photorespiration is eliminated, and additional energy is required to operate the C_4 cycle (2 ATPs per CO_2 assimilated). In dim light, when photosynthesis is linearly dependent on the radiative flux, the rate of CO_2 assimilation depends entirely on the energy requirements of carbon assimilation. The additional ATP required for assimilation of one CO_2 in C_4 photosynthesis, compared with C_3 photosynthesis, increases the energy requirement in C_4 plants. However, when the temperature of a C_3 leaf exceeds about 25 ºC, the amount of light energy diverted into photorespiratory metabolism in C_3 photosynthesis exceeds the additional energy required for CO_2 assimilation in C_4 photosynthesis. This is the reason why at temperatures below 25–28 ºC, C_4 photosynthesis is less efficient than C_3 photosynthesis under light-limiting conditions. It is interesting to note, that while global distribution of C_4 grasses is positively correlated with growing season temperature, the geographic distribution of the different C_4 subtypes is strongly correlated with rainfall. On the contrary, C_4 plants are rare to absent in cold environments. Although there are examples of plants with C_4 metabolisms that show cold adaptation, they still require warm periods during the day in order to exist in cold habitats. In consequence, C_4 species are poorly competitive against C_3 plants in cold climates. The mechanisms explaining the lower performance of C_4 plants under cold conditions have not been clarified. Among early plausible explanations were the low quantum yields of the

C_4 relative to the C_3 pathway and enzyme liability in the C_4 cycle, most notably around PEP metabolism (PEP-carboxylase and pyruvate orthophosphate dikinase). Both hypothesis are insufficient since maximum quantum yield differences do not relate to conditions under which the vast majority of daily carbon is assimilated and there cold-adapted C_4 species that have cold stabled forms of PEP-carboxylase and pyruvate orthophosphate dikinase, and synthesize sufficient quantity to overcome any short term limitation. The current hypothesis is that C_4 photosynthesis is limited by Rubisco capacity at low temperatures. Even in cold-tolerant C_4 species, Rubisco capacity becomes limiting at low temperature and imposes a ceiling on photosynthetic rate below20 ºC.

Glossary:

Aerosol particles: Aerosol particles are referred to as secondary when formed in the atmosphere by chemical reactions.

Atmospheric Aerosol particles: Atmospheric aerosol particles are defined as any solid or liquid droplets suspended in the atmosphere.

Atmospheric chemistry: Atmospheric chemistry is the branch of atmospheric science focused on chemical processes within the Earth's atmosphere, including photochemistry of gas compounds; the formation and properties of airborne aerosol particles; gas–particle interactions; cloud processes; emission, transport, and dispersion of chemical tracers; and biogeochemical cycles (i.e., interaction with the underlying surface).

Farquhar model: The measurements of gas exchange with the model outputs may be compared include those of temperate and partial pressure of CO_2 (pCO_2) dependencies of quantum yield, the variation of compensation point with the temperate and partial pressure of O_2 ($p(O_2)$, the dependence of net CO_2 assimilation rate on p(CO2) and irradiance and the influence of p(CO2) and irradiance on the temperature dependence of assimilation rate.

Leaf water Potential (WP): Water potential is a measure of the potential energy in water as well as the difference between the potential in a given water sample and pure water.

Michaelis constant (Km): it is an approximation of an enzyme's binding affinity for the substrate. it is the substrate concentration at which the enzyme reaches half Vmax. An enzyme with a high Km has a low affinity for its substrate, and requires a greater concentration of substrate to achieve Vmax.

Photosynthetic assimilation rate: The net assimilation rate (E) of a plant population (the mean rate of increase in total dry weight per unit leaf area, measured over a period of 1 or 2 weeks), represents the excess of the rate of photosynthesis of the leaves (P) over the rate of respiration of the whole plants (R), both expressed per unit leaf area.

Radioactive efficiency: The amount of radiation absorbed per unit mass of the gas.

Stomatal conductance (*Gs*): usually measured in mmol m^{-2} s^{-1}, conditions the net molar flux of carbon dioxide (CO_2) entering or water vapor exiting through the stomata of a leaf, for a given concentration difference of CO_2 or water vapor between the atmosphere and the sub-stomatal cavity.

Reference

DAVID R. MuRRAY.(1995). PLANT RESPONSES TO CARBON DIOXIDE. *American Journal of Botany*. 82(5): 690-697.

Farquhar,G.D., Von Caemmerer,S. and Berry, J. A.(1980). A bio chemical model of photosynthetic CO_2 assimilation in leaves of C_3 species. *Planta.* **149**,78-90. https://doi.org/10.1007/BF00386231.

Course Name	Agro-meteorology and climate change
Lesson 11	Plant development affected by growth in elevated CO_2-Physiology of rising CO_2 on nitrogen use and soil fertility-its implication for production- Methodology for studying effect of CO_2
Content Creator Name	Vallal Kannan Sankaralingam
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	Dr. Vijay Gopal More
University/College Name	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Lesson 11

Objectives:

- To understand influence of elevated CO_2 on growth and development of plants
- To understand the physiology of elevated CO_2 on nitrogen use and soil fertility and their implication on production
- To understand the methodology on effect ofCO_2

1. Effect of elevated CO_2 on growth and development of plants

Increased CO_2since the beginning of the 18th century has been postulated to influence climate causing a rise inatmospheric temperature and increased frequency of droughts around the world. This phenomenon may have a significant effect on plant growth and species distribution around the world.

The response of C_3 species to increasedCO_2 may be more positive than that of C_4 species because photosynthetic rate of C_3 species increases by approximately58% due to CO_2 concentrating mechanism doubled CO_2. However, in C_4species, the photosynthesis is nearly saturated under recent ambient CO_2.

On the other hand, in conditions of higher temperature and drought, C_4 species have been predicted to be more favoured than C_3 species due to the (CCM) in C_4 species enables the plants to maintain CO_2assimilation rate when stomatal conductance is lower in limited water availability.

The fertilizer effects of elevated CO_2on C_4 species are not well understood, even though evidence indicates that CO_2 enrichment increased leaf photosynthetic rate(*Pn)*and reduced transpiration rate may cause an increase in *Pn* of C_4 species by increasing leaf temperature.

Increased CO_2 will increase water use efficiency (WUE) of C_3 species, because it causes a reduction in transpiration rate and an increase in CO_2assimilation rate of the plants.

In C_4 species, the positive effect of increased CO_2 on photosynthesis may be pronounced under drought conditions. However, theelevatedCO_2

has increased the growth of several C_4 grasses even under well-watered conditions.

1.1. Increase of CO_2 concentration on growth and yield in horticultural crops

The change in CO_2 concentration in the atmosphere can alter plant tissues in terms of growth and physiological behaviour.

Studies show that at higher CO_2 (550ppm) which influenced growth and development and increased yield by 24.4 per cent in tomato cv. Arka Ashish.

Higher CO_2 influenced overall growth and development of onion cv.Arka Kalyan, producing higher dry matter content in leaves, stems, and bulbs. At the bulb development stage, the photosynthesis rate was higher at elevated CO_2 levels as compared to ambient level.

In tuber crops every 100 ppm increase in CO_2 increases tuber initiation, flowering, tuber weight, tuber number, and tuber yield by approximately10 per cent.

The few negative effects of elevated CO_2 concentration include reduction in chlorophyll content in leaves particularly during late growing season after tuber.

Root crop yield increased by 34 per cent for an increase in CO_2 from 325 to 530 ppm.

In cucumber. yield increased by 34per cent for an increase in CO_2 from 364 to 620 ppm

In coconut, areca nut, and cocoa, increased CO_2 led to higher biomass production and total dry matter content.

2. Physiology of rising CO_2 on nitrogen use and soil fertility

Nitrogen is the most important mineral nutrient needed by plants as large amounts of N is invested in the photosynthetic apparatus. The N availability is a significant determinant of photosynthetic capacity and yield.

Nitrogen deficiency is also a worldwide problem limiting agricultural production. Worldwide nitrogen use efficiency for cereal production is approximately 33-40 per cent. The unaccounted60-67 per cent represents a $15.9 billion annual loss of nitrogen fertilizer.

Extensive loss of N fertilizers has resulted in serious environmental problems, such as greenhouse warming and pollution of drinking water resources.

Nitrate is the major inorganic nitrogen form in aerobic agricultural soils and in plants it also acts as a signalling molecule.

Understanding the mechanism of uptake of nitrogen from soil and its assimilation within crop plants could help in mitigating the poor utilization efficiency of nitrogenous fertilizers, economize the cost of production and avoid environmental and health hazards.

During the last decade considerable attention has been paid to plant growth and metabolism under elevated CO_2. Atmospheric CO_2 is rising steadily from preindustrial values of 280 μmol mol^{-1} to a current global value of approximately 380 μmol mol^{-1} and are projected to increase to approximately550 μmol mol^{-1} by the year 2050.

The effects of elevated atmospheric carbon dioxide concentration on plant growth and tissue composition have been studied extensively with C_3 species as photosynthesis in these plants is unsaturated at the present atmospheric CO_2 concentrations and hence the response to elevatedCO_2 concentration is usually positive.

CO_2 being the primary substrate for photosynthesis influences several plant physiological processes directly. As a result of this primary response, and a range of secondary responses, including growth, dry matter allocation, and nutrient composition and assimilation, may change.

The magnitude and direction of plant responses is determined by the availability of other environmental resources (e.g. water, nutrients, and light). Even though short-term exposure to CO_2 enrichment often stimulates growth and photosynthetic C fixation, in most managed and natural ecosystems, long-term growth and photosynthetic responses may be confined by the limited availability of mineral nutrients, particularly nitrogen (N). Therefore, factors that may affect availability and uptake of N are critical in determining plant and ecosystem responses to high CO_2.

2.1 Nitrogen Use Efficiency of C3 and C4 Plants

The photosynthetic rate per unit of N_2 is usually higher in C_4than C_3plants; CO_2concentrating mechanism of C_4 plants leading to CO_2 saturation of rubisco, consequently, less of this enzyme is required for high rates of photosynthesis in C_4 than C_3 plants.

C4 grasses generally have greater photosynthetic rates per unit of N than C_3grasses and dicots as well as have greater growth and leaf expansion rates per unit N. However, exceptions have been noted and the NUE differences of C_3 and C_4 dicots have not been directly compared.

The relationship between photosynthetic nitrogen use efficiency(PNUE) and photosynthetic capacity is unclear. On the one hand, plants with a greater PNUE may have similar N and therefore greater photosynthetic capacities than less efficient plants. However, as photosynthetic capacity increases, sink capacity and external environmental constraints may lead to a reduction of carbon fixation per unit of N investment.

Alternatively, more efficient plants may invest less N per unit area, and proportionally more N to the production of new leaf area. Leaf area production is often a better predictor of growth than photosynthetic capacity per unit area or net assimilation rate

As N is required for both production of new leaf area and for increasing photosynthetic capacity, the enhancement of one under limiting N could come at the expense of the other.

The effect of leaf nitrogen (N) on the photosynthetic capacity and the light and temperature response of photosynthesis in the ecologically similar annuals *Chenopodiumalbum* (C_3) and *Amaranthusretropxus* (C_4) shows that photosynthesis was linearly dependent on leaf N perunit area (N) in both species. *A. retroflexus* exhibited a greater dependence of photosynthesis on N than *C. album* at any given N. It had a greater light saturated photosynthesis rate than *C. album*. The difference between the species became Larger as N increased. It shows the greater photosynthetic N use efficiency in *A. retroflexus*than *C. album*. However, at a given applied N level, *C. album* allocated more N to a unit of leaf area so that photosynthetic rates were similar in the two species.

Leaf conductance to water vapor increased linearly with N in both species, but at a given photosynthetic rate, leaf conductance was higher in *C. album*. Thus, *A. retroflexus* had a greater water use efficiency than *C. album*. Water use efficiency was independent of leafN in *C. album*, but declined with decreasing N in *A. retroflexus*.

2.2 Interactive effects of nitrogen and elevated CO_2 on crop plants

An understanding of the effect of enhanced carbon dioxide in nitrate metabolism is important because the effect of enhanced carbon dioxide on photosynthesis and growth depends on the availability of nitrogen in the plant. The overall nitrogen concentration in plants on dry weight basis decreases when they are grown in enhanced CO_2.

The survey of literature indicates that the growth of plants at elevated CO_2 decreased plant N by average of 14 per cent. The decreased nitrogen content is partly due to increased non structural carbohydrates, the nitrogen content in enhanced carbon dioxide usually decreases after correcting for this effect. Further, the total amount of nitrogen per plant is often unaltered or reduced in enhanced CO_2. This decrease of the nitrogen concentration and content is usually interpreted as evidence that nitrate uptake and assimilation do not keep pace with photosynthesis and growth in enhanced carbon dioxide.

2.2.1 Nitrogen in relation to plant growth under elevated CO_2

When nitrogen is low or marginal, acceleration of growth in elevated CO_2drives plants into a nitrogen deficiency. This is revealed by lower levels of amino acids and lower protein content. When nitrogen is high, elevated CO_2 leads to a sustained stimulation of photosynthesis and growth. Nitrate, amino acids and protein remain high revealing that the uptake and utilization of inorganic nitrogen has been increased.

Plants grown at enhanced levels of CO_2 often display increase in root: shoot ratios that are symptomatic of N limited plants. Reductions in tissue nitrogen concentrations of high CO_2 grown plants might indicate physiological changes in the efficiency with which plants use nitrogen to gain biomass (i.e. increased nitrogen use efficiency).

It is unclear whether commonly observed increase in plant growth in high CO_2 atmospheres are sustainable without concomitant increases in nitrogen availability, because if reduction in tissue nitrogen concentrations are due to high NUE, nitrogen availability would not limit plant growth in elevated CO_2.

In sunflower, nitrogen uptake was reduced by 25 per cent in elevated CO_2 conditions but there was enhancement of photosynthetic nitrogen use efficiency by 50 per cent, leading to increase of 115per cent in plant biomass under elevated CO_2.

In rice, tiller production increased by 2.3per cent and this increase in biomass was higher with increased N supply. The effect of elevated CO_2 on growth is therefore strongly modulated by N supply and increased growth is supported in the well fertilized plants.

The rate of growth also depends upon the number of active meristems and rate of cell division and cell elongation and the duration of the division and elongation phases. Elevated CO_2 results in the shortening of the cell cycle in the shoot and root meristem.

2.2.2 Nitrogen uptake and accumulation

There is a high degree of heterogeneity with respect to availability of soil N and variation in plant requirement for nitrogen. This imposes a need to regulate N fluxes across the plasma membrane of roots in order to optimize plant N capture. Nitrate uptake system in plants is robust and versatile enough to transport sufficient amounts of nitrate to satisfy total demand for nitrogen depending on external concentrations, which can vary by four orders of magnitude.

The plants have uptake/transport system, which is active, regulated and multiphasic. The plants have at least 3 kinetically distinct nitrate uptake systems low affinity transport system (LATS) constitutive and inducible high affinity transport systems (CHATS and IHATS). Families of membrane proteins have been identified that can mediate active transport of nitrate presumably with symport of 2 protons across the plasma membrane. PTR (Peptide Transporter family) containing NRT1, which represents LATS and NNP (Nitrate–Nitrite Porter family) containing NRT2 which represents HATS. Both NRT1 and NRT2 are assigned to Major Facilitating Super family, having 12 trans membrane domains.58 putative nitrate transporters have been identified in plants (51 PTR and 7 NRT2)of which 13 have been characterized. Nitrate uptake is strongly stimulated after pre incubation with nitrate, which stimulates the expression and activity of high affinity transporter and one low affinity transporter.

2.2.2.1. Uptake of nitrate in response to high CO_2

The physiological studies of nitrate uptake are supported by the molecular studies as a result of the advances made in the molecular cloning of the transporters. The uptake of nitrate is highly regulated and it is subjected to feed back regulation by glutamine. There is also large variation among species in terms of nitrate accumulation. Among the genes coding for the nitrate uptake in higher plants it has been shown that expression of NRT 2:1is restricted to roots. The expression of high affinity nitrate transporter is increased upon addition of nitrate in the medium and was inhibited by excess nitrate in the roots.

The factors that may affect availability and uptake of nutrients particularly N, are critical in determining plant and ecosystem responses to high CO_2. A potentially important mechanism that could influence plant nutrient uptake is root physiological uptake capacity. Expression of the genes involved in N uptake is often coupled to photosynthesis hence the increased availability of photosynthate under elevated CO_2 might increase N uptake.

The expression of many NH_4^+andNO_3^-transport proteins is positively regulated by plant demand for N and these decreases under elevated CO_2, as the level of photosynthetic enzymes declines. This suggests that expression of NH_4^+andNO_3^-transport proteins might be down regulated under elevated CO_2.

Michaelis-Mentenkinetics describe uptake well at realistic soil concentrations, so that physiological uptake capacity is expressible in terms of maximal uptake capacity (Vmax) and the affinity (1/Km),where Km is the Michaelis-Menten constant. While kinetic parameters may have a regulatory role in plant nutrient budgets, changes in Vmax and Km in response to elevated CO_2 have been examined.

Vmax for nitrate uptake increased in the CO_2 enriched wheat seedlings due to increased expression of high affinity transporter (HATS) in wheat seedlings when N supply was low and there was decline in expression and uptakeof low affinity nitrate transporter (LATS) under non-limiting N supply. Hence the change in expression of HATS and LATS is expected under rising CO_2.

The expression of ammonium transporters(AMT) is unaffected in the plants grown under elevated CO_2due to possibly reflects a balance between the effects of increased availability of photosynthate (tending to increase uptake rates) and feedbacks from decreased plant demand for N (tending to decrease uptake rates)or increased uptake under limiting supply indicates the plants ability to maximize the uptake of nutrients and their utilization in synthesis and under ample supply the uptake is restricted as less of photosynthetic enzymes like rubisco are needed in the leaves of the plants growing under enriched CO_2.

2.2.2.2 Assimilation of nitrate and nitrogen use efficiency

Nitrate assimilation is controlled by transcriptional, post transcriptional and post translational regulation of nitrate reductase (NR). Transcription of NR gene *Nia* is induced by nitrate and repressed by glutamine. Inactivation of NR protein occurs in the absence of nitrate by phosphorylation and subsequent binding to 14-3-3 protein. The transcript associated with aromatic amino acid biosynthesis was also increased at elevated CO_2.

Maximum exploitation of the CO_2 rich atmosphere can only be achieved when a plant has sufficient capacity to use the increased supply of carbon available at elevated CO_2 and this should not be limited by the availability of nitrogen.

Indeterminate plants are expected to escape the limitation of sink capacity that determinate species can experience at elevated CO_2.

A set of criteria needs to be identified to assess the changes in plant nitrogen status. Increase in nitrate levels of the plants under elevated CO_2 in some plants species may reflect increased accumulation or reduced assimilation. During the initial stages of acclimation to high CO_2, higher growth rate should increase plant nutrient demand. Although this greater demand can be partially offset by increased nutrient use efficiency and there is no evidence that such a positive response to elevated CO_2 can be sustained over the long term without a concomitant increase in availability and/or acquisition of growth limiting nutrients.

In fact increase inCO_2 may be constrained by plants ability to assimilate the nutrients needed for new tissue in sufficient quantity to match the nutrients and carbon in sufficient quantity to growing organs and tissues. There are shifts in partitioning due to rising CO_2. There are several ecosystems and plant-level mechanisms that could compensate for the greater nutrient demand under high CO_2. A greater below ground C allocation in response to elevated CO_2 may result in increased microbial activity accompanied by higher mineralization and plant uptake.

Increased association with N_2 fixing organisms and mycorrhizal fungi is an effective mechanism by which plants could increase their nutrient uptake per mass of root under high CO_2, thereby increasing RGR and primary productivity.

2.2.3 Nitrogen and carbon metabolism

Uptake and assimilation of N is energy demanding process with carbohydrates derived from photosynthesis providing the required energy (ATP)and reductants (NADH, NADPH). CO_2 enrichment increases the availability of root respiratory substrates and metabolically regulated processes such as active nutrient uptake might be stimulated under high CO_2.

The nutrient flow to root re-circulating from the shoot is a stronger controller. Nitrate can be assimilated in root and shoot or both, and the assimilation rate is directly correlated with NO_3^-uptake. Under optimal light conditions, shoot NO_3^-may be photo assimilated with very little demand for carbohydrates whereas, root assimilation is almost exclusively dependent on respiratory energy supplied by carbohydrates. It is therefore expected that the projected rise in atmosphericCO_2 concentration would disproportionately benefit NO_3^- uptake in root versus shoot reducing species.

In considering the relationship between high CO_2, root energy supply, and inorganic nitrogen uptake, other complexities must also be considered. Plant Nis primarily supplied from the available soil NO_3^- and NH_4^+ solution, but the relative preference for each form may largely depend on the ability of roots to absorb, assimilate, and translocate that form. Although uptake and assimilation of both N forms require expenditure of energy, considerably more energy is associated with the uptake and assimilation of NO_3^- than NH_4^+, because NO_3^- must be metabolically reduced to ammonia before it can be assimilated.

2.2.4 Nitrogen (N) content in response to elevated CO_2

CO_2 enrichment is capable of causing changes in plant metabolism and partitioning of important nutrients. Some studies indicate that CO_2 enrichment ofC_3 plants can results in more efficient carbon fixation by rubisco, so that less leaf protein nitrogen is required to produce a given amount of dry matter.

Consequently, CO_2 enrichment may improve the N use efficiency of C_3 plants and enable these plants growing in soils marginally deficient in nitrogen to have growth comparable to plants growing in soils of adequate nitrogen status.

A better understanding of the effect of enhanced carbon dioxide in nitrate metabolism is important because the effect of enhanced carbon dioxide on photosynthesis and growth depends on the availability of nitrogen in the plant. The overall nitrogen concentration in plants usually decreases when they are grown in enhanced CO_2.Increased nitrogen use efficiency has been reported for several C_3 plants and grasses grown under elevated CO_2.

In wheat and *Amaranthus* elevated CO_2 treatment reduced the shoot nitrogen concentration. Reduction in nitrogen concentration in response to elevated CO_2 levels is probably the result of accelerated growth, and not changes in whole plant nitrogen use efficiency.

Reductions in tissue nitrogen concentrations of high CO_2 grown plants indicate physiological changes in the efficiency with which plants use nitrogen to gain biomass i.e. increased nitrogen use efficiency. It is unclear whether commonly observed increase in plant growth in high CO_2 atmospheres are sustainable without concomitant increases in nitrogen availability. If reduction in tissue nitrogen concentrations is due to high NUE, nitrogen availability would not limit plant growth in elevated CO_2.

2.2.5 Grain protein and quality as affected by rising carbon dioxide

Elevated CO_2 commonly decreases the N concentrations of plant tissues and their effect would hold for the N and protein concentrations of crop plants. The decreases in protein concentration seen across a range of environmental conditions and using a variety of experimental techniques suggests that the decrease in crop protein concentration under elevated CO_2 is of importance as atmospheric CO_2 continues to rise during the 21^{st}century.

It is also possible that rising atmospheric CO_2 may have already affected the protein concentration of some food crops. (10-15, 9.8, 9.9 and 15.3 per cent reduction in the protein content in potato, wheat, rice and barley, respectively).

Elevated CO_2 treatments increased yield of rice by increasing the number of grains and their size. Nutrient value was also changed at high CO_2 as a result of reduction in grain nitrogen and therefore, protein concentration. Atmospheric CO_2 reduced the N content and protein content of the grains. This indicates physiological changes in the efficiency with which plants use N to gain biomass. Major challenge for global nutrition in the next decade is to increase food yield per unit ground area in a sustainable manner while maintaining its end use value. Inverse relationship between grain yield and protein concentration have been observed under rising CO_2.

The overall CO_2 induced impact for essential amino acids was significant. Growth under elevated CO_2 also affected grain macro elements such as calcium, magnesium and micro elements such as zinc and iron.

The amount of protein in wheat grains and products derived from wheat will be reduced in the CO_2 rich world. For adequate bread making quality, required protein concentration is greater than 11.5 per cent. Under rising CO_2 the protein concentrations may decrease to values below the minimum quality standard for bread making. This may not be easily overcome by simply increasing the N fertilization. Effect of rising atmospheric CO_2 on the crop production therefore, seems likely to be of genuine importance for human nutrition in and beyond 21stcentury.

3. Methodology for studying effect of CO_2

According to Intergovernmental Panel on Climate Change (IPCC) methodologies, the main target to develop methodology is to estimate CO_2 emission balance between stored and in the product production released emissions.

According to IPCC the methodology is divided in several parts: (a) quality of product identification, (b) CO_2 calculation in the product, (c) product eco-design estimation, (d) CO_2 emission estimation for product production and (e) stored CO_2 calculation in the product.

Glossary

Michaelis–Menten equation

In biochemistry, **Michaelis–Menten kinetics** is one of the best-known models of enzyme kinetics. It is named after German biochemist Leonor Michaelis and Canadian physician Maud Menten. The model takes the form of an equation describing the rate of enzymatic reactions, by relating reaction rate (rate of formation of product) to , the concentration of a substrate S. Its formula is given by

$$v = \frac{V_{max}[S]}{K_M + [S]}$$

v= velocity of reaction

V_{max} = maximum rate achieved by system

$[S]$= concentration of substrat S

K_M = Michaelis constant

Photosynthetic nitrogen use efficiency: Photosynthetic nitrogen use efficiency (PNUE) was calculated as the ratio of maximum leaf photosynthetic rate (Pn_{max}) to foliar N content.

Water use efficiency (*WUE*): it is *defined* as the amount of carbon assimilated as biomass or grain produced per unit of water used by the crop.

References

Grewer U, Bockel L, Galford G, Gurwick N, Nash J, Pirolli G, Wollenberg E. 2016. A methodology for greenhouse gas emission and carbon sequestration assessments in agriculture: Supplemental materials for info note series analysing low emissions agricultural practices in USAID development projects. CCAFS Working Paper no. 187. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Published by the International Center for Tropical Agriculture (CIAT) and the Food and Agriculture Organization of the United Nations (FAO).

Course Name	Agro-meteorology and climate change
Lesson 12	Change in secondary metabolites and pest disease reaction of plants- The mechanisms of ozone and UV damage and tolerance in plants
Content Creator Name	Vallal Kannan Sankaralingam
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	Dr. Vijay Gopal More
University/College Name	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Lesson 12

Objectives:

- To study the changes in secondary metabolites and response of pest and disease reaction in plants
- To understand the mechanism of Ozone and UV damage and tolerance in the plants.

1. Change in secondary metabolites and pest and disease reaction in plants

1.1 Secondary metabolites

In nature, plants protect themselves against pathogen attack mainly by mechanicaland chemical defences. Mechanical defences include structures such as spines, trichomes, thick cuticle, and hard, sticky, or smooth surfaces which prevent pathogensfrom picking for food or laying eggs. Chemical defences include a variety ofsubstances that are toxic, repellent, or that render plant tissues indigestible to animals. Chemical defence due to secondary metabolites is prominentlydeveloped in plants, providing protection to the plant.

Secondary metabolites are the molecules that appear tobe dispensable for normal growth, or are required only under particular conditions,whereas primary metabolites are involved in the physiological functions. Thesesecondary products are the key components of active and potent defence mechanismsin plants. They are the active part of the chemical war between plantsand their pathogens.Plants synthesize a huge array (around several tens ofthousands) of different secondary metabolites.

Various biosynthetic pathways are involved in secondary metabolites productionand there is requirement of substantial amount of ATP. Besides their synthesis duringthe time of attack by pathogen, their storage in the vacuole also requires energy. The energy for uphill transport and often for trapping the metabolite in thevacuole is provided by H^+ – ATPase. In addition, some metabolites are transportedinto the vacuole with the help of ATP-binding cassette transporters (ABC-transporter)which depend on ATP.

Most of the secondary metabolites are derived from the isoprenoid, phenylpropanoid,alkaloid or fatty acid/polyketide pathways. It is observed thatrelated plant families generally make use of related chemical structures for defence,e.g. sesquiterpenes in the Solanaceae, stilbenes in the Vitaceae, isoflavones in theLeguminosae, sulfur-based glucosinolate–myrosinase in the Brassicaceae andlimonoids among members of the families Meliaceae and Rutaceae.

Secondary metabolites are small organic compounds (molecular massesgenerally less than 3000 Da), which, as opposed to primary metabolites haveno function in the life cycle of cells. The production of specific secondarymetabolites varies between species or genera and is thus, apart fromappearance and size *etc*., an aspect of characterisation of a species. Theboundary between primary and secondary metabolites is not well defined andthe areas overlap. The difference between the meanings of the terms *naturalproduct* and *secondary metabolite* is also difficult to define, since mostcompounds dealt with in natural products research are secondary metabolites.

Plants produce a high diversity of natural products or secondary metabolites with a prominent function in the protection against predators and microbial pathogens on the basis of their toxic nature and repellence to herbivores and microbes and some of which also involved in defence against abiotic stress.

1.1.1 Principal groups

Plant secondary metabolites can be divided into three chemically distinct groups *viz*: Terpenes, Phenolics, N and S containing compounds.

1.1.1.1 Terpenes :

Terpenes constitute the largest class of secondary metabolites and are united by their common biosynthetic origin from acetyl-coA or glycolytic intermediates. A vast majority of the different terpenes structures produced by plants as secondary metabolites that are presumed

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

to be involved in defense as toxins and feeding deterrents to a large number of plant feeding insects and mammals.

(a) *Monoterpenes*(C10):Many derivatives are important agents of insect toxicity. For example, the pyrethroids (monoterpenes esters) occur in the leaves and flowers of *Chrysanthemum* species show strong insecticidal responses (neurotoxin) to insects like beetles, wasps, moths, bees, etc. and a popular ingredient in commercial insecticides because of low persistence in the environment and low mammalian toxicity.

In Gymnosperms (conifers) like Pine and Fir, monoterpenes accumulate in resin ducts found in the needles, twings and trunks mainly as α-pinene, β-pinene, limonene and myrecene, all are toxic to numerous insects including bark beetles, serious pest of conifer species throughout the world.

(b) *Sesquiterpenes*(C15):A number of sesquiterpenes have been till now reported for their role in plant defence such as costunolides are antiherbivore agents of family composite characterized by a five membered lactone ring (a cyclic ester) and have strong feeding repellence to many herbivorous insects and mammals.

(c) *Diterpenes*(C20):Abietic acid is a diterpene found in pines and leguminous trees. It is present in or along with resins in resin canals of the tree trunk. When these canals are pierced by feeding insects, the outflow of resin may physically block feeding and serve as a chemical deterrent to continued predation.

Another compound phorbol (diterpene ester), found in plants of Euphorbiaceae and work as skin irritants and internal toxins to mammals**.**

(d) *Triterpenes*(C30):Several steroid alcohols (sterols) are important component of plant cell membranes, especially in the plasma membrane as regulatory channels and maintain permeability to small molecules by decreasing the motion of the fatty acid chains.

The milkweeds produce several better tasting glucosides (sterols) that protect them against herbivoryby most insects and even cattle.

Phytoecdysones have some defensive role against insects by disrupting moulting and other developmental and physiological processes with lethal consequences.

Another triterpene, limnoid, a group of bitter substances in citrus fruits and act as antiherbivore compounds in members of family-Rutaceae and some other families also. For example, Azadirechtin, a complex limnoid from *Azadirachtaindica*, acts as a feeding deterrent to some insects and exerts various toxic effects.

(e) *Polyterpenes*(C5):Several high molecular weight polyterpenes occur in plants. Larger terpenes include the tetraterpenes and the polyterpenes.

The principal tetraterpenes are carotenoids family of pigments. Other one is rubber, a polymer containing 1500-15000 isopentenyl units, in which nearly all the C-C double bonds have a cis (Z) configuration while in gutta rubber has its double bond in trans (E) configuration. Rubber found in long vessels called laticifers, provide protection as a mechanism for wound healing and as a defence against herbivores.

1.1.1.2 Phenolic compounds

Plants produce a large variety of secondary products that contain a phenol group, a hydroxyl functional group on an aromatic ring called Phenol, a chemically heterogeneous group also. They could be an important part of the plants defence system against pests and diseases including root parasitic nematodes.

(a) *Coumarin*:They are simple phenolic compounds, widespread in vascular plants and appear to function in different capacities in various plant defence mechanisms against insect herbivores and fungi.

They derived from the shikimic acid pathway, common in bacteria, fungi and plants but absent in animals. Also, they are a highly active group of molecules with a wide range of anti-microbial activity against both fungi and bacteria.

It is believed that these cyclic compounds behave as natural pesticide defence compounds for plants and they represent a starting point for the exploration of new derivatives possessing a range of improved antifungal activity.

Halogenated coumarin derivatives work very effectively *in vitro* to inhibit fungal growth. For example, 7-hydroxylated simple coumarins may play a defensive role against parasitism of *Orobanchecernua*, by preventing successful germination, penetration and connection to the host vascular system. Some coumarin derivatives have higher anti-fungal activity against a range of soil borne plant pathogenic fungi and exhibit more stability as compared to the original coumarin compounds alone.

(b) *Furano-coumarins*:Also a type of coumarin with special interest of phyto-toxicity, abundant in members of the family Umbelliferae including celery parsnip and parsley. Normally, these compounds are not toxic, until they are activated by light (UV-A), causes some furano-coumarins to become activated to a high energy electronic state, which can insert themselves into the double helix of DNA and bind to the pyramidine bases and thus blocking transcription and repair and eventually leading to cell death.Psoralin, a basic linear furacoumarin, known for its use in the treatment of fungal defense and found very rarely in SO_2 treated plants.

(c) *Ligin*:It is a highly branched polymer of phenyl-propanoid groups, formed from three different alcohols viz., coniferyl, coumaryl and sinapyl which oxidized to free radicals (ROS) by a ubiquitous plant enzyme-peroxidase, reacts simultaneously and randomly to form lignin. The reactive proportions of the three monomeric units in lignin vary among species, plant organs and even layers of a single cell wall. Its physical toughness deters feeding by herbivorous animals and its chemical durability makes it relatively indigestible to herbivores and insects pathogens. Lignifications block the growth of pathogens and are a frequent response to infection or wounding.

(d) *Flavonoids*:One of the largest classes of plant phenolic, perform very different functions in plant system including pigmentation and defence. Two other major groups of flavonoids found in flowers are flavones and flavonols function to protect cells from UV-B radiation because they accumulate in epidermal layers of leaves and stems and absorb light strongly in the UV-B region, while letting visible (PAR) wavelengths throughout uninterrupted. In addition, exposure of plants to increased UV-B light has been demonstrated to increase the synthesis of flavones and flavonols suggesting that flavonoids may offer a measure of protection by screening out harmful UV-B radiation.

(e) *Isoflavonoids*:Isoflavonoids are derived from a flavonone intermediate, naringenin, ubiquitously present in plants and play a critical role in plant developmental and defence response. They secreted by the legumes and play an important role in promoting the formation of nitrogen-fixing nodules by symbiotic rhizobia. Moreover, it seems that synthesis of these flavonoids is an effective strategy against reactive oxygen species (ROS).

(f) *Tanins*:It included under the second category of plant phenolic polymers with defensive properties. Most tanninhas molecular masses between 600 and 3000. Tannins are general toxins that significantly reduce the growth and survivorship of many herbivores and also act as feeding repellents to a great diversity of animals.

In mammalian herbivores, they cause a sharp, astringent sensation in the mouth as a result of their binding of salivary proteins. Mammals such as cattle, deer and apes, characteristically avoid plant with high tannin contents. The defensive properties of tannins are generally attributed to their ability to bind proteins. Protocatechllic and chlorogenic acids probably have a special function in disease resistance of certain plants. They prevent smudge in onions, a disease caused by the fungus *Colletotrichumcircinans*and prevent spore germination and growth of other fungi as well. It is thought by some that chlorogenic acid and certain other related compounds can be readily formed and oxidised into potent fungi static quinones by certain disease resistant cultivars but less readily so by susceptible ones.

1.1.1.3 Sulphur containing secondary metabolites

They include GSH, GSL, phytoalexins, thionins, defensins and allinin which have been linked directly or indirectly with the defence of plants against microbial pathogens and a number of them thought to be involved in the SIR.

(a) *GSH*:It is one of the major forms of organic S in the soluble fraction of plants and has an important role as a mobile pool of reduced S in the regulation of plant growth and development, and as a cellular anti-oxidant in stress responses.

GSH is rapidly accumulated after fungal attack, may act as systemic messenger carrying information concerning the attack to non-infested tissues.

(b) *GSL*:A group of low molecular mass N and S containing plant glucosides that produced by higher plants in order to increase their resistance against the unfavourable effects of predators, competitors and parasites because their break down products are release as volatiles defensive substances exhibiting toxic or repellent effects.

In studies of crosses of *Brassica* lines with different glucosinolate level resistance to fungal attacks failed to correlate with high and low glucosinolate level.

(c) *Phytoalexins*: Phytoalexins are synthesized in response to bacterial or fungal infection or other forms of stress that help in limiting the spread of the invading pathogens by accumulating around the site of infection, appears to be a common mechanism of resistance to pathogenic microbes in a wide range of plants.

Typically, there are multiple responses involving several related derivatives such as up to nine wyerone (Furano-acetylenic derivatives) forms in *Vicia fava* and several forms of phaseollin in *Phaseolus vulgaris* and glyceollins in *Glycine max*, pistin in *Pisumsativum*pods, ipomeamarone in sweet potato, orchinol in orchid tubers, trifolirhizin in red clover.

(d) *Defensins, thionins and lectins*:All these are S-rich non-storage plant proteins synthesize and accumulate after microbial attack and such related situations. All of which inhibits the growth of a broad range of fungi. Some defensins are antifungal or occasionally anti-bacterial activity. Additionally defensins genes are partly pathogen-inducible and others that are involved in resistance can be expressed constitutively.

The components seem to be involved in the natural defence system of plants as they can be highly toxic to microorganisms, insects and mammals. Accumulation of thionins in the cell wall of infected wheat spikes of resistant wheat cultivars indicating that the accumulation of thionins may be involved in defence responses to infections and in spreading of *Fusariumculmorum.*

Some plant species produce lectins as defensive proteins that bind to carbohydrate or carbohydrate containing proteins. After being ingested by herbivores, lectins bind to epithelial cell lining of the digestive tracts and interfere with nutrient absorption.

1.1.1.4 Nitrogen containing secondary metabolites

They include alkaloids, cyanogenicglucosides, and non-protein amino acids. Most of them are biosynthesized from common amino acids. All are of considerable interest because of their role in the anti-herbivore defence and toxicity to humans.

(a) *Alkaloids*:A large family of N containing secondary metabolites found in approximately 20 per cent of the species of vascular plants, most frequently in the herbaceous dicot and relatively a few in monocots and gymnosperms. Generally, most of them, including the pyrrolizidine alkaloids (PAs) are toxic to some degree and appear to serve primarily in defence against microbial infection and herbivoral attack. They are usually synthesized from one of the few common amino acids, in particular, aspartic acid, lysine, tyrosine and tryptophan. Now most alkaloids are believed to function as defensive elements against predators, especially mammals because of their general toxicity and deterrence capability.

(b) *Cyanogenicglucosides*:They constitute a group of N-containing protective compounds other than alkaloids, release the poison HCN and usually occur in members of families*viz.*, Graminae, Rosaceae and Leguminosae. They are not in themselves toxic but are readily broken down to give off volatile poisonous substances like HCN and H_2S when the plant is crushed; their presence deters feeding by insects and other herbivores such as snails and slugs.

Amygdalin, the common cyanogenicglucoside found in the seeds of almonds, apricot, cherries and peaches, while Dhurrin, found in *Sorghum bicolar*. Normally, both are not broken down in the intact plant because the glucosides and degradative enzymes are separated in different compartments.

Under ordinary conditions, this compartmentalization prevents decomposition, however, on damaging as during herbivore feeding, the cell contents of different tissues mix and form HCN, a toxin of cellular respiration by binding to the Fe-containing heme group of cytochrome oxidase and other respiratory enzymes.

Similarly, the presence of cyanogenicglucosides in cassava, make it suitable for long time storage without being attacked by pests.

(c) *Non-protein amino acids*:Many plants also contain unusual amino acids called non- protein amino acids that incorporated into proteins but are present as free forms and act as protective defensive substances. For examples, canavanine and azetidine-2-carboxylic acid are close analogs of arginine and proline respectively. They exert their toxicity in various ways. Some block the synthesis of or uptake of protein amino acid while others can be mistakenly incorporated in to proteins. After ingestion, canavanine is recognized by herbivore enzyme that normally binds arginine to the arginine transfer RNA molecule and so become incorporated in to proteins in place of arginine. The usual result is a non-functional proteins because either its tertiary structure or it catalytic site is disrupted.

Plants that synthesize non-protein amino acids are not susceptible to the toxicity of these compounds but gain defence to herbivorous animals, insects and pathogenic microbes. Also, a number of plants including Arabidopsis use Arginine as storage and transport form of N and proline as a compatible solute in the defence against abiotic stresses causing water deprivation.

1.2 Mechanism of Secondary Metabolites Action

Flavonoids and phenylpropanoids are widely distributed in plants and exhibit differentmode of action against the pathogens. It is interesting to know that hundreds ofclinical antifungal drugs in use, target only 6 different processes. Mostly they act asanalogues of cellular signal compounds or substrates. They affect various physiologicalprocess and the parts of the pathogens like biomembranes, enzyme inhibition,estrogenic properties and DNA alkylation. These molecules usually haveseveral phenolic hydroxyl groups in common, which can dissociate in negativelycharged phenolate ions. Phenolic hydroxyl groups form hydrogen and ionic bondswith proteins and peptides. The higher the number of hydroxyl groups, the strongerthe astringent and denaturing effect.

Proteins can only work properly if they have the correct three-dimensionalstructure, called conformation. Conformational changes alter their properties andcan prevent effective crosstalk between proteins, and between proteins and DNA orRNA. Most secondary metabolites interact with proteins in one or another way bybinding, complexing, denaturing, thereby changing protein conformations.

Mostsecondary metabolites form covalent bond with protein, often by binding to freeamino-, SH- or OH- groups, e.g., phenylpropanoids binds to amino groups, SHreagents and epoxides couple to free SH groups. The covalent modification can leadto a conformational change and thus loss of activity; or protein turnover is alteredbecause proteases can no longer break down the alkylated protein. Polyphenols(phenylpropanoids, flavonoids, catechins, tannins, lignans, quinines, anthraquinones)interact with proteins by forming hydrogen bonds and the much stronger ionicbonds with electronegative atoms of the peptide bonds and or the positively chargedside chains of basic amino acids (lysine, histidine, arginine). A single of these non-covalentbonds is quite weak. But because several of them are formed concomitantlywhen a polyphenols encounters a protein, a change in protein conformationor a loss in protein flexibility is likely to occur that commonly leads to protein inactivation.Since most polyphenols are quite polar and therefore, hardly absorbed afteroral intake, they are usually not regarded as serious toxins.

2. The mechanisms of ozone and UV damage and tolerance in plants

Ozone is known to be the most widespread phytotoxic air pollutant. Ozone causesvisible injury, reductions in photosynthesis, growth, and yield. Plant response to ozonemay vary with species, varieties, and physiological age. Comparison between sensitiveand tolerant cultivars has a key role in assessing ozone damage, investigating the sitesof cellular injury, and identifying ozone tolerance mechanism.

2.1 Ozone damage

Ozone (O_3) is considered to be the most phytotoxic among common air pollutants. As a secondary pollutant, ozone is formedby photolysis of nitrogen dioxide (NO_2) via a series of complex photochemicalreactions.

Plant damage from ozone is most severe during thesummer when maximum solar radiation occurs and plant growth is rapid. Adverseeffects of ozone on plants include foliar symptoms such as, bronzing, chlorosis, bifacialnecrosis, stipple, or fleck. Foliar injury develops differently depending on plant species, genetic varieties, and age.

Current ambient levels of ozone are reported to be highenough to cause chronic damage such as reduced photosynthesis and prematuresenescence, ultimately impairing plant growth, reducing crop yields and altering geneticcomposition of native plant communities.

Decreased photosynthesis intrees due to long-term ozone exposure can contribute to forest decline.The depression in net photosynthesis caused by ozone has been attributed toboth limitation in stomatal conductance and to changes in mesophyll activity involvedwith CO_2 fixation.Ozone causes significant changes in theprimary photosynthetic reactions. A major effect of ozone includes a lowered PSIIquantum yield which reflects a correspondingly reduced PSII electron transport rate andreduced CO_2 assimilation.

Ozone is taken into the leaf viathe stomata where it interacts with apoplasticcomponents as well as the plasma membrane, and alters physiological function. Membranes are the primary site of ozone interaction due to the susceptibility ofmembrane-bound molecules to ozone. It has been suggested that once ozone enters theleaf by diffusion through stomata, it is rapidly decomposed by a series of reactions inthe cell walls and plasma membrane, leading to the production of reactive oxygenspecies, such as hydroxyl, peroxy, and superoxide radicals. However, it is still unclear whether the effects of ozoneon net photosynthesis are based on direct oxidative damage within the chloroplast, orare a result of a signal produced from outside the chloroplast.

Ozone can also induce subtlephysiological and biological changes that alter plant responses to a range of other bioticand abiotic stresses. Those changes may be asimportant as the direct effects of ozone.

Ozone affects agricultural crop yield and to causereductions in growth and biomass of forest tree species in remote and mountainousareas due to long-distance transport.Currentambient ozone concentrations are high enough to reduce yield in major agriculturalcrops, and as predicted levels are likely to increase, the loss to agriculture will be greater.Production of important crops,particularly wheat and soybeans, is reduced substantially, and crop losses of 5-10 per cent.

2.1.1. Mechanism of tolerance in plants

An extensive investigation of crop loss due to ambient ozone with 15 major annual crops, including corn, soybean, cotton, forage, tomato, turnip, wheat, andbarley, revealed yield depressions in 14 out of 15 crops. Losses attributed toozone ranged from less than 1 per cent in barley to as much as 20 per cent in soybean. Susceptibility to ozone varies from species to species, and even among cultivarsof a single species.

Comparison between sensitive and tolerant cultivars has been usedfor 30 years to assess ozone damage and to investigate the possible mechanisms. Some studies showed stomata closure, avoiding ozone uptake and ozone-induced antioxidant defence systems.

Several mechanisms that may be responsible for ozonetolerance have been put forth. Lower stomatal conductance of tolerant species results ina reduction in ozone uptake, and an increase in respiration rate and/or in antioxidantsmay help prevent and/or repair ozone damages

Most studiesexamining ozone sensitivity and tolerance have focused on observing visible injurydifferentially represented by cultivars. A few studies have reported on the relationbetween inhibition of photosynthesis caused by ozone and its direct effect on stomatalclosure and/or on changes in photosynthetic capacity at the mesophyll level.

The tobacco variety *Bel-W3* (*Nicotianatabacum* L.)has been used as an indicator of ozone for decades since it is extremely sensitive to ozone. This cultivar develops easily recognizable visible symptoms. The tobacco variety Bel-Bis relatively ozone tolerant and it is often used with Bel-W3 to compare ozone-induceddamage. 2 to 3 hours exposure to 0.05 to 0.06ppm of ozone was enough to cause visible symptoms in Bel-W3. Ozone -induced foliarinjury on Bel-W3 consists of bifacial necrosis, however, in Bel-B ozone-induceddamage is typically upper surface flecking.

Thesensitivity to ozone increases as relative humidity and growth temperature increases.These environmental conditions affecting ozone sensitivity are closelyrelated tostomatalbehaviour.

Several studies have attempted to definethe relationship between visible ozone symptoms and growth losses. However, ozoneexposure/tree-response relationships have not been established clearly since ozonesensitivity is affected by species, tree developmental stage, microclimate, and the abilityto compensate for injury through enhanced leaf production, and alteration in carbonpartitioning and allocation.Using these sensitive species as bio-indicators can assist in determiningpresence of ozone in a given area.

2.2 Mechanisms of Ozone and UV damage and tolerance in plants

Photosynthetic organisms need sunlight and are, thus, inevitably exposed to UV radiation. This constitutes three categories on the basis of wavelength band ranges (namely, UV-A, 315–400nm; UV-B, 280–315nm;

and UV-C, 100–280nm), though only wavelengths greater than 290nm can reach the earth's surface.

The ozone layer, at an altitude of 15–35km (stratospheric ozone), effectively absorbs the wavelength of some range of UV-B, and all UV-C rays. While most of the UV-B light is absorbed by the ozone layer, some can penetrate through it into the atmosphere. Ozone layer thinning has resulted in an increase of UV-B radiation on the earth's surface, which has been recognized as one of the serious global environmental problems, and surface UV-B radiation will continue to increase in the next few decades. Terrestrial UV-B levels are influenced by solar peak angle, latitude, altitude, unevenness in cloud cover, time of the day and season of the year, shade, aerosols and surface reflectivity.UV-A and UV-B represent approximately 6 per cent and 0.15 per cent, respectively of the energy in solar radiation at surface level.

About two-thirds of more than 300 species and cultivars tested appear to be susceptible to damage from increase UV-B radiation. The importance of solar angle, atmospheric turbidity, elevation above the sea level, cloud cover, total atmospheric ozone column, and UV albedo of the earth's surface with respect to the total UV irradiation intensity and wavelength composition should be considered in UV radiation natural environments. Though not all the respondents demonstrated as the result of UV radiation are considered as damaging or disadvantageous for the plant the majority of evidence indicate the UV irradiation is usually detrimental, particularly UV-B irradiation. The growth of many plant species is reduced by enhanced levels of UV-B radiation.

Solar UV radiation penetrates to ecologically significant depths in aquatic systems, and can affect both marine and freshwater systems, from major biomass producers (phytoplankton) to consumers (e.g. zooplankton, fish, etc.) higher in the food web.

Solar UV radiation is of particular importance because a number of plant biomacromolecules, including DNA, RNA, lipids and proteins, absorb in this region of the UV spectrum. Furthermore, UV-B photons have the highest energy of all wavelengths in sunlight and, hence, the potential to cause cellular damage through photochemical reactions.

The effect of UV-B enhancement on plants include reduction in yield and quality, alteration in species competition, decrease in photosynthetic activity, susceptibility to disease and changes in plant structure and pigmentation.

A variety of ecological processes have often been classified into direct and indirect effects. Current exposure of UV which affects/alter the normal mechanism of an organism is called a direct effect – that is, some plant diseases can be minimized by UV exposure, as it kills the fungal spores which infect the plants. Indirect effects can be categorized as whenever UV tolerant plants also become tolerant to certain plant diseases, ultimately leading to disease-resistant plants. Disease resistance in plant persists in plants for a longer time if there is no exposure to UV light, because of the adaptation of plants to UV radiation.

It includes effects owing to altered plant chemistry and changes in tissues not directly exposed to radiation. Increases in UV-B radiation can damage many organisms, but the effects of solar UV on many ecological processes also depend on the use of UV-B and UV-A by microbes, plants and animals as a source of information about their environment

2.2.1 UV-B Avoidance and Defence Mechanism:

Avoidance means bypassing any aspect related to a given condition. Plants use certain signalling mechanisms to enhance avoidance at morphological, physiological, biochemical and molecular levels. They show adaptation to environmental stresses, sometimes referred to as ‘plant memory’. There is growing evidence that plants memorize exposure to biotic or abiotic stresses through epigenetic mechanisms at the cellular level.

UV-B radiation is a key environmental signal that is specifically perceived by plants to promote UV acclimation and survival in

Designed and developed under the aegis of NAHEP Component-2 Project “Investments In ICAR Leadership In Agricultural Higher Education”
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

sunlight.Plants are able to sense UV-B through the UV-B photoreceptor UVR8. UV-B photon absorption by a UVR8 homodimer leads to UVR8 monomerization, and interaction with the downstream signalling factor COP1. High UV-B levels will trigger signalling responses that contribute to acclimation and plant survival.

Scattering and reflection of UV-B radiation is achieved by epidermal and cuticular structures, and other leaf optical properties such as waxy layer, leaf hairs and leaf bladders.

UV-B radiation is absorbed by pigments (flavonoids, anthocyanins), particularly in the epidermal cells, photoreactivation enzymes (photolyases). Monomerization of dimers formed by the DNA-absorption of UV-B photons (photo repair) is a rapid process, but it needs sufficient PAR. Excision repair of DNA damage caused by UV-B radiation is a slow process, and also occurs in the dark.

Free radicals formed by absorption of UV-B photons are scavenged by superoxide dismutase (SOD) and catalase. Flavonoids are also involved in neutralizing radicals.

Polyamines may ameliorate UV-B damage to membranes. A relationship between acclimation and UV response of plants can be evaluated, as acclimation to UV-B involves a combination of protective, as well as repair, measures. These include the accumulation of UV-B-absorbing ‘sunscreen’ metabolites in the vacuoles of epidermal cells, increased levels of antioxidants, protection of the photosynthetic apparatus, and increased levels of DNA repair enzymes.

2.2.1.1 Avoidance at Morphological Level:

Leaf morphological and anatomical changes, such as increased epicuticular wax content, increase in cuticle thickness, wider epidermis and palisade layers, are some of the modifications plants employ to avoid UV-B exposure.

a.***Epicuticular Waxes*:**

Plants, in general, possess a suite of mechanisms that act either to prevent absorption of damaging and excess radiation or to mitigate against the damage that such radiation can cause once it is absorbed. An epicuticular wax layer is an important leaf surface character that responds to environmental stresses and acts as an interface between environment and leaf internal structures, providing the first line of defence.

Increased wax provides protection by reflecting 10–30 per cent of the incident UV-B radiation in many plants. Enhanced UV-B radiation not only alters the quantity, but also the chemical composition of leaf surface wax that modifies leaf reflectance of UV-B.

2.2.1.2 Avoidance at Biochemical Level:

Possible Role of Pectin Endocytosis in UV-B Avoidance: Polygalacturonic acid and galacturonic acid are reported to generate superoxide upon UV-B irradiation in the presence of hydrogen peroxide. The superoxide anion radical was observed in vitro by using the isolated cell wall from *Pisumsativum* leaves with the electron paramagnetic resonance method.In root cells, pectin is a major component of the polygalacturonic acid cell wall. Pectin, crosslinked with boron and calcium, has been shown to be internalized and transported by endocytosis.

Furthermore, D-galacturonic acid, released by the degraded cell wall, is known to be re-utilized, not only for forming new cell wall, but also as a substrate of L-ascorbic acid biosynthesis.

L-ascorbic acid is well known as a reducing agent, controlling cellular redox homeostasis via glutathione-ascorbate cycle. It is reasonable to expect the importance of crosslinked cell wall pectin for ROS homeostasis, because UV-B easily breaks down cell wall components, and this might act as a cue for the ascorbate biogenesis at irradiated organ sides, in order to recover the cellular redox balance. Of course, internalized cell wall pectin within endocytic vesicles and endosomes might also be a potential source for the L-ascorbate synthesis.

2.2.1.3 Avoidance at the Molecular Level

DNA Repair:The repair of DNA damage is essential for the survival of organisms, otherwise genomic integrity will not be maintained. To this end, coordination between DNA replication and repair has been considered essential for the maintenance of the genome. UV radiation-induced DNA damage and repair has been well studied, but information on the underlying mechanisms in plant system is still lacking. DNA repair is performed in two conditions:

1) In light conditions, photoreactivation catalyses dimer monomerizations.

2) During dark conditions, nucleotide excision repair (NER) excises helix-distorting lesions, and base excision repair (BER) repairs oxidized or hydrated bases.

2.2.1.4 Genes and Avoidance:

The UV-B specific signalling components orchestrate plant protection against UV-B irradiation. The UV-B photomorphogenic pathway promotes photomorphogenic responses characterized by the inhibition of hypocotyl growth, cotyledon expansion, and stomatal opening. UV Resistance Locus 8 (UVR8) is a key photoreceptor of the photomorphogenic pathway, regulating a range of genes with important roles in UV protection and the repair of UV damage.

The UVR8-COP1-HY5 pathway initiates with UV-B perception by UVR8 in cytosol, further initiating a signalling cascade principally involving a bZIP transcription factor (HY5) and E3 ubiquitin ligase (COP1) in the nucleus.

Different responses mediated by the pathway involve hypocotyl growth inhibition, stomatal closure, phototropic bending and leaf development inhibition of shade avoidance, and osmotic stress and pathogen responses. To balance the UV-B response, a negative feedback loop involves the action of the Repressor of UV-B Photomorphogenesis (RUP) 1 and 2 gene, induced by UV-B through UVR8. UV-B Perceived by UVR8 Strongly Inhibits Shade Avoidance In plants, UV-B is perceived by the photoreceptor protein UVR8. Along with regulating photoprotective responses, UV-B dramatically inhibits stem elongation. When grown in dense stands, plants use reflected far-red light signals from neighbours to detect the threat of shading. In many species, these signals drive rapid elongation responses to overtop competitors. UV-B perceived by UVR8 provides a potent sunlight signal that inhibits shade avoidance. UVR8 activation stimulates multiple pathways that converge to block biosynthesis of the plant growth hormone auxin. Understanding how UV-B regulates plant architecture is central to our understanding of plant growth and development in sunlight. During emergence from the soil, seedlings are exposed to a drastic step change in UV-B and, afterwards, acclimation adjustment depends on gradual changes in UV-B. Therefore, after emergence, for plants growing in sunlight, long-term acclimation is the most important response for coping with UV exposure.

Glossary:

Chemical defences: It include a variety of substances that are toxic, repellent, or that render plant tissues indigestible to animals

Ozone: Ozone is known to be the most widespread phytotoxic air pollutant.

Primary metabolites: metabolites which are involved in the physiological functions.

Secondary metabolites: Secondary metabolites are the molecules that appear to be dispensable for normal growth, or are required only under particular conditions. These secondary products are the key components of active and potent defence mechanisms in plants. They are the active part of the chemical war between plants and their pathogens.

UV radiation: The Ultraviolet (UV) radiation is defined as that portion of the electromagnetic spectrum between X rays and visible light, i.e., between 40 and 400 nm (30–3 eV).

Reference:

Mazid M, Khan TA, Mohammad F.(2011).Role of secondary metabolites in defense mechanisms of plants. *Biology and Medicine, 3 (2) Special Issue: 232-249,* eISSN: 09748369.

Sunil K Gupta, Marisha Sharma, Farah Deeba and Vivek Pandey (2017)Plant response: UV- B avoidance mechanisms. UV-B Radiation: *Environmental Stressor to Regulator of Plant Growth*. John Wiley & Sons Limited, Chichester, West Sussex, UK.

Tadamasa Ueda and Chiharu Nakamura (2011) Ultraviolet-Defense Mechanisms in Higher Plants, *Biotechnology & Biotechnological Equipment,* 25:1, 2177-2182, DOI: 10.5504/BBEQ.2011.0001.

Ulm, R., Jenkins, G.I. Q&A: How do plants sense and respond to UV-B radiation?. *BMC Biol* **13,** 45 (2015). https://doi.org/10.1186/s12915-015-0156-y

Course Name	Agro-meteorology and climate change
Lesson 13	Increased temperature and plants in tropical/sub-tropical climates- Effect on growing season, timing of flowering, duration of fruit development and impacts on crop yields and potential species ranges
Content Creator Name	Vallal Kannan Sankaralingam
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	Dr. Vijay Gopal More
University/College Name	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Lesson 13

Objectives:

- To understand the temperature stress on tropical and sub-tropical plants
- To empower knowledge on effect of temperature on growing season, timing of flowering, duration of fruit development and impacts on crop yields
- To understand the influence of temperature on potential species ranges.

1. Increased temperature and plants in tropical and sub-tropical climate:

Climate change, biotic and abiotic stress affects agriculture, horticultural and crop production adversely. Among the various climatic factors affecting agriculture and horticulture, temperature is one of the most important as higher temperature adversely affects plant growth and yield.

Abiotic stresses are stress produced by natural factors such as extreme temperatures, wind, drought and salinity. Man does not have much control over abiotic stresses. Preventive measures are the only way that humans can protect themselves and their possessions from abiotic stress.

1.1Heat stress.

Heat stress is often defined as the rise in temperature beyond a threshold level for a period of time sufficient to cause irreversible damage to plant growth and development.

In general, a transient elevation in temperature, usually 10-15^{0}C above ambient is considered as heat stress. A sudden long temperature increase could cause damage to the plant because their cells and receptors have not had enough time to prepare for a major temperature change. Heat stress can also have a detrimental effect on plant reproduction.

Temperature 10^0C or more above normal growing temperature can have abad effect on several plant reproduction functions. Pollen meiosis, pollen germination, ovule development, ovule viability, development of embryo, and seedling growth are all aspects of plant production that are affected by heat. However, heat stress is a complex function of intensity, duration, and rate of increase in temperature. Heat stress due to high ambient temperatures is a serious threat to crop production worldwide.

At moderately high temperatures, death may occur only after long term exposure.

Direct injuries due to high temperatures include protein denaturation and aggregation and increased fluidity of membrane lipids.

Indirect heat injuries include inactivation of enzymes in chloroplast and mitochondria, inhibition of protein synthesis, protein degradation and loss of membrane integrity.

Heat stress also affects the organization of microtubules by splitting and elongation of spindles, formation of microtubule asters in mitotic cells and elongation of phragmoplast microtubules.

1.1.1Heat stress threshold temperatures for some major crop species.

A threshold temperature refers to a value of daily mean temperature at which a detectable reduction in growth begins. Upper and lower developmental threshold temperature have been determined for many plant species through controlled condition.A lower developmental threshold or a base temperature is one below which plant growth and development stop. Similarly, an upper developmental threshold is the temperature above which growth and development cease. Upper threshold temperatures differ for different plant species and genotypes within species.

Table-1Threshold level of temperature for major crops

Crops	Threshold level(^{0}C)	Stage of the crop
Rice	34	Grain filling
wheat	26	Post anthesis
corn	38	Grain filling
Cotton	45	Reproductive
Pearl millet	35	Seedling
Tomato	30	Emergence
Brassica	29	Flowering
Cool season pulses	25	Flowering
Groundnut	34	Pollen production
Cowpea	41	Flowering

In tomato, when the ambient temperature exceeds 35^{0}C, its seed germination, seedling and vegetative growth, flowering and fruit set and fruit ripening are adversely affected.

High temperature sensitivity is particularly important in tropical and sub tropical climates as heat stress may become a limiting for field crop production.

1.2. Plant response to heat stress

1.2.1.Morphological symptoms:

Tropical climates, excessive radiation and high temperatures are often most limiting factors affecting plant growth and final crop yield. High temperatures can cause considerable pre-and post-harvest damages like scorching of leaves and twigs, sunburns on leaves, branches and stems, leaf senescence and abscission, shoot and root growth inhibition, fruit discoloration and damage and reduced yield.

Heat temperature induced modification in plants may be direct as on existing physiological process or indirect in altering the pattern of development. Long term effects of heat stress affects development of seeds, delayed seed germination, loss of vigor, ultimately leading to reduced emergence and seedling establishment. High temperatures caused significant declines in shoot dry mass, relative growth rate and net assimilation rate. The most noticeable effect of high temperatures on reproductive processes in tomato is the production of an exerted style (stigma is elongated beyond the anther cone), which prevents self-pollination. Poor fruit set at higher temperature has also been associated with low levels of carbohydrates and growth regulators released in plant sink tissues.

1.2.2 Anatomical change

Anatomical changes under high temperatures are generally similarly to drought stress. At whole plant level, there is a general tendency of reduced cell size, closure of stomata, curtailed water loss, increased stomatal and trichomatous densities and greater xylem vessels in shoot and root. At sub cellular level, modification occurs in chloroplasts, leading to significant changes in photosynthesis.

Studies have revealed that specific effects of high temperature on photosynthetic membranes result in the loss of grana stacking or its swelling. In grape, response to heat stress, chloroplasts in the mesophyll cells become round in shape, stroma lamellae became swollen and the contents of vacuoles formed clumps, whilst the cristae were disrupted and mitochondria became empty resulted in reduced photosynthetic and respiratory activities.

High temperature affects anatomical structures at the tissue and cellular levels andalso in the sub cellular level.

1.2.3 Physiological responses to high temperature stress in plants

1.2.3.1 Water relations:

The decreased in relative water content in stressed plants and decreased in plant vigour. It was generally observed that the higher the leaf water potential and relative water content, the higher was the photosynthetic rate. Plants tends to maintain stable tissue water status regardless of temperature when moisture is ample, however, high temperature severely impair the water level when water is limiting. High temperature stress is frequently associated with reduced water availability.

In Tomato, heat stress perturbed the leaf water relations and root hydraulic conductivity due to enhanced transpiration during day time induces water deficiency in plants, leads to decrease in water potential and leading to perturbation of many physiological processes.

1.2.3.2 Accumulation of compatible osmolytes in the plants

Under stress, different plant species may accumulate a variety of osmolytes such as sugars and sugar alcohols(polyols), proline, tertiary and quaternary ammonium compounds and tertiary sulphonium compounds which may contribute to enhanced stress tolerance to plants.

Under high temperatures, fruit set in tomato plants failed due to the disruption of sugar metabolism and proline transport during the narrow window of male reproductive development.

1.2.3.3 Photosynthesis, chloroplasts and chlorophyll pigments

Any constraint in photosynthesis can limit plant growth at high temperatures. Photochemical reactions in thylakoid lamellae and carbon metabolism in the stroma of chloroplast have been suggested as the primary sites of injury at higher temperatures.

Chlorophyll fluorescence, the ratio of cariable fluorescence to maximum fluorescence and the base fluorescence are physiological parameters have been shown to correlate with heat tolerance.

An increased chlorophyll a:b ratio and decreased chlorophyll:carotenoids ratio was observed in tolerant genotypes of tomato under high temperatures indicating that these changes related to thermo tolerance of tomato.

Degradation of chlorophyll a and b was more pronounced in developed compared to developing leaves under higher temperature. Recent studies have revealed that carotenoids of xanthophylls family and other terpenoids- isoprene or tecopherol, stabilize and photoprotect the lipid phase of the thylakoid membranes.

Phenolics (flavonoids, anthocyanins, lignins) are the most important class of secondary metabolites in plants and play a variety of role in tolerance to abiotic stress.

PSII is highly thermolabile and its activity is greatly reduced or even partially stopped under higher temperatures.

Heat stress reduces the amount of photosynthetic pigments, soluble proteins, rubisco binding proteins (RBP) and large sub units and small sub units of rubisco in darkness but increase them in light.

Stomatal conductance and net photosynthesis are inhibited by moderate heat stress in many plant species due to decrease in the activation state of rubisco. Rate of biochemical reactions decreases and enzyme inactivation and denaturation take place as the temperature increases leading to severely reduced photosynthesis.

1.2.3.4 Hormonal changes in plants at high temperature stress:

Cross talk in hormone signalling reflects an organism ability to integrate different inputs and respond appropriately. Hormonal haemostasis, stability, content, biosynthesis and compartmentalisation are altered under heat stress. Abscisic acid and ethylene as stress hormones are involved in the regulation of may physiological properties by acting as signal molecules. High temperature results in increased levels in ABA.

Ethylene production affected differently in different plant species due to heat stress. Temperature up to 35 ^{0}C has been shown to increase ethylene production and increase in the level of ACC was positively correlated with high temperatures.

Among other hormones, salicylic acid has been suggested to be involved in heat stress responses elicited by plants.

The effects of gibberellins and cytokinins on higher temperature tolerance are opposite to that of ABA.

Brassinosteroids have recently been shown to confer thermotolerance to tomato and oil seed rape.

1.2.3.5 Molecular and genetic response to heat stress:

1.2.3.5.1*Oxidative stress and antioxidants:*

In addition to tissue dehydration, heat stress may induce oxidative stress. Generation and reactions of activated oxygen species incudes singlet oxygen, superoxide radical, hydrogen peroxide and hydroxyl radical are symptoms of cellular injury due to high temperatures.

Decreased in antioxidant activity in stressed tissues results in higher levels of AOS that may contribute to injury.

1.2.3.5.2*Proteins in plants:*

Heat shock proteins (Hsps) and other stress proteins have been known to protect cells against deleterious effects of stress. The major stress proteins occur at low to moderate levels in cells that have not been stressed but accumulate to very high levels in stressed cells. Hsps are induced when the temperature is raised to 29-38 ^{0}C and above, but maximum response is observed at 36-37^{0}C. As long as cells are maintained at high temperatures, hsps continue to be the primary products of protein synthesis, when cells are returned to normal temperatures normal protein synthesis gradually resumes, the timing a reflection of the severity of the preceding heat shock.

1.2.3.5.3Other proteins

Besides, HSPs, there are a number of other plant proteins, ubiquitin,cytosolic Cu/Zn-SOD and Mn-Pod, whose expression are stimulated upon heat stress. In, *Chenopodium murale,* when leaf protein extracts from thylakoid and stromal fractions were subjected to heat stress. Cu/Zn-SOD level was more in heat tolerant than Cu-Zn-SOD from thylakoid and responsible for chloroplastic stability under heat stress.

2. Increased temperature effect on growing season, timing of flowering, duration of fruit development and impacts on crop yields and potential species ranges.

The effects of temperature extremes on the plant could be from the combined effect of the warm air temperatures and the increasing atmospheric demand. The effects of extreme temperature from either acute or chronic exposure can have large impacts on plant growth and development.

Temperature can affect vegetable crops in many ways, including the timing andreliability of plant growth, flowering, fruit growth, and ripening. As a result,temperature related thresholds are frequently a critical production factor.

Some of the potential impacts on horticultural production resulting from climatechange include:

- Changes in the optimum growing period or season,
- Shifts in optimum production locations,
- Changes in the distribution and/or abundance of pests, diseases and weeds,
- Increased incidence of temperature-related disorders,
- Increased risk of impacts on product quality and/or nutrition, and
- Changes in the suitability, availability and adaptability of cultivars.

A greater understanding of these risks within a range of production systems isnecessary to provide the high standard of crop management which will enableadaptation to altered climatic conditions.

2.1 Timing of flowering

The timing of flowering is one of the most important components in the adaptationof plants to their environment, having a fundamental influence on reproduction fitnessand thus on the ability to spread in the case of wild species, and on the realisationof maximum yielding ability in cultivated species. Various environmental factorsplay important roles by activating or repressing the regulatory mechanisms of flowering in plants.

Periods of low temperature (vernalization), day length (photoperiod), the intensity and spectral composition of light, temperature, and the daily fluctuations in environmental factors are the most important stimuli, in addition to genetically coded earliness.

These environmental factors act on complex sets of gene cascades, which involve environmental factor-specific regulator genes, and the central integrating genes of flowering, with several cross links between the different regulating pathways. The regulation of flowering has been discussed and evaluated in various crops.

Temperature has a major individual source of variance in plant development. The two parental varieties differed from each other not only in the optimal temperature level at flowering, but also in their sensitivity to sub- and supra-optimal temperatures. In barley cultivars, the optimal temperature for flowering was approximately 5°C lower in Dicktoo than in Kompolti korai and it was significantly more sensitive to extreme temperatures. In addition to the effect of the absolute temperature level, the results demonstrate that daily temperature fluctuations may also significantly influence plant development in a genotype-dependent way. A daily fluctuation of 2°C significantly delayed the flowering of Dicktoo by 71 days compared to a constant temperature of 18°Cunder otherwise the same growing conditions, while it had a significantly smaller effect on Kompolti korai.

Daily temperature fluctuation may also play an important role in maintain in the circadian rhythm of the plants. A daily fluctuation of 0.5 °C was found to be enough to participate in the entrainment of the circadian rhythm in Arabidopsis. In the case of Dicktoo and Kompolti korai, plant development was the fastest when there was no fluctuating environmental factor in the growing conditions andwas significantly delayed with application of photo cycle. The addition of thermocycle to photo cycle had an even stronger delaying effect, which could be detected in a sample of barley varieties as well. On average, facultative barleys were the most sensitive, followed by winter barleys, while spring barleys the least sensitive to the introduction of thermo cycle, the genomic basis of which is not yet known.

The following examples illustrate the complexity of temperature-related effects inmany vegetable crops.

2.2. Lettuce

Lettuce (*Lactuca sativa*) generally grows best under cool, sunny conditions withtemperatures below 24°C. Although some lettuce cultivars will tolerate warmerconditions, exposure to high temperatures reduces both quality and yield. The'hearting' development phase appears to be the most sensitive to elevatedtemperatures. Warm season lettuce cultivars in Queensland will not produce highquality heads once temperatures exceed 28°C and hot weather during heading willproduce uneven heads which do not form properly.

Temperature has a considerable influence on lettuce seed germination. Experimental trials have shown 90 per cent germination was observed when temperatures were between 15°C and20°C. Soil temperatures above 24°C result in reduced germination, while little germination occurs at or above 30°C.

Mechanistic growth models suggest that temperature changes of up to 3°C would reduce the production time from about 96 to 79 days for April plantings, and from 63to 52 days for August plantings.

2.3 Cauliflower (and related Brassicas)

In general, cauliflower (*Brassica oleracea*) is best suited to cooler growing conditions preferring mild to warm days (18° to 30°C) and cool nights (10° to 15°C). Warm conditions can delay curd initiation and contribute to curddisorders such as riciness (elongated flower buds), misshapen and small curds, hollow stem, curd discolouration and small jacket (wrapper) leaves.

In tropical conditions, cauliflower may fail to flower due to insufficient exposure to low temperatures, while in more temperate locations some cultivars may require protection from low temperature effects in order to produce seed. The stimulus provided by low temperatures can be reduced by subsequent high temperatures.

Curd growth is also affected by temperature; the rate of increase of curd diameter is directly correlated to temperatures between 5°C and 25°C. An upper temperature for curd growth has been identified as 23°Cor 25°C depending on the variety.

The duration of the curd growth phase is highly variable and dependent on the season of planting and temperature variation.

2.4 Tomato

The tomato (*Solanum lycopersicum*) has the ability to compensate for temperature variation within a certain range and period. Mean temperature and the cumulative temperature sum (over a certain period) have greater effects on development than maximum or minimum temperatures. Only large temperature variations inhibit the development of young plants, and this quality may provide a cushion for short-term, transient extreme temperatures likely to be encountered in the coming decades.

Significant flower drop occurs when daytime temperatures exceed 30°C and night time temperatures exceed 20°C. This results in reduced fruit set because of the adverse effect of temperature on pollen germination and pollen viability. The optimum temperature range for fruit set is 18° to 24°C. The period between 8 and 15 days prior to anthesis appears to be the critical period where high temperatures adversely affect yield by influencing fruit set.

Mean daily temperatures of 27°C and 29°C (only a few degrees above optimal)can have adverse effects on tomato fruit set and yield. Similarly, even moderate increases in mean daily temperature (from 28/22°C to 32/26°Cday/night) can result in a significant decrease in the number of fruit set.

Tomato fruit appear to be more sensitive to elevated temperature in their later stages of maturation. Temperature of the fruit also affects growth rates, with low temperatures reducing the absolute volume growth rates. There was a tendency towards small parthenocarpic fruits at both high (26°C) and low (14°C)temperature regimes which, combined with low flower numbers and poor fruit set at26°C, resulted in low fruit yields Even short-term temperature perturbations following first fruit-set can influence both the external appearance of fruit and their internal characteristics.

2.5Capsicum

Temperatures above 30°C can cause reduced fruit growth in capsicum (*Capsicumannuum*). When pollen from flowers exposed to 33°C during early flowerdevelopment were used to pollinate new flowers, the yield of fresh fruit produced was reduced and the fruit were deformed.

Temperature-sensitive cultivars usually respond to high temperatures by the abortion of flowers prior to anthesis. Heat tolerant cultivars exposed to a high temperature regime (32/26°C day/night) for the 8-day period leading up to anthesis have slightly higher rates of flower abortion than those raised under normal temperatures (28/22°C).

High temperatures after pollination result in decreased fruit set, indicating that fertilisation is sensitive to high temperatures. Although the effect of high temperature depends on the developmental stage of the flower. Flowers exposed to elevated temperature for 48 to 120 hours during bud stage (less than 2.5 mm in length) and bud stage (6.6 to 11mm in length) had fruit set reduced byup to 79 per cent depending on the duration of exposure. In contrast, flowers exposed during stages 2 or 3 (2.5 to 6.5mm) did not show reduced fruit set after any period of exposure to the higher temperature.

Exposure to high temperatures (38/30°Cday/night) following anthesis may result in reduced fruit growth. The effect of heat stress varies with the timing of exposure relative to the developmental stage of the fruit. For example, exposure to heat stress in the period up to 10 days following anthesis can result in lower fruit weight. Heat stress between 10 and 30 days after anthesis resulted in reduced fruit weight and fruit width. Exposure to heat stress for the whole period after anthesis, or for the period between 30 days after anthesis and harvest, reduces the growth period by 10 to 15 days.

2.6 Sweet corn (*Zea mays* var. *rugosa*) and other crops that feature the C_4 photosynthetic pathway may have some advantages over plants with the more common C_3 pathway under conditions of drought, high temperatures, and nitrogen or CO_2 limitation.

Optimal temperatures during reproductive stages are important for maximising yield. During the period up to three to four weeks following pollination, temperatures greater than 32°C can cause yield reductions greater than 4 per cent per day. High temperature treatments can reduce final kernel dry weights by as much as 95 per cent. Climatic factors can have significant effects on sweet corn quality. For example, extreme drought and heat can result in low values for kernel water and sugar content. The most significant temperature threshold for the successful production of cornappears to be 32°C during the period three to four weeks after pollination. Temperatures above this threshold during this period have been demonstrated to cause significant reductions in yield.

2.7. Pumpkin and other cucurbits

Despite the importance of pumpkins and other *Cucurbita* in global agriculture, there has been surprisingly little published research tackling physiological aspects of production, including responses to temperature.

Modelling of germination temperatures in cucurbits suggests that pumpkins(*Cucurbita moschata* and *C. maxima*) have an optimum temperature of 27°C for both germination percentage and germination speed. For *C. maxima*, germination percentage and speed decline rapidly at temperatures higher than about30°C, and germination fails at 42°C.

Pumpkins (and all other *Cucurbita*) are monoecious with male and female flowers occurring on the same plant. The pattern of flowering is generally similar across the domesticated species and plays a central role in productivity. Staminate (“male”)flowers tend to appear several days before the pistillate (“female”) flowers. In summer squash (*C. pepo*), the number of staminate flowers increases with increasing temperatures between 20°C and 27.5°C but declines at higher temperatures.

In another species of subtropical cucurbit apparently adapted to similar environmental conditions to *C. moschata*, pollen viability is reduced following short periods of exposure to temperatures above 35°C. There is some evidence that high temperatures may have a greater negative effect on the initiation and development of pistillate flowers than on pollen viability or flower function before or during anthesis.

2.8 Potato

High temperatures during tuber initiation in potato (*Solanum tuberosum*) appear to have negative effects on yields; new tubers are unlikely to set at temperatures above about 29°C. Average temperatures between 15 and20°C seem optimal for tuber set. High temperatures above 32°C during tuber growth and maturation may result in tuber damage.

Tolerance of high temperatures varies among varieties. High night temperatures in warmer regions can limit production because higher rates of respiration consume carbohydrate reserves. High temperatures may also result in lower solid matter content relative to potatoes produced in cooler climates.

Glossary:

Abiotic stresses are the stress produced by natural factors such as extreme temperatures, wind, drought and salinity.

Heat stress is often defined as the rise in temperature beyond a threshold level for a period of time sufficient to cause irreversible damage to plant growth and development.

Threshold temperature refers to a value of daily mean temperature at which a detectable reduction in growth begins

Designed and developed under the aegis of NAHEP Component-2 Project “Investments In ICAR Leadership In Agricultural Higher Education”
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Course Name	Agro-meteorology and climate change
Lesson 14	Interaction of temperature with other abiotic/biotic stress
Content Creator Name	Vallal Kannan Sankaralingam
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	Dr. Vijay Gopal More
University/College Name	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Lesson 14

Objectives:

- To understand the interaction of temperature with biotic stress.
- To empower knowledge on interaction of temperature on abiotic stress.
- Interaction of temperature on biotic stress

1.1 Potential effects of climate change oninsect pest dynamics

Climatic factors like temperature and precipitation in particular, have avery strong influence on the development, reproduction and survival of insect pestsand pathogens. It is predicted that some extreme events will increasein frequency as a result of a change in natural climate variability. Such changes in climatic conditions could profoundly affect thepopulation dynamics and the status of insect pests of the crops. These effects could either be direct, through the influence of weather on theinsects' physiology and behaviour.

Climate change related factorslike rise in temperature, changes in precipitation patterns, milder and shorterwinters, rise of sea levels and increased incidence of extreme weather events candirectly influence insects by affecting their rate of development, reproduction,distribution, migration and adaptation.

The population dynamics is the aspect of population ecology dealing with factors affecting change in population densities.The seasonal effects of weather and ongoing changes in climatic conditions will directly lead to modification in dispersal and development of insect species.

The change in the surrounding temperature regimes certainly involve alternations in development rates, voltinism and survival of insects and subsequently act upon size, density and genetic composition of populations, as well as on the extent of host plant exploitation.

The change in the environment affects the pest population dynamics in two ways either directly or indirectly by altering the host physiology.Host availability and the probability of pest outbreaks are further determined by the incidence and character of abiotic disturbances.

The developmental success of insect herbivores also indirectly depends on climate, as environmental parameters impact on plant physiology.

1.1.1Direct effects of climatic parameters on population dynamics.

Climate change is likely to involve higher frequency of abiotic disturbance. Local to regional dynamics of insect populations and species composition will be strongly affected due to dimension of disturbance.Insects find optimum conditions for development within the range of temperature limited by species specific lower and upper developmental thresholds. These alteration and gradual changes might affect the population dynamics parameters like development and reproduction, diapauses and winter mortality and dispersal.

1.1.2 Development and reproduction:

As long as species optima for development are not exceeded, there might be positive direct responses of insects to increasing temperature conditions, such as enhanced reproductive potential, are to be expected.

Polyvoltine species of bark beetle will profit from accelerated development rates allowing for an earlier completion of life cycles and the establishment of additional generations with ina season.

Temperature above the specific optimum range lead to decreased growth rates reduced fecundity and increased rates of mortality for a multitude of species. Milder winters and decreasing frequencies of temperature extremes, enhanced reproductive capacity and changes in distribution are to be expected for a variety of pest species.

Temperature increase coupled with reduced snowfall and earlier snow melt may on the one hand lead to decreased overwinter survival of species hibernating under the protection of snow.

1.1.3 Diapauses and winter mortality

Increased temperature conditions may be beneficial for species with low frost resistant and those which are actively feeding during winter. They are not beneficial for species which do need low temperatures to manifest diapauses or to increase their frost resistance.

1.1.4 Migration and movement:

Temperature thresholds for insect flight vary both among and within species, with seasonand also with regions.Different thresholds have also been described for different phases of fight activity, 17^0C required for take-off, 15^0C for sustained upward flight, 13^0C for horizontal flight and 6.5^0C for wing beating in aphids.

Furthermore, insect emergence and first appearance after hibernation may depend ona combination of day length and temperature thresholds. The geographic range of many insect species of the temperate zone is determined by temperature thresholds of frost resistance.Global warming may be responsible for the recent decline in abundance of *Plutellaxylostella* and the increase in *Helicoverpaarmigera* and *Trichoplusiani*.

1.2 Direct Effects of Increasing Temperature on Insect:

Increase in temperature might affect any stage of the life cycle and therefore limit distribution and abundance through its effects on survival, reproduction and development.

1.2.1Survival Rate of Insects:

Warm temperature halved the time required to reproduce. The population of pine beetle is reduced drastically at 16^0C but better survival and distribution at warm winter. In case of aphids a 2^0C temperature increase causes one to five additional life cycles per season. The adult survival of brown plant hopper remained almost unchanged between 15 and 35^0C, but was drastically reduced at 40^0C.

The oviposition of females at35 and 40^0C was relatively higher than at 25 and 30^0C but egg survival was markedly reduced at 35^0C.

At higher temperatures, duration of pre oviposition periods was also reduced.

Temperature above 35^{0}C is likely to limit Brown plant hopper development. Global warming is likely to increase BPH abundance in areas with temperatures below 30^{0}C.

Survival of different stage of rice leaf folder was greatly affected at 35^{0}C. The upper temperature threshold for survival of the leaf folder appears to lie between 30 and 35^{0}C. Shifts in climate can differentially affect the development rates of pest and predator species. The egg predator had increased instantaneous attack rates and decreased handling times with increasing temperatures until 32^{0}C. At 35^{0}C the attack rate and handling time decreased drastically. Global warming may cause temporal asynchrony between interacting populations.

Insect populations from environments with higher temperatures mayhave higher fecundity and shorter growth stage durations to increase fitness.The egg duration was 10.4 days at 25^{0}C and 7.9 days at 27-28^{0}C. The viability of eggs of *Helicoverpaarmigera* and day degrees required for egg hatching decreased with an increase in temperature from 10 to 27 ^{0}C and egg age from 0 to 3 days. In rice bug 0.5 to 2^{0}C rise in daily average temperature caused no effect on the generation time but 3^{0}C caused 1 to 3 days increase in generation time. 0.5 to 1^{0}C rise reduced the population of non wing padded nymphs, wing padded nymphs and adults.

1.2.2 Effect of temperature on growth rate of insects.

The rate of development of pests will enable a more rapid response to a change in temperature.The population of *Nephotettixcincticeps* will increase by a ratio of from 3 to 4.An increase in winter temperature enhances the abundance of *Chilosuppressalis* and *Nephotettixcincticeps*. Such difference may be related to the difference in the number of generations per year. *Nephotettixcincticeps* has twice the number of generations which may cause a sensitive response to change in temperature.

Winter mortality of adults of *Nezaraviridula* and *Halyomorphahalys* is predicted to be reduced by 15 per cent by each rise of 1^{0}C and *Chilosuppressalis*two generation per year after 2^{0}C warming.

Slower accumulation of heat units promotes aphid infestation. The rise in temperature beyond 3^0C, affects the population growth of rice ear head bug.

1.2.3. Effect of temperature on Voltinism

Climate change can cause major change to the dynamics of individual species and those communities in which they interact. One effect of increasing temperature is on insect voltinism, with the logical assumption that increases in surface temperatures would permit multivoltine species to increase the number of generations per year.

1.2.4 Species distribution:

Distributions of spruce budworm under climate change willshift towards the poles. The distribution shifts may be good or bad, depending on the species and the regions concerned.

1.3.Indirect Effects of Climate Change on Insect Pests via Host Plants:

The nutritional quality of plant tissue for insect herbivores generally increases with nitrogen content and decreases with lower water content and rising concentrations of secondary metabolites. The atmospheric carbondioxide are likely to stimulate plant defence and resistance to the colonisation of phytophagous insects.

Under moderate water stress, turgor pressure and water content of plant tissue decrease, leading to tougher foliage.Exposure to elevated CO_2 increases significantly western corn rootworm adults and soybean aphids.Higher concentrations of CO_2in the atmosphere may increase herbivory in the soybean agro eco system.

1.3.1.Pest population via Natural enemies

Shifts in climate can differentially affect the development rates of pest and predatory species. Normal increases in metabolic rate with increasing temperature are accompanied with increase in developmental rate. The egg predator of BPH had increased instantaneous attack rates and handling time decreased drastically.Predator activity is likely to increase with increasing temperatures up to a critical temperature of about 35^0C. Insect may also evade climate stress through change in life cycle. Insect populations from environments with higher temperatures may have higher fecundity and shorter growth stage duration was 10.4 days at 25^0C and 7.9 days at 27 to 28 ^{0}C. The parasitoid *Campolestischlorideae* developed successfully over the temperature range of 12-37^0C. There was no parasitoid larval survival in H. armigera larvae kept at 12 ± 1°C and 35 ± 1°C after parasitization, might be because of incompatible growth of the host and the parasitoid larvae, suggesting >12°C to <35°C as the minimum and maximum threshold temperatures for the survival and development of the parasitoid(Dhillon and Sharma,2008). As temperature increased, longevity decreased accordingly.

1.3.2Outbreak of insect-pest:

Changes in temperature and variability in rainfall,unseasonal rains, and heavy dew during the flowering and fruiting period would affectincidence of insect-pests, diseases, and virulence of major crops. Higher temperaturegenerally results in increased insect-pest activity e.g., an extra generation of insect pests such as halitosis may be possible in most locations. Higher temperatures mayresult in a longer period of pest activity; especially where production is extended e.g.,diamondback moth (DBM) is a pest of worldwide significance wherever *Brassica*vegetables are grown. With a warming climate DBM will have an increased impactin all *Brassica* growing regions, particularly sub-tropical regions and increasingly soin temperate regions.

Pollinating insect activities were also reducedto the minimum, resulting in poor setting of fruits, vegetables, and nuts during thatperiod. Due to the climate change, the number of crops (host) affected by a particularpest has increased.

2.Rising temperature and carbon dioxide on host-insectinteraction

The capacity of an herbivore insect to complete its development dependson the adaptation to both, the environmental conditions and the host plant. Thechanged temperature, which promotes the expansion of insect’s range, may alsoinvolve a new association between an herbivore and its host. The effects of a modifiedatmosphere on herbivore insects could alsoinvolve the third trophic level, i.e., their parasitoids and predators. A delay in thedevelopmental time of the herbivores after exposure to high CO_2 can increasethe probability of parasitism and predation as well. Increase in temperature by 3°C might lead to the same effect as that ofan increase in CO_2 (decreased nitrogen and increase in condensed tannins) onoak leaves. However, an increase in temperature may enhance the feeding of theherbivore and thus compensate for the negative effects of a lower food quality.The effects of different levels of CO_2, nitrogen and temperature on themonoterpene production of *Pseudotsugamenziesii*was tested and it was indicatedthat the synthesis of these defence compounds were more affected by variabilityin individual trees rather than by the treatments.

The response of herbivore insects to increased CO_2 may also differ amongthe feeding guilds. Defoliators are generally expectedto increase leaf consumption by about 30 per cent, but leaf miners show a much lowerrate.

Phloem-sucking insects appear to take the greater advantage from increasedCO_2, as they grow bigger in a shorter time. Elevated CO_2 increased thesusceptibility of soybean to invasive insects by down-regulating the expressionof genes related with hormonal defence, which down-regulate important anti-digestivedefences against beetles.

Soybean respond to insect attack by producingdefence compounds that inhibit digestive enzymes (proteinases) in the gut ofinsects, thereby reducing their performance and crop damage. The productions of these anti-digestive compounds are regulated in plants by the hormone jasmonicacid. However, elevated CO_2 levels disrupt this equilibrium in plant-insectinteractions and benefit the herbivore.

3.Abiotic stress:

The individual climate change inducing stressors are abiotic in nature and they impose stress on different plant species, these abiotic plantstressors include drought, elevated CO_2, temperature (low and high), waterlogging, rainfall and sunshine intensity, chemical factors (heavymetals and $_{P}$H)

3.1 Drought and rainfall pattern

Drought is one of the major abiotic stressors of agricultural plants restraining crops' return globally. It does not only affect the crops' growth, but it also affects the quality of yield.Drought as an abiotic stress factor is being projected to hinder productivity in more than 50 per cent of the arable lands in the world by the next 50 years.But the availability of saline water might lighten the world's water problem if plants that are salt tolerant are being developed. However, in response to this kind of plant stress, the need for drought tolerant plant is a necessity to boycott or reduce its negative impacts on food security. Also, there is a noticeable variability in soil water content in tropical countries because of the rainfall pattern and distribution in these areas. This is an indication that the soil water content is becoming scarce for plants use.That is, when rainfall distribution uniformity is low, the available soil water content would reduce, hence will not uniformly meet the plant's soil-water-nutrient need, thus inducing stress on plants in those affected areas.

Climate change alternates the timing of rainfall from one season or period to the other either resulting in smaller precipitation event or large one depending on the shift. This sudden shift in the precipitation affect plant growth and causes plant stress by disturbing plant metabolism, arresting photosynthesis, and may finally cause plants to die off.Change in the soil water content and soil features has a notable impact on the plant and soil processes. The response in above-ground net primary productivity (ANPP) depends on which season receives extra water and which one receives less.

Generally effects of drought stress on plants are;

- Reduction in seed germination and development

- Poor growth in vegetation
- Poor reproductive growth
- Reduction in leaf weight
- Reduced photosynthesis
- Reduced stomatal conductance and
- A significant reduction in the total dry matter

3.2 Water logging/flooding

Climate change has altered the hydrological cycle processes which have resulted to impairment or reduction in crop growth in so many areas around the world. Consequently, there is a large scale reduction in agricultural production especially on a flatland or places near the river due to waterlogging. Waterlogging occurs as result of leakage from irrigation canals or pure surface drainage but predominantly caused by heavy rainfall. As a result, there is increased soil compaction, also the available oxygen (O_2) for plants cells are reduced because the diffusion process of O_2 is slow in ponding water. Due to the limited supply in O_2, anaerobic bacteria releases enormous amount of iron ion, manganese ion and sulphide.

Crops grown in a waterlogged condition undergo different physiological and morphological variations. One of the major responses of plant to waterlogging stress is stomatal cessation which impacts not only gas exchange, but also reduces the submissive absorption of H_2O, which is harmfully prejudiced by anaerobic conditions in the rhizosphere.

Transpiration is also reduced which eventually results to wilting of the leaf and early senescence; consequentially, foliar abscission. In flood logged area, respiration of roots are not aerated in which gas diffusion are severely reserved, thereby resulting to it changing from aerobic to anaerobic conditions which is dangerous to plants development. Waterlogging also deters the nutrients intake of plants by reduction in nutrients such as Nitrogen, Phosphorus, Potassium, Manganese, Copper, Zinc and Magnesium.

3.3 Salinity

The effect of salinity on agricultural crop production and food supply has been on the increase worldwide, with the cultivation of salt-sensitive crops such as rice and wheat being a worldwide practice salinity stress needs to be promptly addressed.

Salinity is a stressor common to arid and semi-arid regions of the world where evapotranspiration exceeds rainfall, and as a result leads to inadequate rain to filter away the soluble salts from the root zone.Lands with salinity stress problem covered at least 7 per cent of the world land area four decades ago according to and has been seen to double every two decades. Approximately 1.6 mha of land is being lost to salinity stress every year, with 60 per cent salinization coming from natural sources (weathering of minerals, and soils developed from saline rocks) and 40 per cent coming from secondary sources (irrigation, deforestation, overgrazing or intensive cropping). But ironically majority of the land lost as a result of secondary salinization is caused as an adverse effect of irrigation of the farmland with both normal water and treated sewage effluents. The salinity stressor reduces drastically the ability of plants to take up water and other nutrients from the soil, leading to stunted growth; salt deposits find their way into the transpiration stream and damage the cells in leaves thereby causing leaf burn; it also affects the enzyme activity happening within the plant.The salinity of a soil is measured in terms of electrical conductivity (EC), and these soils have a mixture of salts of Sulfate, Sodium, Magnesium, Chlorine and Calcium.But most often, it is the combination of two more stressor that affects growth of a plant.

Several researches have investigated the combine effects of drought and heat stress on maize, sorghum and turf-grasses growth and productivity. The studies showed that the combine effects of the two stressors were higher compared to when the stresses were applied individually

3.4 Effects of temperature on weed physiologicalcharacteristics

Various responses to temperature fluctuations havebeen reported for seed germination of weed species.Common chickweed (*Stellaria media* L.) survives well in coldclimates whereas some of the most troublesomeweeds in soybean, maize, and cotton respond to temperaturegradients to varying degrees.

Barnyardgrass(*Echinochloa* spp.) is a weed of warm regions that requireshigh temperatures for dry matter production and growth. Similarly, prickly sida (*Sidaspinosa* L.) needs high temperatures for its development. The spatial distribution of Johnson grass[*Sorghumhalepense* (L.) Pers.], in colder climates is restrictedby its rhizome intolerance to temperatures below −3 °C. Similarly, morning glories arefrost intolerant but their germination occurs over a wide range of temperatures (15–35 °C). In addition 88per cent increase in biomass and 68 per cent increasein leaf area of itchgrass in response to a 3 °C increase in temperature.

3.2.2 Effects of temperature on weed distribution

The geographical range of many weed species is largely determinedby temperature and it has long been recognized thattemperature determines successful colonization of new environmentsby weedy species.

Warming will affect the growth, reproduction, and distributionof weeds. Temperature increases are likely to be particularlyimportant in affecting the relative plant growth of C_3 and C_4plants, potentially favouring C_4. This again could provide suitable conditions for more robustgrowth of some species, which are currently limited by lowtemperatures, whereas the distribution of some tropical andsubtropical C_4 species could shift northwards.

In addition, expansion of invasive weed species such as itchgrass, and witchweed will be facilitated by temperature increases. They also reported an increasein biomass and leaf area of itchgrass by 88 and68 per cent, respectively, in response to a 3°C increase. Onthe contrary, additional warming could restrict thesouthern range of other cooler climate invasive weeds such as wild proso millet.

Glossary

Voltinism is a term used in biology to indicate the number of broods or generations of an organism in a year. The term is most often applied to insects, and is particularly in use in sericulture, where silkworm varieties vary in their voltinism.

Halitosis: It is an oral health problem where the main symptom is bad smelling breath. In most cases, finding the cause of the bad breath is the first step toward treating this preventable condition.

Reference:

Dhillon,M.K., and Sharma. H.C.(2008). Influence of temperature and Helicoverpa armigera Food on survival and Development of the Parasitoid , Campoletis chlorideae. Indian Journal of Plant Protection Vol. 36. No. 2, 2008 (240-244).

Skendzi,S., Zovko, M., Zivkoci,I.P., Lesi,V. and Lemi,D. (2021)The Impact of Climate Change on Agricultural Insect Pests. Insects, 12, 440. https://doi.org/10.3390/ insects12050440.

Somala Karthik, Sai Reddy, M.S. and Gummudala Yashaswini.(2021).Climate change and its potential impacts on Insect-Plant Interactions.DOI:10.5772/intechopen.98203.

Sudhanshu Bala Nayak, Kavadana Sankara Rao, V Ramalakshmi. (2020). Impact of Climate Change on Insect Pests and their Natural Enemies. International Journal of Ecology and Environmental Sciences. 2; (4); 579-584.

Course Name	Agro-meteorology and climate change
Lesson 15	Mitigation strategies and prospects for genetic manipulation of crops to maximize production in the future atmosphere
Content Creator Name	Vallal Kannan Sankaralingam
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	Dr. Vijay Gopal More
University/College Name	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Lesson 15

Objectives:

- ➢ To understand the mitigation strategies to enhance the crop production
- ➢ To equip the knowledge on genetic manipulation of crops to maximize the production.

1 Mitigation strategies

A drier climate will reduce the availability of water and increase cost of water for horticulture. For successful adaptation of climate change,there is need to improve irrigation practices. Temperature changes in absolute terms are expected to be greater.Matching crop type to climatic area will be increasingly important, particularly for long-lived perennial crops.

Various management practices have the potential to increase the yield of fruits andvegetables grown under adverse conditions. Several technologies available to alleviate production challenges such as limited irrigationwater and flooding to mitigate the effects of salinity, and also to ensure appropriateavailability of nutrients to the plants. Strategies include modifying fertilizerapplication to enhance nutrient availability to plants, direct delivery of water to roots(drip irrigation), grafting to increase disease tolerance, and use of soil amendmentsto improve soil fertility and enhance nutrient uptake by plants.

1.1 Improve water harvesting and storage

Technology and infrastructure for harvesting and storing water need to be improved in a changing climate. There are many options like design dams and catchments to cope with projected rainfall and evaporation rates, treat roaded catchments with chemical sealants to reduce the rainfall run-off threshold to 4–6mm, reduce evaporation loss from dams by usingsuspended and floating covers and mono-layer films applied to the water surface, windbreaks to reduce air movement over the water surface, if available, use treated sewage or grey water for crop irrigation, use in-row water harvesting for grapes and tree crops, harvest water run-off from greenhouses, use desalination and reverse osmosis to recover otherwise poor quality or water, increase investment in tanks and dam storages.

1.1.1Water harvesting:

Collection of rain water is termed as water harvesting. It canbe collected both in-situ and ex-situ modes. In in-situ method, the rain dropis collected wherever it falls. In ex-situ conservation, water which otherwise formsrun-off, is collected in a suitable structure. It may be a farm pond, reservoir or othersuitable structures. A country like India wherethe annual rainfall is more than 500 mm, barring arid region, receives a calculated amount of more than 5,00,00,000 litres water per ha. However, after cessation of rains, no moisture is left for successful cultivation. This calls for collection of the rain water. A farmer by constructing a farm pond of 1 m^3 size can store 1.0 lakh litreof water. This much water is sufficient for life saving irrigation, especially in a moderatelyspaced new orchard for almost one month which continues to be very criticalduring summer month.

1.1.2 Water saving irrigation:

The quality and efficiency of water management determinethe yield and quality of the products. Too much or too little water causes abnormalplant growth, predisposes plants to infection by pathogens, and causes nutritionaldisorders. The timely irrigation and conservation of soil moisture reserves are themost important agronomic interventions to maintain yield during drought stress.

The water use efficiency by chilli wassignificantly higher in drip irrigation as compared to furrow irrigation. For drought tolerant crops like watermelon, the yield difference wasnon-significant between furrow and drip irrigation, but there was a reduction in theincidence of *Fusarium* wilt in drip irrigation method. In general, the use of low-costdrip irrigation is cost-effective, labour-saving, and allows more plants to be grownper unit of water, thereby saving water and increasing the farmers' incomes at thesame time.

1.1.3.Cultural practices to conserve water:

Several crop managements practicessuch as mulching, use of shelters and raised beds help to conservesoil moisture, prevent soil degradation, and protect plants from heavyrains, high temperatures, and flooding. The use of mulches helps reduceevaporation, soil temperature, erosion, and minimizes weed growth.

Mulching has been found to improve the growth of brinjal, okra, bottlegourd, round melon, ridge gourd, and sponge gourd as compared tothe non-mulched crop. Planting of fruit andvegetableseedlings in raised beds can ameliorate the effects of floodingduring the rainy season. Additional effects onyield were observed when the seedlings were planted in raised beds withrain shelters.

1.2 Improve irrigation efficiency

Technology and management improvements to gain the best production per unit of irrigation water includes watering at night, drip irrigation, subsurface drip irrigation, improved irrigation scheduling based on monitoring soil water content, soil type, crop factors and evaporation timing and volume of irrigation, regulated deficit irrigation, partial root zone drying, improved water distribution systems, reduced evaporation of soil water through mulching with organic materials, mulching with plastic, rapid crop canopy development/closure, increased speed and depth of infiltration by usingclaying application of surfactants (wetting agents), reducing run-off by using appropriate irrigation rates mulches, contour sowing, minimum tillage and claying.

1.3 Increase volume of plant available soil water

Improve soil water-holding capacity by using increased soil organic carbon content, reduced tillage, deep-ripping, gypsum to improve soil structure claying (surface application/delving/spading) to reduce non-wetting.

1.4 Improve plant water use efficiency

Increase plant ability to access soil waterthrough remove physical constraints to root growth with gypsum to improve soil structure, increased soil organic carbon content, using organic mulches and manure, deep-ripping to remove hard pans, drainage, such as deep drains, raised beds and surface drainage, to reduce waterlogging. Remove chemical constraints to root growth by applying micronutrients and macronutrients, liming to reduce low pH (acid soils), applying ameliorants and/or draining to reduce sodicity.

1.5 Improved stress tolerance through grafting:

Grafting involves unitingof two living plant parts (rootstock and scion) to produce a single growingplant. It has been used primarily tocontrol soil-borne diseases affecting the production of fruit vegetables such as tomato, brinjal, and cucurbits.However, it can provide tolerance to soil-related environmental stressesuch as drought, salinity, low soil temperature, and flooding if appropriatetolerant rootstocks are used.

Use crop varieties, species or rootstocks with increased ability to explore soil profile, the right root morphology (deep versus lateral roots),tolerance of chemical soil constraints, such as pH, boron, aluminium, transient sodicity, tolerance of saline irrigation water, ability to grow through soil physical constraints, such as a hard pan or transient waterlogging

1.6 Use of resilient source:

An improved and adapted germplasm is themost cost-effective option for farmers to meet the challenges of a changingclimate.However, most modern cultivars represent a limited samplingof the available genetic variability, including tolerance to environmentalstresses. New breeding varieties particularly for intensive, high input productionand tolerance to different biotic and abiotic stresses are worth using

1.6.1. Varieties tolerant to high temperatures:

The key to obtaininghigh yieldwith heat tolerant cultivars is the broadening of their genetic base throughcrosses between heat tolerant tropical lines and disease resistant temperateor winter varieties. The heat tolerant tomatolines were developed using heat tolerant breeding lines and landracesfrom the Philippines (VC11-3-1-8, VC 11-2-5, Divisoria-2) and the United States. However, loweryields in the heat tolerant lines are still a concern.

1.6.2. Use best-adapted crop species and varieties:

Options include crop varieties, species or rootstocks with increased physiological tolerance of hot conditions, varieties with reduced chill requirements,varieties or species which are better able to exploit the fertilisation effect of increased atmospheric carbon dioxide to improve water use efficiency, changed crop rotations and schedules, crop varieties or species bred to resist current pest and disease risks and new risks presented by changing climate and crop rotations with break-crops for disease management.

1.6.3Drought tolerance sources:

Some rootstocks like Dogridge (*Vitischampine*) of grape, *Zizyphus rotundifolia* of ber, MM-111 and MM-104of apple, Mahaleb of cherry, *Rosa canina* and *Rosa indica* var. *Odorata*of rose were found promising both for improvement in vigor, yield andquality as well as for tolerance to drought and salinity.

Genetic variability for drought tolerance in*Solanum lycopersicum*is limited and inadequate. The stress toleranttomato germplasm includes accessions of *S.cheesmanii*, *S. chilense*,*S. lycopersicum*var. *cerasiforme*, *S. pennellii*, *S. peruvianum*and*S. pimpinellifolium*. Drought tests show that *S. chilense*is five timesmore tolerant than cultivated tomato.

1.6.4. Salinity tolerant lines:

Genetic variation for salt tolerance during seedgermination in tomato has been identified within cultivated and wildspecies. A cross between a salt sensitive tomato line (UCT5) and a salttolerant*S. esculentum* accession (PI174263) showed that the ability ofthe tomato seed to germinate rapidly under salt stress is genetically controlled. In pepper, salt stress significantlydecreases germination, shoot height, root length, fresh and dry weightand yield. In the fruit crops, rootstocks Bappakai, Kurrukanof mango; Rangpur lime, Cleopatra mandarin of citrus, and *Z. nummularia*of ber were found to be more tolerant to saline soil levels of up to 5.3 $dSm^{-1}$and saline water irrigations.

1.6.5Manage higher temperatures

There are chemical and management options, includingchemical dormancy breakers, such as application of hydrogen cyanamide, as a method to promote budburst, crop regulation and canopy management, such as using temperature dataloggers to optimise bunch-zone temperaturesusing irrigation to ameliorate temperature extremes; sprinkler irrigation can reduce canopy temperatures.

1.6.6Grow crops under shelters or greenhouses

Shelters or greenhouses can ameliorate the affect of higher temperatures and provide better water management. There are several options like use netting to provide shade (reduced canopy temperature and evaporation) and reduce risk of hail and bird damage, grow crops in greenhouses to increase productivity by usingplastic tunnels, plastic structures with computerised temperature control and shading systems, glass structures with computerised temperature control and shading systems, hydroponics to increase water use efficiency.

2. Climate proofing though Genomics and Biotechnology:

Increasing crop productivity in unfavourable environments will require advanced technologies to complement the traditional methods which are often unable to prevent yield losses due to environmental stresses. National and international institutes are retooling for plant molecular genetics research to enhance traditional plant breeding and benefit from the potential of genetic engineering to increase and sustain crop productivity (CGIAR, 2003).

2.1 Quantitative trait loci (QTLs) and gene discovery for tolerance to stresses:

Genetic enhancement using molecular technologies has revolutionized plant breeding. The use of molecular markers as a selection tool provides the potential for increasing the efficiency ofbreedingprograms by reducing environmental variability, facilitating earlierselection, and reducing subsequent population sizes for field testing.

Scientist identified drought tolerance in tomato, and threeQTLs were linked towater use efficiency in *Solanum pennellii*based on13C composition. An identified four QTLs were associated with tomatoseed to germinate rapidly under the drought and salt tolerance whichwas contributed by *S. Pimpinellifolium.*

Random amplified polymorphic DNA (RAPD) markerslinked to heat tolerance in tomato line CL5915. "Osmotin" gene in potato, tolerant to water stresscondition, has also been identified.

2.2 Engineering stress tolerance:

Environmental stress tolerance isa complex trait and involves many genes. Inresponse to stresses, bothRNA and protein expression profiles change.Approximately 130 drought-responsive genes have been identified usingmicroarrays. These genes areinvolved with transcription modulation, ion-transport, and carbohydratemetabolism and transpiration control. Dehydration-responsiveelement-binding (DREB) protein1, C-repeat binding factors(CBF)and Heat shock transcription factors(HSF)genes are transcription factors implicated in drought and heat response,respectively. The CBF/DREB1genes have been used successfully to engineer drought tolerance andincreased stress tolerance without plant growth retardation in tomatoand other crops.

3. Prospects for genetic manipulation of crops to maximize production in the future atmosphere.

3.1 Genetic engineering

Abiotic stress is most universal problems and can affect yield productivity and quality of horticultural crops. Biotic and abiotic stresses also affect all secondary metabolites like photosynthesis, polysaccharide, protein synthesis, lipid metabolism, physiological and biochemical processes. Genetic engineering via gene transfer can be change the gene expression or activity in response to salt stress and drought stress. Genetic Manipulation (GM) or genetic modified is one of the important factors to avoid the dissertation by water shortage and plant irrigation with salty water. Transgenic plants of the many tools available for modern plant improvement programs.

Gene identification and functional genomics projects have revealed multi stressed gene families, which enhance productivity improvement and acclimation to abiotic stresses. Several investigators discovered several genes in different gene family that can be introduced to different plant with different families. The approach from gene transfer is demonstrated and provides more options for selectivity of stressed and multi stressed genes from different organisms to introduce them into plants to provide resistance against different biotic stresses.

3.2 Genetic engineering for heat tolerance in plants

Plant scientists have a concern in altering the heat shock (HS)response as high ambient temperature is one of the major constraints in obtaining maximum output from the crop plants. Most crops are affected by daily fluctuations in high day and/or night temperatures. While some stages of plant growth may be more sensitive to high temperature than others, there is an overall reduction in plant performance when temperature is higher than the optimal temperature at specific growth stages.

Conventional breeding for high temperature stress tolerance has not been much successful due to several reasons like lack of suitable source of genes in sexually compatible gene pools, complex nature of the heat shock (HS) trait, lack of understanding on the genetic mechanisms of the high temperature tolerance response, etc.

Advent of recombinant DNA (rDNA) technology methods has opened avenues for tackling issues relating to complex genetic traits. In early 1990s, low temperature tolerant transgenic tobacco plants were raised by over-expressing desaturase gene isolated from *Arabidopsis* or cucurbits, heralding the beginning of transgenic solution to the problems of abiotic stresses.

During the past 15 years of research (1992-2007), there have umpteen reports on the production of abiotic stress tolerant transgenic plants providing testimony that rDNA approach has great potential in alleviating abiotic stress induced injuries. The need for raising high temperature tolerant crops using rDNA methods was felt since the early days of rDNA science but however, not much could be achieved as the underlying physiological processes, biochemical enzymes and molecular mechanisms, that impart high temperature tolerance were not precisely understood.

In recent times, several reports have appeared wherein it has been possible to address the issue of raising high temperature stress tolerant plants by manipulating the heat shock resistance(HSR) components. It has been shown that plants for high temperature tolerance can be genetically-engineered by altering heat shock proteins (Hsps) either directly or through regulatory circuits that govern Hsp levels, levels of osmolytes, components of the cell detoxification mechanisms and components that regulate membrane fluidity.

3.3 High temperature tolerant transgenic raised through haltering HSPs

High temperature stress is, in general, simulated in laboratory experiments by subjecting biological systems to HS treatment. Plants mount resistance to HS by eliciting specific metabolic adjustments. The temperature for the induction of plant HSR varies amongst different plant species but an increase of 5-10^{o}C over and above the ambient temperature is generally sufficient to elicit the HSR. Hsps have been reported from a large number of plants, those plant species which are extensively analysed for Hsps include *Arabidopsis*,maize, tomato, rice and wheat. Hsps are broadly classified on the basis of their molecular weights as high molecular weight (HMW-Hsps; 70-100 kDa) and low molecular weight (sHsps; 15-20 kDa) Hsps. The level of accumulation of different Hsps is often variable. Under stress conditions, sHsps may comprise up to 1% of the cellular proteins. It has been shown that Hspare highly-conserved proteins across different species.

Besides HS, selectiveplant Hsps are induced in response to several different abiotic stresses as well such as heavy metal stress, water stress, wounding stress, salt stress, cold shock stress and anoxia stress. Plants, in general, survive lethal high temperature stress more efficiently after prior exposure to a mild high temperature stress as against direct response to lethal high temperature stress. This phenomenon is termed as acquired thermo tolerance.Hsps are believed to be important for the protection of cells against heat injury both in basal thermo tolerance (i.e. thermo tolerance achieved without prior HS) as well as in acquired thermo tolerance responses. Over the years, large number of HSPgenes has been isolated, sequenced and cloned. This has been achieved from varied plant species representing diverse taxonomic classes. Availability of complete genomic sequence data of *Arabidopsis thaliana* and *Oryza sativa* has provided vast information on different families of the HSP.

Several groups have altered levels of sHsps in bacterial systems and shown that when over-expressed in bacterial cells, sHsps have a role in conferring thermo tolerance. The involvement of Hsps in regulating thermo tolerance in plants has been indicated by down regulating their levels through antisense and RNAi approach.

Tomato plants silenced for Hsp100/ClpBprotein were impaired in thermo tolerance.Tomato Lehsp(mitochondrial) gene over-expressed in tobacco showed that transgenics were more thermo tolerant at 48ºC than the transgenics produced with the antisense construct of the same gene.

3.4 High temperature tolerant transgenic raised through altering osmolytes

Certain low molecular weight compounds such as aminoacids (e.g. proline), polyamines (e.g. putrescine), quaternary ammonium compounds (e.g. glycinebetaine),sugars (e.g. mannitol, fructans, sorbitol, trehalose) andsugar alcohols (e.g. polyols) help plants to acclimatize largely against the osmotic stresses. Such compounds are usually referred asosmolytes.

Glycinebetaine is proposed to protect the photosynthesis machinery by stabilizing O_2 evolving photosystem II complex.

Increased biosynthesis of glycine betaine in *Arabidopsis* plants is by introduction of bacterial *codA*gene (choline oxidaseprotein). The seeds of transgenic plants were moretolerant to heat stress as compared to the wild type, at the imbibition and germination stage. Over production of glycinebetaine also provided significant advantage to the growth of young transgenic seedlings at supra-optimal temperature. Betaine aldehyde dehydrogenase protein is transferred from spinach to tobacco plants, to increase glycinebetaine levels.

3.5 High temperature tolerant transgenic raised through haltering membrane fluidity

Living cells adapt to the extracellular low temperature stress through alteration in the composition of membrane lipids. Membrane fluidity is increased in response to low temperature stress due to elevated activity of desaturase enzymes responsible for bringing out increased unsaturation of membrane lipids. Saturation of membranelipids is increased when cells are subjected to supra optimal temperatures, resulting in increased membrane rigidity.

Thermo tolerance assays revealed that transgenic tobacco plants were resistant to high temperature stress (41ºC, 2 h), where as wild type plants could not survive in response to such extreme temperature treatment.

Brassica napus cytosolic Fad8 protein in tobacco and showed that over-expression of Fad8imposed much greater heat sensitivity than that observed with other desaturases (such as Fad3).

3.6 High temperature tolerant transgenic raised throughaltering cell detoxification components

Reactive oxygen species (ROS) are produced in cells under normal as well as under stress conditions. Levels of ROS can be immensely high under stressed conditions. Electron transport systems in chloroplasts and mitochondria are the major source for the production of the O_2 radicals. Free radicals are by products of the electron transport chain during the generation of cellular energy.

Biological systems have evolved defence systems against ROS, involving both limiting the formation as well as removing the excess levels. Component of cell detoxification mechanisms have been employed in specific experiments to alter thermo tolerance response in transgenic plants.

Overexpressionof barley *hvapx1* (peroxisomal ascorbate peroxidase) gene in *Arabidopsis* causedincreased thermotolerance of transgenic plants as compared to wild type plants.

Over expressed tomato gene encoding for glutathione peroxidase in tobacco. Over expression of Cu/Zn superoxidedismutase is also noted to protect plants from high temperature stress.

Glossary:

Biotechnology is the use of biology to solve problems and make useful products. The most prominent approach used is genetic engineering, which enables scientists to tailor an organism's DNA at will

Irrigation efficiency (IE) is the ratio of the amount of water consumed by the crop to the amount of water supplied through irrigation (surface, sprinkler or drip irrigation).

Genomics is the study of all of a person's genes (the genome), including interactions of those genes with each other and with the person's environment.

Osmolytes are low-molecular weight organic compounds that influence the properties of biological fluids. Their primary role is to maintain the integrity of cells by affecting the viscosity, melting point, and ionic strength of the aqueous solution. bout its role in imparting thermotolerance to cells. Certain low molecular weight compounds such as amino acids (e.g. proline), polyamines (e.g. putrescine),quaternary ammonium compounds (e.g. glycinebetaine),sugars (e.g. mannitol, fructans, sorbitol, trehalose) and sugar alcohols (e.g. polyols) help plants to acclimatize against largely the osmotic stresses

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Thermo tolerance: Plants, in general, survive lethal high temperature stress more efficiently after prior exposure to a mild high temperature stress as against direct response to lethal high temperature stress. This phenomenon is termed as acquired thermo tolerance.

Water harvesting: Collection of rain water is termed as water harvesting

Recombinant DNA (rDNA) is a technology that uses enzymes to cut and paste together DNA sequences of interest. The recombined DNA sequences can be placed into vehicles called vectors that ferry the DNA into a suitable host cell where it can be copied or expressed.

The **chloroplast HSP100/ClpB** is a newly documented member of the ClpB family, but little was known about its role in imparting thermotolerance to cells.

Reference:

Amanjot Singh and Anil Grover. (2008). Genetic engineering for heat tolerance in plants. Physiol. Mol. Biol. Plants, 14(1&2):155-166.

Furbank,R.T and Taylor,C.W(1995). Regulation of Photosynthesis in C3 and C4 Plants:A Molecular Approach. The Plant Cell, Vol. 7, 797-807. American Society of Plant Physiologists.

Helaly AA (2017) Strategies for Improvement of Horticultural Crops against Abiotic Stresses. J Hortic 4: e107. doi:10.4172/2376-0354.1000e107.

Mariangela Diacono , Alessandro Persiani, Angelo Fiore, Francesco Montemurro and Stefano Canali.(2017). Agro-Ecology for Potential Adaptation of Horticultural Systems to Climate Change: Agronomic and Energetic Performance Evaluation. Agronomy 2017, 7, 35; doi:10.3390/agronomy7020035.

Sumi,A.,Fukushi, K. And Hiramatsu,A.(2010).Adaptation and mitigation strategies for climate change.DOI 10.1007/978-4-431-99798-6-9.

Course Name	Agro-meteorology and climate change
Lesson 16	Modifying Rubisco acclimation, metabolism of oxidizing radicals and sink capacity as potential strategies
Content Creator Name	Vallal Kannan Sankaralingam
University/College Name	Tamil Nadu Agricultural University, Coimbatore
Course Reviewer Name	Dr. Vijay Gopal More
University/College Name	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Lesson 16

Objectives:

- To understand modification in Rubisco and their acclimation
- To empower knowledge on metabolism oxidizing radicals and sink as potential strategies.

1. Modifying Rubisco acclimation.

The realization that crops yields are reaching a plateau, while population increase continue at pace, has placed manipulation of photosynthesis in a central position to achieve increases in yield.Rubisco is the key enzyme responsible for photosynthetic carbon assimilation in catalysing the reaction of CO_2 with ribulose 1,5-bisphosphate (RuBP) to form two molecules of D-phosphoglyceric acid (PGA).It also initiates photorespiration by catalysing the reaction of oxygen, also withRuBP, to form one molecule each of phosphoglycolate and PGA. It is a complex enzyme and catalyses these reactions at rather slow rates. It constitutes about 30 per cent of the total protein in many leaves for which reason it is of considerable interest in relation to the nitrogen nutrition of plants. Physiologists have been concerned because of the consequences of the properties of Rubisco for the gas exchange characteristics of photosynthetic tissues and because of the consequences of the amount of nitrogen tied up in the enzyme and its recycling upon senescence of leaves.

The significance of the inhibition of photosynthesis in many organisms by oxygen became evident with the discovery of the oxygenation of RuBP and consequent stimulation of photorespiration.Increased CO_2 concentration diminished the inhibitory effect of oxygen on photosynthesis and this also finds explanation in the properties of Rubisco as a catalyst, the carboxylation and oxygenation reactions are catalysed at the same active site on the enzyme and CO_2 and O_2 are competitive substrates.Evolution in various environments, usually hot or deficient in available inorganic carbon (CO_2, HCO_3-, CO_3^{2-}), has resulted in photosynthetic organisms that can concentrate CO_2 in cells or organelles containing their Rubisco.

Terrestrial plants with a CO_2 concentrating mechanism, C_4 plants, have much higher rates of photosynthesis in warm conditions at high light intensities than C_3 plants that have no CO_2 concentrating mechanism. Also, C_3 plants in atmospheres with low O_2, or elevated CO_2, assimilate CO_2 and grow more quickly than in ambient conditions, provided that nutrients and temperature are not limiting. Mechanistic models of photosynthetic gas exchange based upon Rubisco kinetics have proved very successful in representing the effects of light, temperature and atmospheric composition on assimilation of carbon by plants.

Genetic manipulation of Rubisco to double its specificity for CO_2 would theoretically increase saturating light intensity $A_{(max)}$ by perhaps 20 per cent, and photosynthesis at subsaturating light intensities would also be improved. Consequently, it has been accepted that the manipulating Rubisco to decrease the inhibitory effect of oxygen and its competitive involvement in reaction with RuBP, as opposed to reaction with CO_2, is a worthwhile target to increase the productivity of plants.

Essential to the activity of Rubisco is the carbamylation of an active site lysine residue. The extent of this carbamylation depends on the concentrations of CO_2 and Mg^{2+}, the absence from the non-carbamylated sites of certain phosphorylated compounds and particularly RuBP, and the activity of an enzyme called Rubisco activase.The activity of Rubisco activaseenzyme is controlled by the ratio of ATP/ADP and redox potential, in effect by light intensity. Rubisco activase also facilitates the removal of 2-carboxyarabinitol 1-phosphate (CA1P) from carbamylated sites of Rubisco. CA1P is a tight binding naturally occurring inhibitor of Rubisco which is present bound to the enzyme in many species at night. The significance of the presence of CA1P is subject to some debate. It could be a regulator of activity at low light intensities, but may be more important in protecting Rubisco from degradation by proteases, when the natural substrate, RuBP, is present at low concentrations. Manipulation of the activity of Rubisco activase or of the synthesis and breakdown of CA1P may be of value.

The large amounts of Rubisco in leaves have consequences for the development of research on this enzyme. There is so much present that not only can it sometimes be seen as crystals in the chloroplast stroma but it also crystallizes very readily from relatively crude extracts. It has been estimated to be normally present at a concentration of 240 mg ml^{-1} in the stroma of chloroplastsand constitutes some 30-50 per cent of the soluble protein in the leaves of C_3 plants and a very high percentage of the total protein in leaves.Nevertheless, particularly in bright light it may exert considerable limitation over the rate of CO_2 fixation. The fate of Rubisco during leaf senescence has been intensively studied and the nitrogen from this source has been shown to be extensively reutilized in the synthesis of proteins in seeds and perennating organs. Thus,the function of Rubisco as a store of nitrogen has resulted in much speculation and research.

The genes for the Rubisco polypeptide subunits from many species have been cloned and sequenced, as have genes for Rubisco activase polypeptides. Furthermore, the crystal structure of Rubisco from several species and the extensive homology of amino acid sequences have allowed the advance of genetic manipulation, protein engineering and transformation experiments.

One problem with the manipulation of Rubisco in higher plants is that it is composed of eight large and eight small polypeptide subunits and that the genes for the small subunit are in the nuclear genome, but those for the large subunit are encoded in the chloroplast genome. Problems have also been encountered in assembling large and small subunits into the hexadecameric holoenzyme following manipulation. Many protein engineering projects have, therefore, been conducted using cyanobacterial, algal and bacterial Rubiscos for which assembly into the holoenzyme is less problematic.

Mutagenesis in vitro has been used to make changes to DNA encoding both large and small subunits. The effects of such changes on the expressed protein have been used to increase understanding of the catalytic properties of Rubisco and the extent to which the specificity and activity can be altered.

The use of antisense constructs to alter the amount of expression of Rubisco has been used both to determine whether the amount of Rubisco in plants can be decreased to save nutrient nitrogen and to determine the extent to which Rubisco controls the rate of photosynthesis.

Transgenic plants expressing altered amounts of Rubisco activase or Rubisco activase polypeptides with mutations or from different species have also increased the understanding of the details of Rubisco activation.

1.1 Transforming higher plant Rubiscos

Recent advances in chloroplast transformation have circumvented many of the previous obstacles to alter higher plant Rubisco. Moreover this approach allows the consequences for leaf photosynthesis and productivity to be determined. For example, in tobacco changing the loop 6 residue leucine 335 for valine decreased both specificity factor and carboxylation rates to 25 per cent of the wild-type values; consequently, the plants were unable to survive without elevated CO_2.Further mutations of this type not only have the potential to improve the specificity factor, but, more importantly, allowanalysis of consequential changes on the physiological properties of the whole plant.

Nuclear transformation has been used to relocate the plastid rbcL gene to the nucleus. Agrobacteriummediated transformation of tobacco lacking the chloroplast rbcL with the rbcL coding region preceded by a plastid targeting sequence was able to supply the defective plastids with fully functional Rubisco. Conversely, although rbcS relocated to the tobacco plastid genome folded correctly and assembled into active holoenzyme, it contributed less than 1 per cent of the total small subunits in the holoenzyme. The scarcity of the transplastomic small subunits may result from inefficient translation or assembly, although the assembled small subunits were as stable as the native counterparts.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Of possible significance is the demonstration that sequences downstream of the translation initiation codon are important determinants of translation efficiency in chloroplasts.

Models for photosynthesis suggest that at elevated CO_2 and temperatures below 25 °C Rubisco from the photosynthetic bacterium Chromatiumvinosum should outperform higher plant Rubiscos. However, attempts to use nuclear transformation to introduce the C. vinosumrbcL into Rubisco-deficient tobacco were not successful. Although the C. vinosumrbcL was transcribed into mRNA, no C. vinosum large subunits were detectable

. Similarly, lines in which the native rbcL of tobacco was replaced with the cyanobacterial rbcL by chloroplast transformation had no large subunit protein or enzyme activity although mRNA was produced. The failure to recover a fully active enzyme could be caused by incompatibility between the large subunits and the small subunits or by inability of the foreign Rubisco subunits to fold or assemble efficiently in the plastid.

Further attempts that avoided the problem of assembling hybrid enzymes involved introduction of both rbcL and rbcS operons of Galdieriasulphuraria and Phaeodactylumtricornutum into the inverted repeats of theplastid genome of tobacco. Whilst the transgenes directed the synthesis of transcripts in abundance, the subunits of these foreign Rubiscos were insoluble, indicating problems with folding or assembly.

In addition, the accumulation of large amounts of insoluble protein decreased the amount of tobacco Rubisco, CO_2 assimilation, and growth. Greater promise has been shown by tobacco lines in which the native rbcL was replaced with rbcL from another higher plant, sunflower (Helianthus annuus), by means of chloroplast transformation, which produced a catalytically active enzyme composed of sunflower large subunits and tobacco small subunits. Whilst the specificity factor of this hybrid enzyme was similar to that of wild-type tobacco it had decreased affinities for both CO_2 and ribulose bisphosphate and greatly decreased activity.

The performance of a further line that expressed a chimeric (sunflower±tobacco) large subunit was similar to that of the other hybrid enzyme.

The ability to recover active Rubisco protein probably reflects the simple dimeric structure of the holoenzyme and consequential simplicity of subunit assembly. Consistent with the kinetic properties of therhodospirillumrubrum Rubisco (whose specificity factor is very small) survival of these lines required elevated CO_2.

Clearly, the introduction of a high specificity factor Rubisco into crop plants remains a realistic goal. Modest changes in key catalytic properties achieved through small changes in rbcL sequences may have considerable significance to the whole plant.. Such differences occur naturally amongst higher plants with high overall sequence homology.

Further technological advances will expedite progress. These include developing chloroplast transformation techniques for the major crop species and overcoming the additional complexities of sufficient expression, post-translational modification, interaction with chaperonins and assembly. This remains a major challenge. Selection even prior to the discovery of the oxygenase activity of Rubisco there had been attempts to manipulate the specificity factor of Rubisco by selection. Such selection relied on maintaining plants at, or slightly above the compensation point; any plant with relatively low rates of photorespiration should thrive whereas plants with relatively high rates of photorespiration should die.

The method is very simple and offers the possibility of screening very large populations. The discovery of the oxygenase activitystimulated further attempts to screen both different genotypes and induced mutants. However, in higher plants the method was not effective at selecting genotypes with increased specificity factor, but did identify some genotypes with improved capacity for dry matter accumulation because of other characteristics.

Investigations with photosynthetic bacteria exploit the potential to screen very large populations e.g. *Rhodobactersphaeroides* and

Rhodobactercapsulatus, *Cyanobacteria*. However, the potential of the unicellular green alga chlamydomonas in selection systems has been studied most.

Changes in photosynthesis have been directly linked to alterations in the Rubisco large subunit gene. Mutants were selected by requirement for acetate as a carbon source and then revertants that were no longer acetate-dependent were selected and characterized. Some of the revertants restored the gene sequence to the wild-type sequence while some were pseudo-revertants, with a second mutation that partly restored the ability to photosynthesize.

The interpretation of these results was based on the crystal structures for tobacco and spinach Rubisco available at the time; now that the C. reinhardtii crystal structure is available this will aid both interpretation and future work in this area. These results, like those from sitedirected mutants, demonstrate how alterations in amino acids remote from the active site of an enzyme can play a significant role in the stability and function of Rubisco. However, in none of the revertants was the specificity factor greater than that of the wild type. Nevertheless, such non-directed approaches have greatly increased understanding about certain regions involved in catalysis. In many cases, photosynthetic mutants have been isolated that are found to have mutations in genes that encode proteins involved in the control of Rubisco expression, rather than within Rubisco itself.

The first successful genetic manipulation of the amount of Rubisco in a higher plant was by transformation of tobacco with a construct containing an antisense rbcS sequence. This decreased the amount of Rubisco via a decrease in the level of endogenous rbcS transcript. Since then, the same antisense approach has been used to decrease the amount of Rubisco in tobacco, the C_4 plant Flaveriabidentis, rice and wheat.

There have been several attempts to increase Rubisco content by overexpressing the rbcS gene, but these have failed, often resulting in decreased Rubisco content by cosuppression. Increases in Rubisco content on a leaf area basis have been observed in plants transformed with transgenes aimed at other targets. In such cases, interpretation is equivocal, since other components may also have been altered (such as chlorophyll content in the example cited).

1.2 Effects on physiology of decreasing Rubisco content

Decreasing Rubisco content decreased photosynthesis nearly proportionately at ambient CO_2 and high light. By contrast, there was little or no effect of small reductions under lightlimiting conditions or at elevated CO_2.Growth at low N supply lowers photosynthetic capacity and extremely low N supply results in photosynthesis being saturated by quite low growth light intensities. Thus, decreased Rubisco content increasingly limits photosynthesis at lower N supplies.Decreased Rubisco content decreases the sink for electrons and thus photoprotective mechanisms are induced at lower light intensities.Transformants of the C_4 plant Flaveriabidentis with lower Rubisco content had lower photosynthetic rates, despite the high CO_2 concentration in the bundle sheath.The amount of Rubisco in wild-type Flaveria plants must therefore be close to the point at which it would limit photosynthetic capacity.

An unexpected result of lowering Rubisco content by antisense rbcS was that stomatal conductance was greater for a given photosynthetic rate, thus giving a higher internal CO_2 concentration in all species.

Possible benefits of decreasing Rubisco content under elevated CO_2

It has been suggested that the increasing atmospheric CO_2 concentration makes a reduction in Rubisco amountdesirable. This is because it becomes increasingly in excess for a given light environment as compared to other photosynthetic components which increasingly limit lightsaturated photosynthesis at high CO_2.This depends on the extent to which acclimation to elevated CO_2 occurs to redress this balance.

Excess Rubisco is only a problem when the resources invested in it could be usefully deployed elsewhere, for example, when growth is N-limited. It now seems clear that the reduction in Rubisco content at elevated CO_2 occurs only when there is demand for N elsewhere in the

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

plant.When N content of cereal leaves is decreased by low N supply or senescence, Rubisco decreases more than other photosynthetic components.In some cases acclimation to elevated CO_2 simply involves earlier leaf senescence that also has the net effect of a relatively larger decrease in Rubisco content. However, this acclimation is usually slow and incomplete.Decreasing the Rubisco content would increase the N-use efficiency both at elevated CO_2 and even at current CO_2 concentrations in moderate light environments.

No evidence of greater efficiency was found for tobacco antisense lines at elevated CO_2. However, rice plants transformed with a construct with an antisense rbcS gene driven by the endogenous rbcS promoter (in contrast to the constitutive promoters used in other studies) did show increased photosynthetic rate at high CO_2 concentration for a given leaf N content. However, the benefit became less at lower leaf N content, so there may be less effect under N-limiting conditions. The growth of the transgenic plants was not greater than the wild type under conditions of saturating CO_2 concentration, but it is not clear whether N supply was limiting growth in this experiment. However, interesting traits associated with decreased Rubisco were identified, including greater allocation of N to leaves and delayed leaf senescence.

1.3 Future manipulation of Rubisco amount

There remains a case for continued attempts to decrease the Rubisco content of crops for nutrient-limited conditions as atmospheric CO_2 concentration increases. However, an important agronomic goal is to increase N uptake by crops during periods of high N supply following fertilizer application before it is lost into the environment. Since high plant N status suppresses N uptake, uptake may be stimulated by increasing N demand.In many crop species during vegetative growth, N is stored primarily as increased photosynthetic capacity in leaves, with a proportionally greater increase in Rubisco content. There may therefore be a case for increasing photosynthetic capacity in crops under conditions of high N supply to maximize storage and decreasing it at low N supply to maximize N-use efficiency. These changes could be brought about using existing natural genetic variation or by direct genetic manipulation of the signalling processes that determine the amounts of Rubisco, given a better understanding of these than currently exists. Such approaches might overcome the undesirable pleiotropic effects of direct manipulation of rbcS expression, such as altering the link between photosynthetic rate and stomatal conductance.

1.4 Regulation

The reversible formation of a carbamate by reaction of CO_2 with the amino group of a lysine residue in the catalytic site and its stabilization by Mg^{2+} is a basic mechanism underlying the control of Rubisco activity. However, since the carbamate group is directly involved in catalysis of both carboxylation and oxygenation, changing residues in Rubisco to change the reactivity of this lysyl residue are reflected in changes in activity.The identification and characterization of a mutant (*rca*) of arabidopsis (*Arabidopsis thaliana*), in which the carbamylation of the catalytic site lysine was impaired, because of the absence of another protein, Rubisco activase, has provided an alternative and adaptable target for changing the regulation of Rubisco activity in leaves.Rubisco activase has been likened to a molecular chaperone and there is clear evidence that it requires a binding site on Rubisco in order to facilitate carbamylation of the lysine residue. Rubisco activase from petunia or tobacco was not effective in the activation of Rubisco from spinach, barley, wheat, soybean, arabidopsis, pea, maize or chlamydomonas, in vitro. Conversely, Rubisco activase from barley or spinach was ineffective in the activation of Rubisco from petunia, tobacco or tomato. Activation of Rubisco is decreased by a high ADP/ATP ratio and is increased by light through the operation of a ferredoxin/thioredoxin-linked mechanism involving redox-sensitive cysteine residues in Rubisco activase itself.

1.5 Effects of decreasing Rubisco activase on Rubisco activity

The arabidopsis mutant (*rca*) completely lacking Rubisco activase is unable to survive in ambient air because the active site lysine does not become fully carbamylated. The mutant survives in air enriched with CO_2 where carbamylation is favoured.Tobacco plants in which activase expression was decreased by transformation with antisense DNA showed no distinct phenotype until the activase was very low. Plants with very little Rubisco activase needed CO_2-enriched atmospheres for survival. Such transgenic plants eventually reached a size similar to the wild type because senescence was delayed.Transgenic arabidopsis plants with 40 per cent of normal activase concentration showed decreased growth and photosynthesis compared to wild-type plants especially as light intensity was increased. Recent interesting observations have been reported with the rca mutant of arabidopsis that has been transformed with DNA coding for either or both isoforms of the Rubisco activase normally found in this plant. Substitution of either C-terminal cysteine for alanine diminished the ATP/ADP sensitivity of activase and the light responsiveness of Rubisco activity in vivo.

2. Metabolism of oxidizing radicals

Molecular oxygen was brought into our atmosphere about 2.7 billion years ago by the O_2 evolving photosynthetic organisms, and reactive oxygen species (ROS) have been the unavoidable by-products of aerobic metabolism. The ROS are highly reactive and are restrained to the different cellular compartments of plant, such as chloroplasts, mitochondria and peroxisomes. Apoplast has also been reported as a site for ROS production.

Under normal environmental conditions, ROS molecules are incapable to cause any damage as they are constantly being scavenged by a range of antioxidative mechanisms. But, the delicate equilibrium between the ROS production and their scavenging by antioxidants is disturbed by different biotic and abiotic stress factors such as salinity, water scarcity, UV radiation, heavy metals, temperature extremes, deficiency of nutrients, pesticides and infection by pathogens. These disturbances lead an increased intracellular production of ROS which may cause substantial damage to the cellular components.It has been reported that about 2 per cent of O_2 consumption by plant cells leads to the ROS generation in these cells. The ROS include both free radical (O2•, superoxide radical; OH•, hydroxyl radical; HO_2•, perhydroxyl radical; and RO•, alkoxy radicals) and nonradical (molecular) forms (H_2O_2, hydrogen peroxide, and 1 O_2, singlet oxygen). These reactive intermediates are very toxic and cause extensive damage to biomolecules like proteins, DNA and lipids and eventually lead to cell death.

During stressful environments, the increased levels of ROS get scavenged by the plant's antioxidative machinery comprising of the enzymatic components that include superoxide dismutase (SOD), ascorbate peroxidase (APX), guaiacol peroxidase (GOPX), glutathione-S-transferase (GST) and catalase (CAT) and the non-enzymatic metabolites such as ascorbic acid (AA), reduced glutathione (GSH), α-tocopherol, carotenoids, phenolics, proline and flavonoids. The presence of the antioxidative compounds in majority of the cellular compartments reveals the importance of ROS detoxification for continuous cellular existence.

2.1 Detoxification by Antioxidative Machinery Under Stressful Environments

Under normal environmental conditions, the generation of ROS in plants is low. However, under stress conditions, ROS production considerably increases in plants, misbalancing the normal production of O2•, OH• and H_2O_2 in the intracellular environment.Under drought stress, SOD activity increased in different cultivars of *Phaseolus vulgaris*and *Oryza sativa*and in the leaves of *Trifolium repens*.During the drought stress conditions, the enhancement in ROS generation may occur in many ways. Under drought stress, there is restricted fixation of CO_2 due to closing of stomata, leading to reduced NADP+ regeneration via C_3 cycle. Due to shortage of electron acceptors, overloading of the electron transfer occurs in photosynthetic electron transport chain, which results in higher seepage of electrons to O_2 by the Mehlerreaction.

Drought stress also causes enhanced activity of photorespiration, particularly, when RuBP oxygenation is higher due to less availability of CO_2.More than 70 per cent of total H_2O_2 generation via photorespiration occurs under drought stress environments. The overexpression of APX in the chloroplasts of *Nicotiana tabacum* reduced the toxicity of H_2O_2, resulting in the generation of drought tolerance in a plant.The greater vulnerability of the sensitive varieties IR-29 and Pusa Basmati to water deficiency was due to significant decline in GSH/GSSG ratio, as compared to the tolerant variety Pokkali.

Exogenous application of AA to wheat cultivars increased the level of photosynthetic pigments, net photosynthesis and growth, compared to the untreated plants grown under drought conditions.The SOD activity also enhanced under salt stress conditions in chickpea and tomato Transgenic Arabidopsis overexpressing Mn-SOD was witnessed to have increased tolerance against salt stress.High CAT activity was noticed in *Cicer arietinum* under salt stress.Under saline conditions, the activities of APX and GR (glutathione reductase)were reportedly higher in salt-tolerant cultivars of potato, whereas significantly reduced in salt-sensitive varieties.Overexpression of MDHAR(monodehydroascorbate reductase) in Nicotiana tabacum and DHAR (dehydroascorbate reductase) in arabidopsis improved their tolerance against salt stress.Both AA and GSH contents were found to be higher in salt-tolerant cultivar Pokkali as compared to sensitive cultivar Pusa Basmati.Exogenous application of AA to the salt stressed tomato plants accelerated their recovery process and certified their long-lasting survival.Ascorbic acid also helped to mitigate oxidative stress in wheat, by improving its photosynthetic capability.Salt stress causes closure of stomata, which limits CO_2 fixation in the leaves, and finally results in the overreduction of photosynthetic electron transport system, leading to increased ROS production. Low CO_2/O_2 ratio in chloroplasts also promotes photorespiration resulting into enhanced generation of H_2O_2.

It is also reported that heavy metals like cadmium (Cd) stress enhanced the CAT activity in *Phaseolus aureus*, *Pisum sativum* and *Lemna minor*.The plant species *Vaccinium myrtillus* is well known as a colonist of heavy metal-contaminated soil, and contents of GSH, GPX, nonprotein thiols and proline in this plant were found to be enhanced when grown in heavy metal-contaminated sites.Transgenic tobacco overexpressing Arabidopsis VTE1 (encoding tocopherol biosynthesis enzyme) showed diminished lipid peroxidation, electrolyte leakage and H_2O_2 content but had higher chlorophyll contents as compared to its wild species.Carotenoid an essential component of the defence mechanism of plants, protects chlorophyll and photosynthetic membrane from photo-oxidative damage.

Drought-like conditions created by 20 per cent polyethylene glycol (PEG 6000) treatment to rice seedlings increased the levels of flavonoids and phenolics in the plant.The level of these non-enzymatic antioxidants was found to be many times higher in the tolerant variety Pokkali, as compared to the sensitive cultivars IR-29 and Pusa Basmati.The accumulation of an osmo-protectant proline was higher in drought-tolerant cultivars of chickpea as compared to its sensitive varieties under both normal and drought-stressed environments.The salt-tolerant cultivar of rice showed higher accumulation of flavonoids than the salt-sensitive cultivars.

3. Sink capacity

Source strength for photo assimilates is dictated by both net photosynthetic rate and the rate of photoassimilate remobilisation from source tissues.Crop yield potential is the yield of an adapted cultivar grown in an ideal environment where abiotic and biotic stresses are effectively controlled. Metrics used to quantify yield are crop-specific, commonly including volume and/or weighttogether with plant efficiency expressed in terms such as harvest index. These metrics provideinformation on the characteristics that determine yield improvements under both controlledand field conditions.

Specifically, ability to reduce the yield gap and enhance the security offood production is limited by misconceptions and knowledgegaps in (1) the clarification of metrics to describe yieldproduction, (2) coupling of source strength to yield production,(3) characterizing the source-path-sink transition for resourceswithin the plant, (4) defining sink strength and its measurement,and (5) characterizing the resilience of yield quantity andquality.

Transfer of materials from source to sink is controlledby a highly regulated signalling network elicited by resourceavailability. Despite theimportance of such a relationship, the mechanistic basis for thisregulation is poorly described. In the broadest sense, it is thoughtthat the source-sink relationship is impacted by the environmentwhich drives source activity (photosynthesis) and consequentlyincreases sink activity (tissue growth and storage). Less considered is the influence of sink strength in thisrelationship and its capacity to influence source activity. Therelationship is complex, and consideration must begin to focuson the dynamic nature of the network, both for source and sinkstrength to fully comprehend the plasticity of yield development,particularly under changing environmental conditions whereelements such as carbon, nitrogen and water govern the fluxesand hence source-sink dynamics

3.1 Source- sink pathway

It is understood that only 2–4 per cent ofavailable radiation is converted into growth andtypically that 50–80 per cent of photoassimilates from a single mature leaf are transported into the phloem. However, we have less of an understanding about the influence ofchanging environmental conditions on the export of carbon fromleaves and import to sinks, partitioning between heterotrophictissues and remobilization of carbohydrates into reproductivestructures. To capitalize on recent advances that have improvedphotosynthetic efficiency, developing an understanding of theway energy and nutrients move through a plant and intoa developing seed is key to ensuring the efficiency of yieldproduction, particularly under abiotic stress.

3.2 Defining and measuring sink strength

In many cases, particularly for agricultural activities, thenet cumulative result of sink strength under a given sourceavailability is yield. Whilst the relationship between sources and sinks is undoubtedly complex, the definition typically given forsink strength is:

Sink strength = sink size x sink activity

where; sink size is the total biomass of sink tissue (g), andsink activity refers to the specific uptake rate of the resourcein mol g^{-1} s^{-1}.

Ambiguity surroundingsink strength occurs due to an inability to directly measure(quantify) it and lack of understanding of the processes thatdrive sink activity. Given the number of factors that relateto sink activity (growth, metabolism), it is incongruous thatsink size has a proportional influence on sink activity oversink strength. Whilst it is recognizedthat sink size has some influence over total metabolic activity,rates of metabolism vary according to ontological and tissuedevelopment.Understanding the processes and conditionsgoverning changes to sink strength, along with improvements intechnology that allow for the direct measurement of sink demandwill lead to greater accuracy in the way sink strength is described.The realized movement and metabolism of sugars alongthe path between source and sink ultimately determines yieldfor which some elements of this system are well described.Movement or “loading” of photo assimilates from leaf tissuesinto the phloem pathway is likely an important rate-limitingstep for photo assimilate movement therefore an importantcandidate process for improvement of transport rates. Themain mechanisms for phloem loading that exist in plants are,apoplastic loading and symplastic loading for a “comprehensivepicture of phloem loading strategies. The predominant mechanisms employed are supposedto be species specific although evidence is emerging formultiple mechanisms functioning in the same plant. It is likely that plants are flexible intheir mode of phloem loading and alter mechanisms acrossdevelopment and in response to biotic and abiotic stress. The capacity for phloem loadingdepends upon the transport mechanism. Sucrose transporters function in apoplastic loading whereas in symplastic loading, plasmodesmal conductance for the polymer trapping mechanismare determined by catalytic interconversion of sucrose intoraffinose family oligosaccharides (RFOs).

The capacity of phloem loading impacts on the relationship between source and sink. If sink demand is high,sucrose levels are low and transcription is high. If sink demand drops, export slows and sucrose builds up and down-regulatessymporter transcription and abundance. As phloem loadingcapacity drops, carbohydrate then builds up in the mesophylland photosynthesis is down-regulated.The dynamic feedback between carbohydrate utilization by the sink and productionby the source clearly identifies a framework for demanddriven production by alleviating sugar mediated repression ofphotosynthesis.

Understanding the processes and conditionsgoverning changes to sink strength, along with improvements intechnology that allow for the direct measurement of sink demandwill lead to greater accuracy in the way sink strength is described.Measuring sink strength is difficult. For provision ofphoto assimilates, source activity can be well characterized bymeasurement of net photosynthetic rate. However, due to thecomplexity of sinks, measurement is typically confined to aquantification of sink size, typically via the removal of sink tissue,along with some measure or estimate of sink activity.In essence,the ability to explore the complexity of sinks in the context ofthe whole plant without altering the system requires non-invasivetechnologies.

Plants aim to maintain a consistent supply of carbon andmineral nutrients to support metabolism and growth. To dothis, photo assimilates are stored as starch, used directly formetabolism or synthesized into non-reducing sugars for export tosinks.Distribution is thought to be determinedby a sinks ability to accept photoassimilates which is dependent on the capacity to metabolize or store sugars for use. Despite theimportance of partitioning on yield volume, we have just begunto understand the mechanisms responsible for the distributionof photoassimilates throughout the plant.Underlying partitioning is a complex signalling network involving both physical and chemical signals that play an important influencing overall source-sink activity. Further understanding of allocation and partitioningprocesses on a whole plant level may enhance yield potentials byreducing photosynthate partitioned to other areas and allocatingthis carbon to yield. In doing so, care must be taken to ensurethat this does not impact on essential aspects of plant function orreduce strategies that plants can employ in response to changesin environmental conditions.

Glossary

Carbamylation (carbamoylation) is a post-translational modification resulting from the nonenzymatic reaction between isocyanic acid and free functional groups of proteins, in particular with the free amino groups.

Perennation

In botany, **perennation** is the ability of organisms, particularly plants, to survive from one germinating season to another, especially under unfavourable conditions such as drought or winter. It typically involves development of a **perennating organ**, which stores enough nutrients to sustain the organism during the unfavourable season, and develops into one or more new plants the following year. Common forms of perennating organs are storage organs (e.g. tubers, rhizomes and corm), and buds. Perennation is closely related with vegetative reproduction, as the organisms commonly use the same organs for both survival and reproduction.

Holoenzymes: Holoenzymes are the active forms of enzymes. Enzymes that require a cofactor but are not bound by one are called apoenzymes. Holoenzymes represent the apoenzyme bound to its necessary cofactors or prosthetic groups.

Antisense: Antisense is **the non-coding DNA strand of a gene**. A cell uses antisense DNA strand as a template for producing messenger RNA (mRNA) that directs the synthesis of a protein. Antisense can also refer to a method for silencing genes.

Mehler reaction: The **Mehler reaction** is named after Alan H. Mehler, who, in 1951, presented data to the effect that isolated chloroplasts reduce oxygen to form hydrogen peroxide (H_2O_2). Mehler observed that the H_2O_2 formed in this way does not present an active intermediate in photosynthesis; rather, as a reactive oxygen species, it can be toxic to surrounding biological processes as an oxidizing agent. In scientific literature, the Mehler reaction often is used interchangeably with the **Water-Water Cycle**to refer to the formation of H_2O_2 by photosynthesis. *Sensustricto*, the Water Water Cycle encompasses the Hill reaction, in which water is split to form oxygen, as well as the Mehler Reaction, in which oxygen is reduced to form H_2O_2 and, finally, the scavenging of this H_2O_2 by antioxidants to form water.

Arabidopsis: Arabidopsis (rockcress) is a genus in the family Brassicaceae. They are small flowering plants related to cabbage and mustard.

References

GHANNOUM, O., VON CAEMMERER,S., ZISKA, L.H and CONROY,J.P (2000).The growth response of C4 plants to rising atmospheric CO2 partial pressure: a reassessment. *Plant, Cell and Environment.* 23, 931–942.

Lawlor, D.W and Tezara,W. (2009). Causes of decreased photosynthetic rate and metabolic capacity in water-deficient leaf cells: a critical evaluation of mechanisms and integration of processes. Annals of Botany 103: 561–579, 2009 doi:10.1093/aob/mcn244.

Parry,M.A.J., Andralojc,P.J.,Mitchell,R.A.C.,Madgwick, P.J. and Keys, A.J. (2003). Manipulation of Rubisco: the amount, activity, function and regulation Journal of Experimental Botany, Vol. 54, No. 386.