UNIT II

ENVIRONMENT CONTROL SYSTEMS

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

Introduction:

1. **Plants and light signaling**

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

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

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

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

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

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

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

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

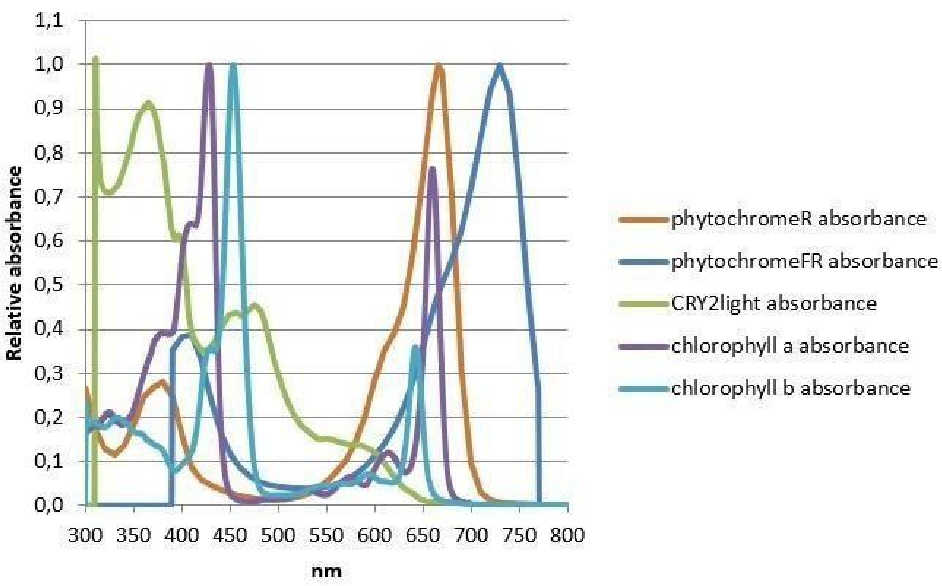
   However, chlorophyll is not the only plant pigment; the so-called accessory pigments (carotenoids, xanthophylls, etc.) and phenolic substances (flavonoids, anthocyanins, flavones and flavonoids) capture wavelengths other than only red and blue. The accessory pigments are yellow, red and violet in color.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

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

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

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

Figure 1. Relative absorbance of different photoreceptors in plant



3. **Light quality**

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

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

Photosynthesis is a series of processes driven by photons absorbed by the plant pigments. Photosynthesis is not very efficient since only 4-6% of the energy available in the radiation is converted into biomass. Photosynthesis can be intensified with elevated CO2 concentration, however an increase in photosynthesis rate does not translate into a linear increase in plant growth or yield increase. Plants control their own development so that they cannot grow indefinitely.

4. **The colors of light**

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

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

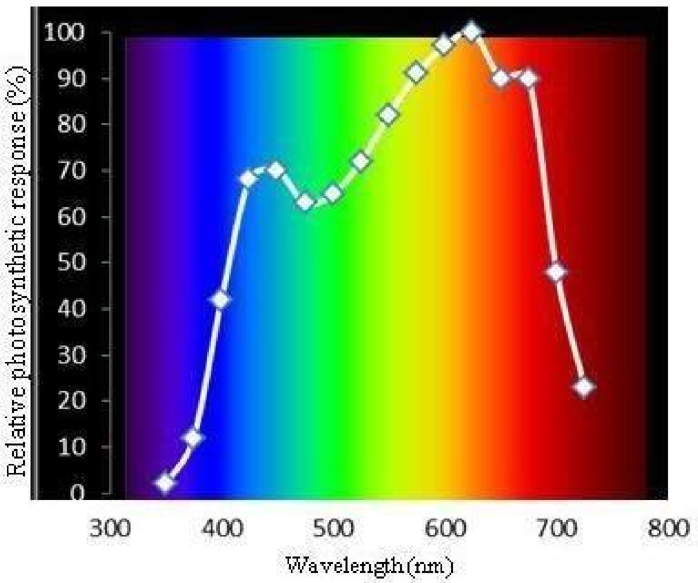


Figure 2. McCree's curve of the photosynthetic response (1972)

The effect of different wavelengths on plant growth and development:

- Ultraviolet. UV-B light is captured by the UVR8 photoreceptor. A large dose is harmful to plants, since it degrades DNA. However, in small doses, both UV-B and UV-A increase the stress tolerance of plants. In general, plants grown under ultraviolet light have thick leaves and stems and short internodes.
- Blue. Blue light is perceived by the blue light photoreceptors, phototropins and cryptochromes. Phototropins mediate stomatal regulation and plant movement towards light. Cryptochromes regulate many photomorphological responses, such as inhibition of stem elongation. Plants grown under high blue irradiation have short internodes, high dry matter content and low leaf temperature (efficient transpiration).
- Green. Green light is at least partially perceived by phototropins and cryptochromes (blue light receptors). Most green light is reflected or penetrated
  through the canopy. However, green light contains valuable information about the plant's surroundings, guiding the growth accordingly. Plants grown under green light have long petioles internodes and high leaf temperature.
- Red. Red light is perceived by phytochromes. Phytochromes absorb both red and far-red light and are the main regulators of the shade avoidance syndrome. Red light converts phytochromes to their inactive state, Pr, which has an absorption peak at 660 nm. The Pr form of phytochrome is synthesized in dark conditions or in far-red light conditions. When the Pr absorbs red light, it transforms to the far- red absorbing Pfr form, which has the absorption peak at 730 nm. The conversion from Pr to Pfr can be reversed with far-red light or darkness.
- Far-red. Far-red light is absorbed by the phytochromes. Phytochromes absorb both red and far-red light and are the main regulators of the shade avoidance syndrome. High far-red irradiation causes premature flowering in many species, and elongation of stem and petioles.

5. **Vernalization**

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

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

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

1. Artificial lighting for plant growth

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

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

The most commonly used greenhouse lights, the high-pressure sodium (HPS) lamps, irradiate mainly in the yellow and red area of the visible spectrum, while fluorescent lights, which have traditionally been used in growth chambers have more blue light in their spectrum.Artificial lighting applied to greenhouses has historically been linked to areas that receive few hours of sunshine during winter, or to the modification of the photoperiod to induce flowering of ornamental crops at times of the year in which they have greater commercial value.

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

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

What is LED Farming?

Growing plants indoors, in the presence of LED lights and using multiple layers to maximize production.

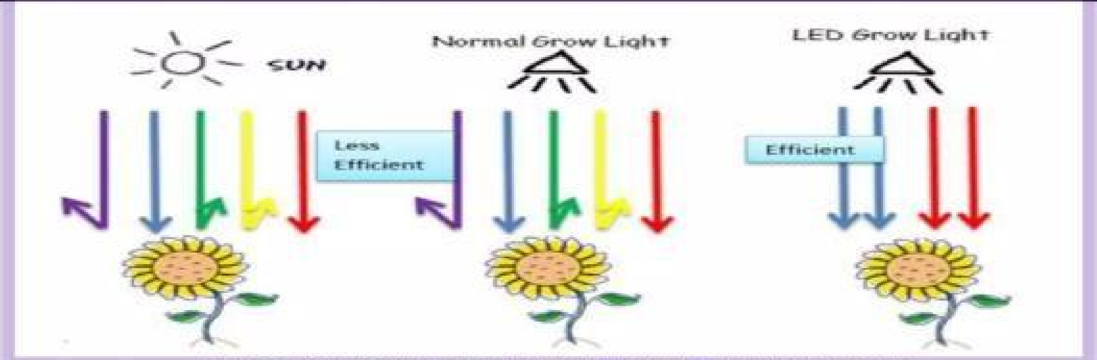
Why LED Farming?

- Population increase.
- 80% land for growing food is already in use.
- LEDs surpass 50% efficiency.
- Year round production irrespective of climatic changes.

80% OF THE EARTH'S AVAILABLE LAND IS ALREADY FARMED

LED LIGHTING VS. SUNLIGHT

- LED lighting has reduced the heat transferred onto plants.
- According to urban farming research(2013), the blue-red spectra is ideal for plant growth instead of sunlight that has a variety of colour spectra.



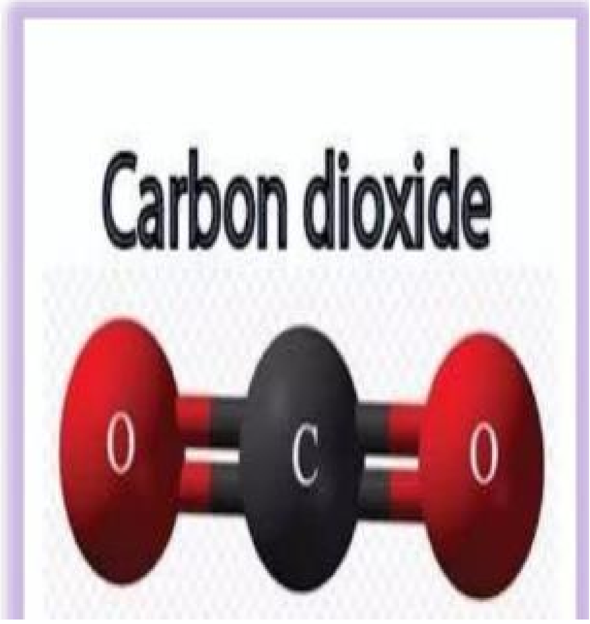
LED GROW LIGHTS ARE MORE EFFICIENT THAN SUNLIGHT

GROWTH MEDIUM

- No soil.
- Plants are suspended in a fabric made from old pop bottles.
- Hydroponics,Aeroponics, Aquaponics used.

CO_2 INJECTION

Net photosynthesis increases by 50% as CO_2 levels increase from 340–1,000 ppm (parts per million).



AIR FLOW

- In poorly ventilated rooms, the crops menaced by pests will be increased.
- 4-6 inch fans are adequate.

AEROFARMS GROWS GREENS UNDER INTENSE LED GROW LIGHTS AND FANS

LIGHTING TIME AND HANGING DISTANCE

- Approximately 12 to 18 hours of light is required for active photosynthesis and healthy growth.
- Hanging distance : 12-30''

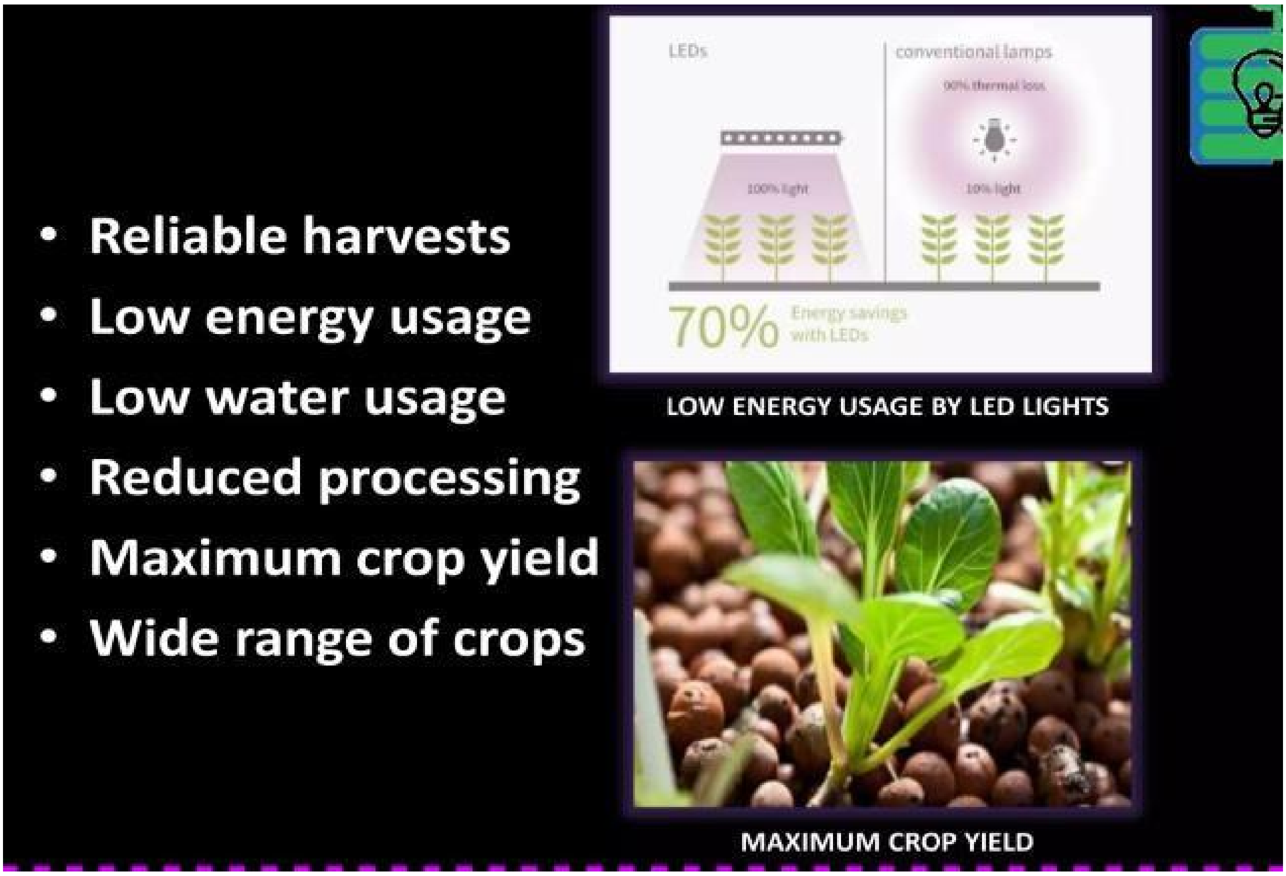
EFFECT OF LIGHTING TIME AND HANGING DISTANCE OF LEDs ON PLANTS

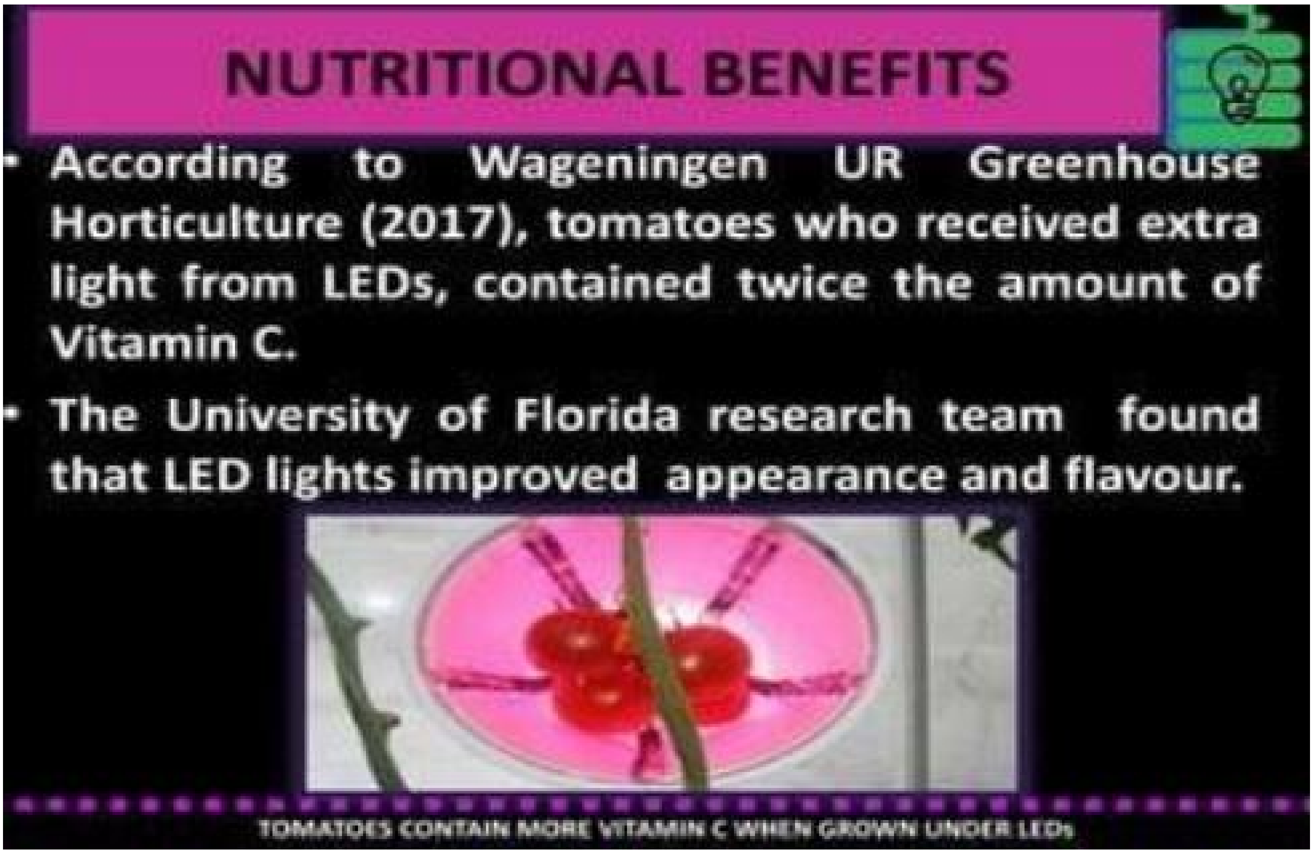
Plants grown by LED farming

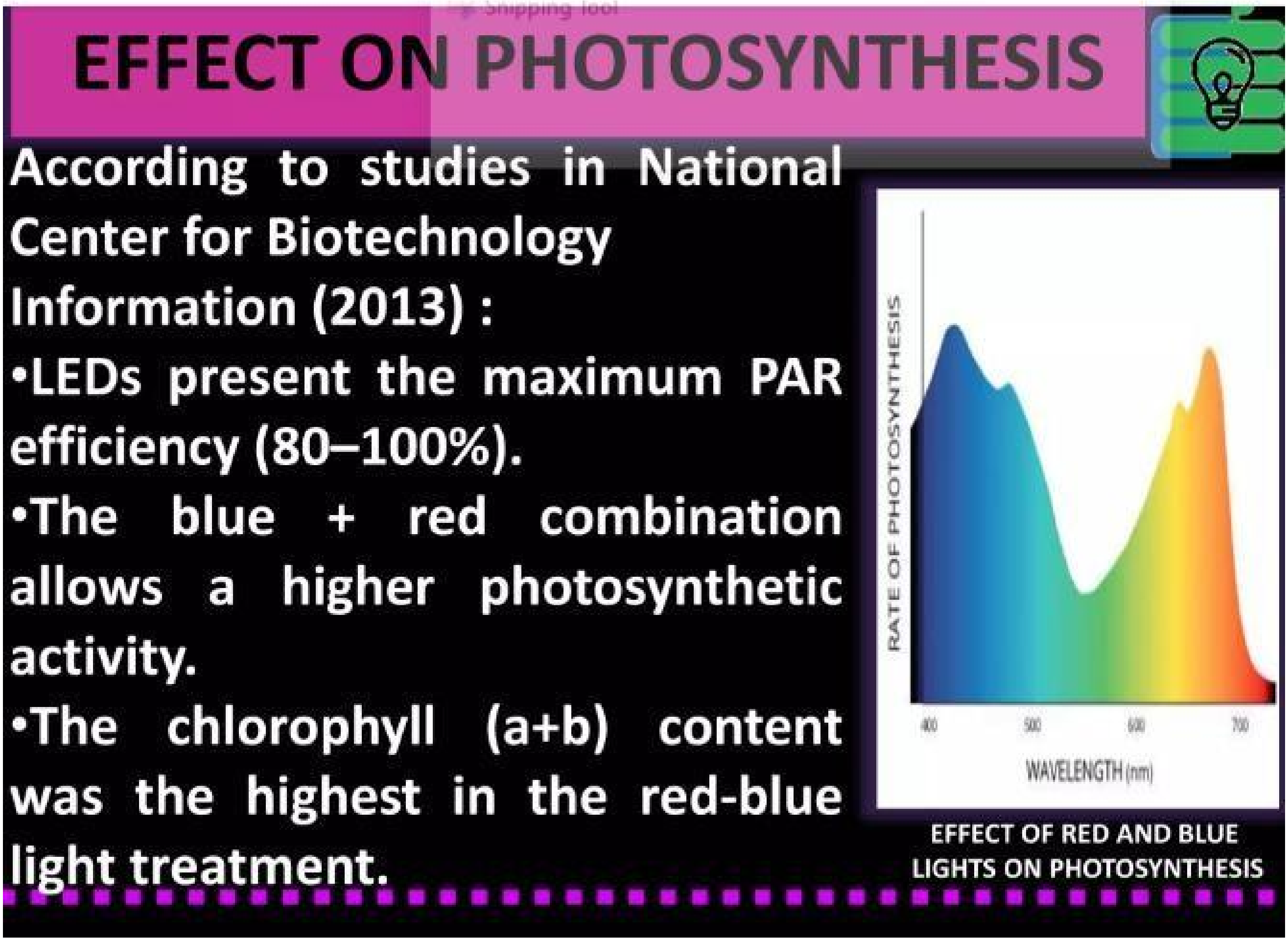
- **Basil, microgreens** (Bedford Park, Illinois)
- **Strawberry** (Ichigo Company, Tainai, Niigata, Japan)
- **Medical cannabis** (Oakland, California)
- **Tomato** (Pasona O_2, Tokyo)
- **Potato** (Astroculture, Barneveld, Wisconsin)
- **Lettuce** (Green Sense Farms, US)


Basil, microgreens (Bedford Park, Illinois)
Strawberry (Ichigo Company, Tainai, Niigata, Japan)
Medical cannabis (Oakland, California)
Tomato (Pasona O_2, Tokyo)

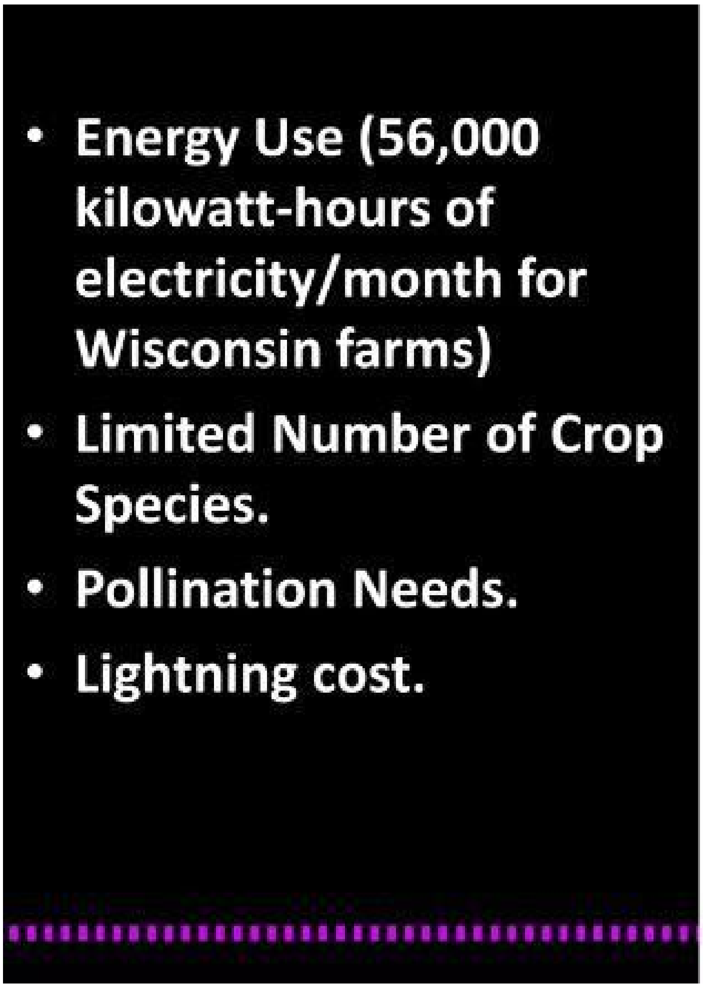
Advantages


• Reliable harvests
• Low energy usage
• Low water usage
• Reduced processing
• Maximum crop yield
• Wide range of crops
LEDs
conventional lamps
70%
Energy savings with LEDs
LOW ENERGY USAGE BY LED LIGHTS
MAXIMUM CROP YIELD


NUTRITIONAL BENEFITS
• According to Wageningen UR Greenhouse Horticulture (2017), tomatoes who received extra light from LEDs, contained twice the amount of Vitamin C.
• The University of Florida research team found that LED lights improved appearance and flavour.
TOMATOES CONTAIN MORE VITAMIN C WHEN GROWN UNDER LEDs


EFFECT ON PHOTOSYNTHESIS
According to studies in National Center for Biotechnology Information (2013) :
•LEDs present the maximum PAR efficiency (80–100%).
•The blue + red combination allows a higher photosynthetic activity.
•The chlorophyll (a+b) content was the highest in the red-blue light treatment.
RATE OF PHOTOSYNTHESIS
400
500
600
700
WAVELENGTH (nm)
EFFECT OF RED AND BLUE LIGHTS ON PHOTOSYNTHESIS

Drawbacks



RISING ENERGY USE

MORE LIGHTNING COST

Greenhouse

Greenhouse is the most practical method of achieving the objectives of protected agriculture, where the natural environment is modified by using sound engineering principles to achieve optimum plant growth and yields.

Green House:

A greenhouse is a framed or an inflated structure covered with a transparent or translucent material in which crops could be grown under the conditions of at least partially controlled environment and which is large enough to permit persons to work within it to carry out cultural operations.

The growing of off - season cucumbers under transparent stone for Emperor Tiberius in the 1st century, is the earliest reported protected agriculture. The technology was rarely employed during the next 1500 years. In the 16th century, glass lanterns, bell jars
and hot beds covered with glass were used to protect horticultural crops

against cold. In the 17th century, low portable wooden frames covered with an oiled translucent paper were used to warm the plant environment.

In Japan, primitive methods using oil -paper and straw mats to protect crops from the severe natural environment were used as long ago the early 1960s. Greenhouses in France and England during the same century were heated by manure and covered with glass panes. The first greenhouse in the 1700s used glass on one side only as a sloping roof. Later in the century, glass was used on both sides. Glasshouses were used for fruit crops such as melons, grapes, peaches and strawberries, and rarely for vegetable production.

Protected agriculture was fully established with the introduction of polyethylene after the World war II. The first use of polyethylene as a greenhouse cover was in 1948, when professor Emery Myers Emmert, at the University of Kentucky, used the less expensive material in place of more expensive glass.

The total area of glasshouses in the world (1987) was estimated to be 30,000 ha and most of these were found in North- Western Europe. In contrast to glasshouses, more than half of the world area of plastic green houses is in Asia, in which China has the largest area. According to 1999 estimates, an area of 6, 82,050 ha were under plastic greenhouses (Table 1.1). In most of the countries, green houses are made of plastic and glass; the majority is plastic.

Glasshouses and rigid plastic houses are longer-life structures, and therefore are most located in cold regions where these structures can be used throughout the year. In Japan, year-round use of greenhouses is becoming predominant, but in moderate and warm climate regions, they are still provisional and are only used in winter.

In India, the cultivation in the plastic greenhouses is of recent origin. As per 1994-95 estimates, approximately 100 ha of India are under greenhouse cultivation.

Since 1960, the greenhouse has evolved into more than a plant protector. It is now better understood as a system of controlled environment agriculture (CEA), with precise control of air and root temperature, water, humidity, plant nutrition, carbon dioxide and light. The greenhouses of today can be considered as plant or vegetable factories. Almost every aspect of the production system is automated, with the artificial environment and growing system under nearly total computer control.

Greenhouse Effect

In general, the percentage of carbon dioxide in the atmosphere is 0.035% (345 ppm). But, due to the emission of pollutants and exhaust gases into the atmosphere, the percentage of carbon dioxide increases which forms a blanket in the outer atmosphere. This causes the entrapping of the reflected solar radiation from the earth surface. Due to this, the atmospheric temperature increases, causing global warming, melting of ice caps and rise in the ocean levels which result in the submergence of coastal lines. This phenomenon of increase in the ambient temperature, due to the formation of the blanket of carbon dioxide is known as **greenhouse effect**.

The greenhouse covering material acts in a similar way, as it is transparent to shorter wave radiation and opaque to long wave radiation.

During the daytime, the shorter wave radiation enters into the greenhouse and gets reflected from the ground surface. This reflected radiation becomes long wave radiation and is entrapped inside the greenhouse by the covering material. This causes the increase in the greenhouse temperature. It is desirable effect from point of view of crop growth in the cold regions.

Advantages of Greenhouses

The following are the different advantages of using the green house for growing crops under controlled environment:

1. Throughout the year four to five crops can be grown in a green house due to availability of required plant environmental conditions.
2. The productivity of the crop is increased considerably.
3. Superior quality produce can be obtained as they are grown under suitably controlled environment.
4. Gadgets for efficient use of various inputs like water, fertilizers, seeds and plant protection chemicals can be well maintained in a green house.
5. Effective control of pests and diseases is possible as the growing area is enclosed.
6. Percentage of germination of seeds is high in greenhouses.
7. The acclimatization of plantlets of tissue culture technique can be carried out in a green house.
8. Agricultural and horticultural crop production schedules can be planned to take advantage of the market needs.
9. Different types of growing medium like peat mass, vermiculate, rice hulls and compost that are used in intensive agriculture can be effectively utilized in the greenhouse.
10. Export quality produce of international standards can be produced in a green house.
11. When the crops are not grown, drying and related operations of the harvested produce can be taken up utilizing the entrapped heat.
12. Greenhouses are suitable for automation of irrigation, application of other inputs and environmental controls by using computers and artificial intelligence techniques.
13. Self-employment for educated youth

2 Greenhouse Structure

Greenhouse structures of various types are used successfully for crop production. Although there are advantages in each type for a particular application, in general there is no single type greenhouse, which can be considered as the best. Different types of greenhouses are designed to meet the specific needs.

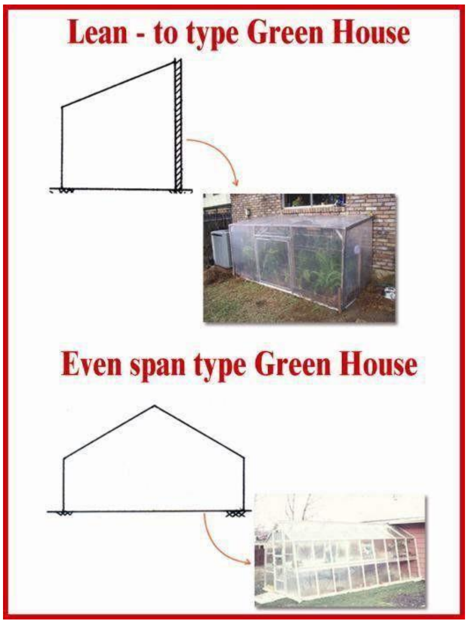
2.1 Greenhouse type based on shape

Greenhouses can be classified based on their shape or style. For the purpose of classification, the uniqueness of the cross section of the greenhouses can be considered as a factor. As the longitudinal section tend to be approximately the same for all types, the longitudinal section of the greenhouse cannot be used for classification. The cross sections depict the width and height of the structure and the length is perpendicular to the plane of cross section. Also, the cross section provides information on the overall shape of the structural members, such as truss or hoop, which will be repeated on every day.

The commonly followed types of greenhouse based on shape are lean-to, even span, uneven span, ridge and furrow, saw tooth and quonset.

2.1.1 Lean-to type greenhouse

A lean-to design is used when a greenhouse is placed against the side of an existing building. It is built against a building, using the existing structure for one or more of its sides (Fig.1). It is usually attached to a house, but may be attached to other buildings. The roof of the



building is extended with appropriate greenhouse covering material and the area is properly enclosed. It is typically facing south side. The lean-to type greenhouse is limited to single or double-row plant benches with a total width of 7 to 12 feet. It can be as long as the building it is attached to. It should face the best direction for adequate sun exposure.

The advantage of the lean-to type greenhouse is that, it usually is close to available electricity, water, and heat. It is a least expensive structure. This design makes the best use of sunlight and minimizes the requirement of roof supports. It has the following disadvantages: limited space, limited light, limited ventilation and temperature control. The height of the supporting wall limits the potential size of the design. Temperature control is more difficult because the wall that the greenhouse is built on, may collect the sun's heat while the translucent cover of the greenhouse may lose heat rapidly. It is a half greenhouse, split along the peak of the roof.

2.1.2 Even span type greenhouse

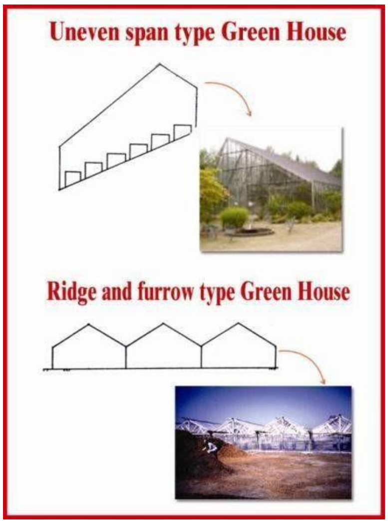
The even-span is the standard type and full-size structure, the two roof slopes are of equal pitch and width (Fig.1). This design is used for the greenhouse of small size, and it is constructed on level ground. It is attached to a house at one gable end. It can accommodate 2 or 3 rows of plant benches. The cost of an even-span greenhouse is more than the cost of a lean-to type, but it has greater flexibility in design and provides for more plants. Because of its size and greater amount of exposed glass area, the even-span will cost more to heat. The design has a better shape than a lean-to type for air circulation to maintain uniform temperatures during the winter heating season. A separate heating system is necessary unless the structure is very close to a heated building. It will house 2 side benches, 2 walks, and a wide center bench. Several single and multiple span types are available for use in various regions of India. For single span type the span in general, varies from 5 to 9 m, whereas the length is around 24 m. The height varies from 2.5 to 4.3 m.

2.1.3 Uneven span type greenhouse

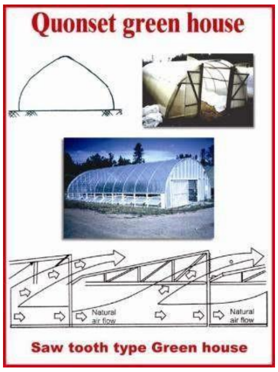
This type of greenhouse is constructed on hilly terrain. The roofs are of unequal width; make the structure adaptable to the side slopes of hill (Fig. 2). This type of greenhouses is seldom used now-a-days as it is not adaptable for automation.

2.1.4 Ridge and furrow type greenhouse

Designs of this type use two or more A-frame greenhouses connected to one another along the



length of the eave (Fig. 2). The eave serves as furrow or gutter to carry rain and melted snow away. The side wall is eliminated between the greenhouses, which results in a structure with a single large interior, Consolidation of interior space reduces labour, lowers the cost of automation, improves personal management and reduces fuel consumption as there is less exposed wall area through which heat escapes. The snow loads must be taken into the frame specifications of these greenhouses since the snow cannot slide off the roofs as in case of individual free standing greenhouses, but melts away. In spite of snow loads, ridge and furrow greenhouses are effectively used in northern countries of Europe and in Canada and are well suited to the Indian conditions.



2.1.5 Saw tooth type Greenhouse

These are also similar to ridge and furrow type greenhouses except that, there is provision for natural ventilation in this type. Specific natural ventilation flow path (Fig. 3) develops in a saw- tooth type greenhouse.

2.2 Greenhouse type based on utility

Classification of greenhouses can be made depending on the functions or utilities. Of the different utilities, artificial cooling and heating of the greenhouse are more expensive and elaborate. Hence based on the artificial cooling and heating, greenhouses are classified as green houses for active heating and active cooling system.

2.2.1 Greenhouses for active heating

During the night time, air temperature inside greenhouse decreases. To avoid the cold bite to plants due to freezing, some amount of heat has to be supplied. The requirements for heating greenhouse depend on the rate at which the heat is lost to the outside environment. Various methods are adopted to reduce the heat losses, viz., using double layer polyethylene, thermo pane glasses (Two layers of factory sealed glass with dead air space) or to use heating systems, such as unit heaters, central heat, radiant heat and solar heating system.

2.2.2 Greenhouses for active cooling

During summer season, it is desirable to reduce the temperatures of greenhouse than the ambient temperatures, for effective crop growth. Hence suitable modifications are made in the green house so that large volumes of cooled air is drawn into greenhouse, This type of greenhouse either consists of evaporative cooling pad with fan or fog cooling. This greenhouse is designed in such a way that it permits a roof opening of 40% and in some cases nearly 100%.

2.3 Greenhouse type based on construction

The type of construction is predominantly influenced by the structural material, though the covering material also influences the type. Span of the house inurn dictates the selection of structural members and their construction. Higher the span, stronger should be the material and more structural members are used to make sturdy truss type frames. For smaller spans, simpler designs like hoops can be followed.

2.3.1 Wooden framed structures

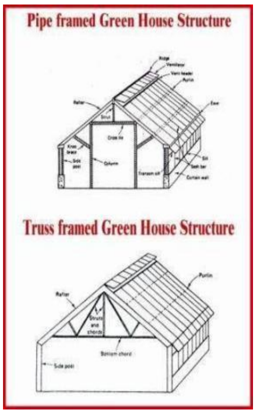
In general, for the greenhouses with span less than 6 m, only wooden framed structures are used. Side posts and columns are constructed of wood without the use of a truss. Pine wood is commonly used as it is inexpensive and possesses the required strength. Timber locally available, with good strength, durability and machinability also can be used for the construction.

2.3.2 Pipe framed structures

Pipes are used for construction of greenhouses, when the clear span is around 12m (Fig. 4). In general, the side posts, columns, cross ties and purlins are constructed using pipes. In this type, the trusses are not used.

2.3.3 Truss framed structures

If the greenhouse span is greater than or equal to 15m, truss frames are used. Flat steel, tubular steel or angular iron is welded together to form a truss encompassing rafters, chords and struts (Fig. 4). Struts are support members under compression and chords are support members under tension. Angle



iron purlins running throughout the length of greenhouse are bolted to each truss. Columns are used only in very wide truss frame houses of 21.3 m or more. Most of the glass houses are of truss frame type, as theseframes are best suited for pre-fabrication.

2.4 Greenhouse type based on covering materials

Covering materials are the major and important component of the greenhouse structure. Covering materials have direct influence on the greenhouse effect inside the structure and they alter the air temperature inside the house. The types of frames and method of fixing also varies with the covering material. Based on the type of covering materials, the greenhouses are classified as glass, plastic film and rigid panel greenhouses.

2. 4.1 Glass greenhouses

Only glass greenhouses with glass as the covering material existed prior to 1950. Glass as covering material has the advantage of greater interior light intensity. These greenhouses have higher air infiltration rate which leads to lower interior humidity and better disease prevention. Lean-to type, even span, ridge and furrow type of designs are used for construction of glass greenhouse.

2.4.2 Plastic film greenhouses

Flexible plastic films including polyethylene, polyester and polyvinyl chloride are used as covering material in this type of greenhouses. Plastics as covering material for greenhouses have become popular, as they are cheap and the cost of heating is less when compared to glass greenhouses. The main disadvantage with plastic films is its short life. For example, the best quality ultraviolet (UV) stabilized film can last for four years only. Quonset design as well as gutter-connected design is suitable for using this covering material.

2.4.3 Rigid panel greenhouses

Polyvinyl chloride rigid panels, fibre glass-reinforced plastic, acrylic and polycarbonate rigid panels are employed as the covering material in the quonset type frames or ridge and furrow type frame. This material is more resistant to breakage and the light intensity is uniform throughout the greenhouse when compared to glass or plastic. High grade panels have long life even up to 20 years. The main disadvantage is that these panels tend to collect dust as well as to harbor algae, which results in darkening of the panels and subsequent reduction in the light transmission. There is significant danger of fire hazard.

2.5 Shading nets

There are a great number of types and varieties of plants that grow naturally in the most diverse climate conditions that have been transferred by modern agriculture from their natural habitats to controlled crop conditions. Therefore, conditions similar to the natural ones must be created for each type and variety of plant. Each type of cultivated plant must be given the specific type of shade required for the diverse phases of its development. The shading nets fulfill the task of giving appropriate micro-climate conditions to the plants.

Shade nettings are designed to protect the crops and plants from UV radiation, but they also provide protection from climate conditions, such as temperature variation, intensive rain and winds. Better growth conditions can be achieved for the crop due to the controlled micro-climate conditions "created" in the covered area, with shade netting, which results in higher crop yields.

All nettings are UV stabilized to fulfill expected lifetime at the area of exposure. They are characterized of high tear resistance, low weight for easy and quick installation with a 30-90% shade value range. A wide range of shading nets are available in the market which are defined on the basis of the percentage of shade they deliver to the plant growing under them.

Plant response to greenhouse environments

Plant response to greenhouse environments - light, temperature, relative humidity, ventilation and carbon dioxide and environmental requirement of agriculture and horticulture crops inside green houses.

The productivity of a crop is influenced not only by its heredity but also by the microclimate around it. The components of crop microclimate are light, temperature, air compositions and the nature of the root medium. In open fields, only manipulation of nature of the root medium by tillage, irrigation and fertilizer application is possible. The closed boundaries in greenhouse permit control of any one or more of the components of the micro climate.

3.1 Light

The visible light of the solar radiation is a source of energy for plants. Light energy, carbon dioxide (Co_2) and water all enter in to the process of photosynthesis through which carbohydrates are formed. The production of carbohydrates from carbon dioxide and water in the presence of chlorophyll, using light energy is responsible for plant growth and reproduction. The rate of photosynthesis is governed by available fertilizer elements, water, carbon dioxide, light and temperature.

The photosynthesis reaction can be represented as follows

Chlorophyll Co_2 + water+ light energy------------ carbohydrates + oxygen Plant nutrients

Considerable energy is required to reduce the carbon that is combined with oxygen in CO_2 gas to the state in which it exists in the carbohydrate. The light energy thus utilized is trapped in the carbohydrate. If the light intensity is diminished, photosynthesis slows down and hence the growth. If higher than optimal light intensities are provided, growth again slows down because of the injury to the chloroplasts.

The light intensity is measured by the international unit known as Lux. It is direct illumination on the surrounding surface that is one meter from a uniform point source of 1 international candle. Green house crops are subjected to light intensities varying from 129.6kluxon clear summer days to 3.2 Klux on cloudy winter days. For most crops, neither condition is ideal. Many crops become light saturated, in other words, photosynthesis does not increase at light intensities higher than 32.2klux. Rose and carnation plants will grow well under summer light intensities. In general, for most other crops foliage is deeper green if the greenhouse is shaded to the extent of about 40% from mid spring (May) to mid fall (August and September). Thus, it is apparent that light intensity requirements of photosynthesis are vary considerably from crop to crop.

Light is classified according to its wave length in nanometers (nm). Not all light useful in photosynthesis process. UV light is available in the shorter wavelength range, i.e less than 400nm. Large of quantities of it is harmful to the plants. Glass screens are opaque to the most UV light and light below the range of 325nm. Visible and white light has wavelength of 400 to 700nm.Far red light (700 to 750nm) affects plants, besides causing photosynthesis. Infrared rays of longer wavelengths are not involved in the plant process. It is primarily, the visible spectrum of light that is used in photosynthesis. In the blue and red bands, the photosynthesis activity is higher, when the blue light (shorter wavelength) alone is supplied to plants, the growth is retarded, and the plant becomes hard and dark in colour. When the plants are grown under red light (longer wavelength), growth is soft and internodes are long, resulting in tall plants. Visible light of all wavelengths is readily utilized in photosynthesis.

3.2 Temperature

Temperature is a measure of level of the heat present. All crops have temperature range in which they can grow well. Below this range, the plant life process stop due to ice formation within the tissue and cells are possibly punctured by ice crystals. At the upper extreme, enzymes become inactive, and again process essential for life cease. Enzymes are biological reaction catalyst and are heat sensitive. All biochemical reactions in the plant are controlled by the enzymes. The rate of reactions controlled by the enzyme often double or triple for each rise of temperature by 10^0C, until optimum temperature is reached. Further, increase in temperature begins to suppress the reaction and finally stop it.

As a general rule, green house crops are grown at a day temperature, which are 3 to 6^0C higher than the night temperature on cloudy days and 8^0C higher on clear days. The night temperature of green house crops is generally in the range of 7 to 21^0C. Primula, mathiola incana and calceolaria grow best at 7^0C, carnation and cineraria at 10^0C, rose at 16^0C, chrysanthemum and poinsettia at 17 to 18^0C and African violet at 21 to 22^0C.

3.3 Relative humidity

As the green house is a closed space, the relative humidity of the green house air will be more when compared to the ambient air, due to the moisture added by the evapo-transpiration process.

Some of this moisture is taken away by the air leaving from the green house due to ventilation. Sensible heat inputs also lower the relative humidity of the air to some extent. In order to maintain the desirable relative humidity levels in the green houses, processes like humidification or dehumidification are carried out. For most crops, the acceptable range of relative humidity is between 50 to 80%. However for plant propagation work, relative humidity up to 90% may be desirable.

In summer, due to sensible heat addition in the daytime, and in winters for increasing the night time temperatures of the green house air, more sensible heat is added causing a reduction in the relative humidity of the air. For this purpose, evaporative cooling pads and fogging system of humidification are employed. When the relative humidity is on the higher side, ventilators, chemical dehumidifiers and cooling coils are used for de- humidification.

3.4 Ventilation

A green house is ventilated for either reducing the temperature of the green house air or for replenishing carbon dioxide supply or for moderating the relative humidity of the air. Air temperatures above 35^0C are generally not suited for the crops in green house. It is quite possible to bring the green house air temperature below this upper limit during spring and autumn seasons simply by providing adequate ventilation to the green house. The ventilation in a green house can either be natural or forced. In case of small green houses (less than 6m wide) natural ventilation can be quite effective during spring and autumn seasons. However, fan ventilation is essential to have precise control over the air temperature, humidity and carbon dioxide levels.

3.5 Carbon dioxide

Carbon is an essential plant nutrient and is present in the plant in greater quantity than any other nutrient. About 40% of the dry matter of the plant is composed of carbon. Under normal conditions, carbon dioxide (CO_2) exits as a gas in the atmosphere slightly above 0.03% or 345ppm. During the day, when photosynthesis occurs under natural light, the plants in a green house draw down the level of Co_2 to below 200ppm. Under these circumstances, infiltration or ventilation increases **carbon dioxide levels,** when the outside air is brought in, to maintain the ambient levels of CO_2. If the level of CO_2 is less than ambient levels, CO_2 may retard the plant growth. In cold climates, maintaining ambient levels of CO_2 by providing ventilation may be un-economical, due to the necessity of heating the incoming air in order to maintain proper growing temperatures. In such regions, enrichment of the green house with CO2 is followed. The exact CO_2 level needed for a given crop will vary, since it must be correlated with other variables in greenhouse production such as light, temperature, nutrient levels, cultivar and degree of maturity. Most crops will respond favorably to Co_2 at 1000 to 1200 ppm.

Equipment required for controlling green house environment – summer cooling and winter cooling, natural ventilation, forced ventilation and computers.

Precise control of various parameters of green house environment is necessary to optimize energy inputs and thereby maximize the economic returns. Basically, the objective of environmental control is to maximize the plant growth. The control of green house environment means the control of temperature, light, air composition and nature of the root medium. A green house is essentially meant to permit at least partial control of microclimate within it. Obviously green houses with partial environmental control are more common and economical. From the origin of greenhouse to the present there has been a steady evolution of controls. Five stages in this evolution include manual controls, thermostats, step-controllers, dedicated micro processors and computers. This chain of evolution has brought about a reduction in control labour and an improvement in the conformity of green house environments to their set points. The benefits achieved from green house environmental uniformity are better timing and good quality of crops, disease control and conservation of energy.

4.1 Active summer cooling systems

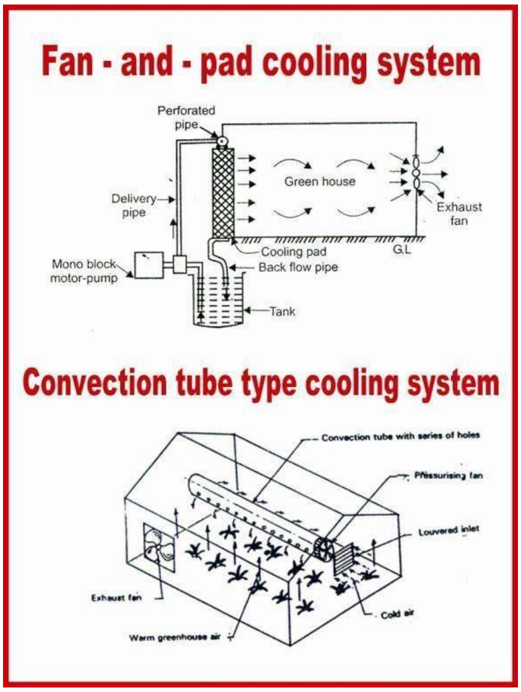
Active summer cooling is achieved by evaporative cooling process .The evaporative cooling systems developed are to reduce the problem of excess heat in green house. In this process cooling takes place when the heat required for moisture evaporation is derived from the surrounding environment causing a depression in its temperature. The two active summer cooling systems in use presently are fan-and pad and fog systems. In the evaporative cooling process the cooling is possible only up to the wet bulb temperature of the incoming air.

4.1.1 Fan-and Pad cooling system

The fan and pad evaporative cooling system has been available since 1954 and is still the most common summer cooling system in green houses (Fig.5). Along one wall of the green house, water is passed through a pad that is usually placed vertically in the wall. Traditionally, the pad was composed of excelsior (**wood shreds**), but today it is commonly made of a **cross-fluted-cellulose material** some what similar in appearance to corrugated card board. Exhaust fans are placed on the opposite wall. Warm outside air is drawn in through the pad. The supplied water in the pad, through the process of evaporation, absorbs heat from the air passing through the pad as well as from surroundings of the pad and frame, thus causing the cooling effect. Khus-khus grass mats can also be used as cooling pads.

4.1.2 Fog cooling system

The fog evaporative cooling system, introduced **in** green houses in 1980, operates on the same cooling principle as the fan and pad cooling system but uses quite different arrangement (Fig.5). A high pressure pumping apparatus generates fog containing water droplets with a mean size of less than 10 microns using suitable nozzles. These droplets are sufficiently small to stay suspended in air while they are evaporating. Fog is dispersed throughout the green house, evaporation of the water is not taking place because of bigger droplet size in fad and pad, whereas in the fog cooling system, there will be complete evaporation because of the minute size of the water droplets. Thus lesser the dryness of the air, greater evaporative cooling is possible.



4.2 Active winter cooling systems

Excess heat can be a problem during the winter. In the winter, the ambient temperature will be below the desired temperature inside the green house. Owing to the green house effect the entrapment of solar heat can rise the temperature to an injurious level if the green house is not ventilated. The actual process in winter cooling is tempering the excessively cold ambient air before it reaches the plant zone. Otherwise, hot and cold spots in the green house will lead to uneven crop timing and quality .This mixing of low temperature ambient air with the warm inside air cools the green house in the winter. Two active winter cooling systems commonly employed are convection tube cooling and horizontal air flow (HAF) fan cooling systems.

4.2.1 Convection tube cooling

The general components of convection tube are the louvered air inlet, a polyethylene convection tube with air distribution holes, a pressurizing fan to direct air in to the tube under pressure, and an exhaust fan to create vacuum. When the air temperature inside the green house exceeds the set point, the exhaust fan starts functioning thus creating vacuum inside the green house. The louver of the inlet in the gable is then opened through which cold air enters due to the vacuum. The pressurizing fan at the end of the clear polyethylene convection tube, operates to pick up the cool air entering the louver. A proper gap is available for the air entry, as the end of the convection tube is separated from the louvered inlet by 0.3 to 0.6m and the other end of the tube is sealed. Round holes of 5 to 8 cm in diameter are provided in pairs at opposite sides of the tube spaced at 0.5 to 1m along the length of the tube.

Cold air under pressure in the convection tube shoots out of holes on either side of the tube in turbulent jets. In this system, the cold air mixes with the warm greenhouse air well above the plant height. The cool mixed air, being heavier gently flows down to the floor level, effects the complete cooling of the plant area. The pressurizing fan forcing the incoming cold air in to the convection tube must be capable of moving at least the same volume of air as that of the exhaust fan, thereby avoiding the development of cold spots in the house. When cooling is not required, the inlet louver closes and the pressurizing fan continues to circulate the air within the greenhouse. The process minimizes the temperature gradient at difference levels. The circulation of air using convection tube consumes more power than a circulation system.

4.2.2 Horizontal air flow cooling

HAF cooling system uses small horizontal fans for moving the air mass and is considered to be an alternative to convection tube for the air distribution. In this method the green house may be visualized as a large box containing air and the fans located strategically moves the air in a circular pattern. This system should move air at 0.6 to 0.9 $m^3/min/m^2$ of the green house floor area. Fractional horse power of fans is 31 to 62 W (1/30 to 1/15hp) with a blade diameter of 41cm are sufficient for operation. The fans should be arranged in such a way that air flows are directed along the length of the greenhouse and parallel to the ground. The fans are placed at 0.6 to 0.9m above plant height and at intervals of 15m.They are arranged such that the air flow is directed by one row of the fans along the length of the greenhouse down one side to the opposite end and then back along the other side by another row of fans (Fig. 6). Greenhouses of larger widths may require more number of rows of fans along its length.

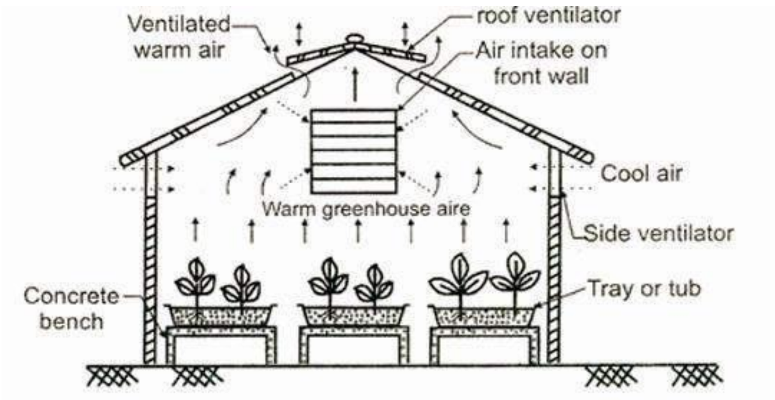
Temperatures at plant height are more uniform with HAF system than with convection tube system. The HAF system makes use of the same exhaust fans, inlet louvers and controls as the convection tube system. The only difference is the use of HAF fans in the place of convection tubes for the air distribution. Cold air entering through the louvers located at the higher level in the gables of the green house is drawn by the air circulation created by the net work of HAF fans and to complete the cycle, proper quantity of air is let out through the exhaust fans. The combined action of louvered inlet, HAF fans and the exhaust fans distribute the cold air throughout the greenhouse.

4.3 Green house ventilation

Ventilation is the process of allowing the fresh air to enter in to the enclosed area by driving out the air with undesirable properties. In the green house context, ventilation is essential for reducing temperature, replenishing COo_2 and controlling relative humidity. Ventilation requirements for green houses vary greatly, depending on the crop grown and the season of production. The ventilation system can be either a passive system (natural Ventilation) or an active system (forced ventilation) using fans. Usually green houses that are used seasonally employ natural ventilation only. The plant response to specific environment factor is related to the physiological processes and hence the latter affects the yield and quality. Hence, controlling of environment is of great importance to realize the complete benefit of CEA. Manual maintenance of uniform environmental condition inside the green house is very difficult and cumbersome. A poor maintenance results in less crop production, low quality and low income. For effective control of automatic control systems like micro processor and computer are used presently to maintain the environment.

4.3.1 Natural ventilation

In the tropics, the sides of greenhouse structures are often left open for natural ventilation. Tropical greenhouse is primarily a rain shelter, a cover of polyethylene over the crop to prevent rainfall from entering the growing area. This mitigates the problem of foliage diseases. Ventilators were located on both roof slopes adjacent to the ridge and also on both side walls of

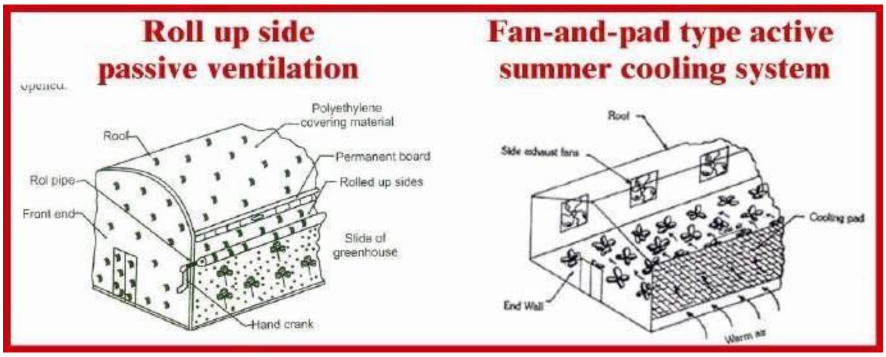


the greenhouse. The ventilators on the roof as well as those on the side wall accounts, each about 10% of the total roof area. During winter cooling phase, the south roof ventilator was opened in stages to meet cooling needs. When greater cooling was required, the north ventilator was opened in addition to the south ventilator. In summer cooling phase, the south ventilator was opened first, followed by the north ventilator. As the incoming air moved across the greenhouse, it was warmed by sunlight and by mixing with the warmer greenhouse air. With the increase in temperature, the incoming air becomes lighter and rises up and flows out through the roof ventilators. This sets up a chimney effect (Fig. 7), which in turn draws in more air from the side ventilators creating a continuous cycle. This system did not adequately cool the greenhouse. On

hot days, the interior walls and floor were frequently injected with water to help cooling.

4.3.1.1 Roll up side passive ventilation in poly houses

In roll up method of ventilation, allowing the air to flow across the plants. The amount of ventilation on one side, or both sides, may be easily adjusted in response to temperature, prevailing wind and rain (Fig.8). During the periods of excessive heat, it may be necessary to roll the sides up almost to the top. Passive ventilation can also be accomplished by manually raising or parting the polyethylene sheet. The open vent areas must be covered with screens to prevent virus diseases. The holes must be large enough to permit free flow of air. Screens with small holes blocks air movement and cause a build up of dust. Rollup side passive ventilation on plastic greenhouses is only effective on free standing greenhouses and not on gutter connected greenhouses.



4.3.2 Forced Ventilation

In forced or active ventilation, mechanical devices such as fans are used to expel the air. This type of ventilation can achieve uniform cooling. These include summer fan-and-pad and fog cooling systems and the winter convection tube and horizontal airflow systems. For mechanical ventilation, low pressure, medium volume propeller blade fans, both directly connected and belt driven are used for greenhouse ventilation. They are placed at the end of the green house opposite to the air intake, which is normally covered by gravity or motorized louvers. The fans vents, or louvers, should be motorized, with their action controlled by fan operation. Motorized louvers prevent the wind from opening the louvers, especially when heat is being supplied to the green house. Wall vents should be placed continuously across the end of the greenhouse to avoid hot areas in the crop zone.

Evaporative cooling in combination with the fans is called as fan-and-pad cooling system. The fans and pads are usually arranged on opposite walls of the greenhouse (Fig.8). The common types of cooling pads are made of excelsior (wood fiber), aluminum fiber, glass fiber, plastic fiber and cross-fluted cellulose material. Evaporative cooling systems are especially efficient in low humidity environments. There is growing interest in building greenhouses combining both passive (natural) and active (forced) systems of ventilation. Passive ventilation is utilized as the first stage of cooling, and the fan-pad evaporative cooling takes over when the passive system is not providing the needed cooling. At this stage, the vents for natural ventilation are closed. When both options for cooling are designed in greenhouse construction, initial costs of installation will be more. But the operational costs are minimized in the long run, since natural ventilation will, most often meet the needed ventilation requirements.

Fogging systems is an alternative to evaporative pad cooling. They depend on absolutely clean water, Free of any soluble salts, in order to prevent plugging of the mist nozzles. Such cooling systems are not as common as evaporative cooling pads, but when they become more cost competitive, they will be adopted widely. Fogging systems are the second stage of cooling when passive systems are inadequate.

4.3.3 Microprocessors

Dedicated microprocessors can be considered as simple computers. A typical microprocessor will have a keypad and a two or three line liquid crystal display of, sometimes, 80-character length for programming. They generally do not have a floppy disk drive. They have more output connections and can control up to 20 devices. With this number of devices, it is cheaper to use a microprocessor. They can receive signals of several types, such as, temperature, light intensity, rain and wind speed. They permit integration of the diverse range of devices, which is not possible with thermostats. The accuracy of the microprocessor for temperature control is quite good. Unlike a thermostat, which is limited to a bimetallic strip or metallic tube for temperature sensing and its mechanical displacement for activation, the microprocessor often uses a thermistor. The bimetallic strip sensor has less reproducibility and a greater range between the ON and OFF steps. Microprocessors can be made to operate various devices, for instance, a microprocessor can operate the ventilators based on the information from the sensor for the wind direction and speed. Similarly a rain sensor can also activate the ventilators to prevent the moisture sensitive crop from getting wet. A microprocessor can be set to activate the CO_2 generator when the light intensity exceeds a given set point, a minimum level for photosynthesis.

4.3.4 Computers

Now-a-days, computer control systems are common in greenhouse installation throughout Europe, Japan and the United States. Computer systems can provide fully integrated control of temperature, humidity, irrigation and fertilization, CO_2, light and shade levels for virtually any size growing facility. Precise control over a growing operation enables growers to realize saving of 15 to 50% in energy, water, chemical and pesticide applications. Computer controls normally help to achieve greater plant consistency, on-schedule production, higher overall plant quality and environmental purity.

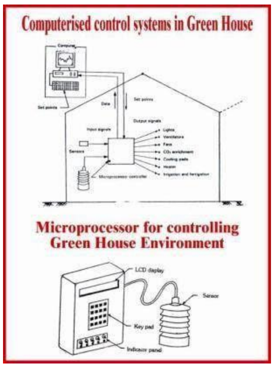
A computer can control hundreds of devices within a green house (vents, heaters, fans, hot water mixing valves, irrigation valves, curtains and lights) by utilizing dozens of input parameters, such as outside and inside temperatures, humidity, outside wind direction and velocity, CO_2 levels and even the time of the day or night. Computer systems receive signals from all sensors, evaluate all conditions and send appropriate commands every minute to each piece of equipment in the greenhouse range thus maintaining ideal conditions in each of the various independent greenhouse zones defined by the grower (Fig.9). Computers collect and record data provided by greenhouse production managers. Such a data acquisition system will enable the grower to gain a comprehensive knowledge of all factors affecting the quality and timeliness of the product. A computer produces graphs of past and current environmental conditions both inside and outside the greenhouse complex. Using a data printout option, growers can produce reports and summaries of environmental conditions such as temperature, humidity and the CO_2 status for the given day, or over a longer period of time for current or later use.

As more environmental factor in the greenhouse is controlled, there comes a stage when individual controls cannot be coordinated to prevent system overlap. An example is the greenhouse thermostat calling for heating while the exhaust fans are still running. With proper software program, which uses the environmental parameters as input from different sensors, can effectively coordinate all the equipment without overlap and precisely control all parameters affecting plant development as desired. Despite the attraction of the computer systems, it should
be remembered that the success of any production system is totally dependent on the grower"s
knowledge of the system and the crop management. Computers can only assist by adding precision to the overall greenhouse production practice, and they are only as effective as the software it runs and the effectively of the operator. The advantages and disadvantages of computerized control system are as follows:

Advantages

1. The computer always knows what all systems are doing and, if programmed properly, can coordinate these systems without overlap to provide the optimum environment.
2. The computer can record the environmental data, which can be displayed to show current conditions or stored and processed ones to provide a history of the cropping period, and if desired it may also be displayed in table or graph form.
3. A high-speed computer with networking facility can control several remotely located greenhouses, by placing the computer in a central area and the results can be monitored frequently by the management.
4. With proper programming and sensing systems, the computer can anticipate weather changes and make adjustments in heating and ventilation systems, thus saving the energy.

5. The computer can be programmed to sound an alarm if conditions become unacceptable to and to detect sensor and equipment failure.



Disadvantages

1. High initial cost investment.
2. Requires qualified operators.
3. High maintenance, care and precautions are required.
4. Not economical for small scale and seasonal production.

CO2 Consumption in Greenhouses:

Carbon Dioxide (CO_2)

Photosynthesis is the process which involves a chemical reaction between water and carbon dioxide in the presence of light, to make food (sugars) for plants and as a byproduct releases oxygen in the atmosphere. Carbon dioxide currently comprises .04% (400 ppm) of the atmospheric volume. It is a colorless and odorless minor gas in the atmosphere, but has an important role for sustaining life. Plants take in CO_2 through small cellular pores called stomata in the leaves during the day. During respiration (oxidation of stored sugars in plants producing energy and CO_2) plants take in oxygen (O_2) and give off CO_2 , which complements photosynthesis when plants take in CO_2 and give off O_2 . The CO_2 produced during respiration is always less than the amount of CO_2 taken in during photosynthesis. So, plants are always in a CO_2 deficient condition, which limits their potential growth.

CO_2 Concentration in Relation to Plants Photosynthesis utilizes CO_2 in the production of sugar which degrades during respiration and helps in plant's growth. Although atmospheric and environmental conditions like light, water, nutrition, humidity and temperature may affect rate of CO_2 utilization, the amount of CO_2 in the atmosphere has a greater influence. Variation in CO_2 concentration depends upon the time of day, season, number of CO_2 -producing industries, composting, combustion and number of CO_2 -absorbing sources like plants and water bodies nearby. The ambient CO_2 (naturally occurring level of CO_2) concentration of 400 ppm can occur in a properly vented greenhouse. However, the concentration is much lower than ambient during the day and much higher at night in sealed greenhouses. Carbon dioxide level is higher at night because of plant respiration and microbial activities. Carbon dioxide level may drop to 150-200 ppm during the day in a sealed greenhouse because CO_2 is utilized by plants for photosynthesis during daytime. Exposure of plants to lower levels of CO_2 even for a short period can reduce rate of photosynthesis and plant growth. Generally, doubling ambient CO_2 level (i.e. 700-800 ppm) can make a significant and visible difference in plant yield. Plants with a C3 photosynthetic pathway (geranium, petunia, pansy, aster, lily and most dicot species) have a 3-carbon compound as the first product in their photosynthetic pathway, thus are called C3 plants and are more responsive to higher CO2 concentration than plants having a C4 pathway (most of the grass species have a 4-carbon compound as the first product in their photosynthetic pathway, thus are called C4 plants). An increase in ambient CO2 to 800-1,000 ppm can increase yield of C3 plants up to 40%–100% and C4 plants by 10%–25% while keeping other inputs at an optimum level. Plants show a positive response up to 700-1,800 ppm, but higher levels of CO2 may cause plant damage.

CO2 Supplementation In general, CO2 supplementation is the process of adding additional CO2 in the greenhouse, which increases photosynthesis in a plant. Although benefits of high CO2 concentration have been recognized since the early 19th century, growth of the greenhouse industry and indoor gardening since the 1970s has dramatically increased the need for supplemental CO2 . The greenhouse industry has advanced with new technologies and automation. With the development of improved lighting systems, environmental controls and balanced nutrients, the amount of CO2 is the only limiting factor for maximum growth of plants. Thus, keeping the other growing conditions ideal, supplemental CO2 can provide improved plant growth. This is also called CO2 enrichment' or 'CO2 fertilization.

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Advantages

- Increase in photosynthesis results in increased growth rates and biomass production.
- Plants have earlier maturity and more crops can be havested annually. The decrease in time to maturity can help in saving heat and fertilization costs.
- In flower production, supplemental CO2 increases the number and size of flowers, which increase the sales value because of higher product quality.
- Supplemental CO2 provides additional heat (depending upon the method of supplementation) through burners, which will reduce heating cost in winter.
- It helps to reduce transpiration and increases water use efficiency, resulting in reduced water use during crop production.

Disadvantages

- Higher production cost with a CO2 generation system.
- Plants may not show a positive response to supplemental
- CO2 because of other limiting factors such as nutrients, water and light. So, all factors need to be at optimum levels.
- Supplementation is more beneficial in younger plants.
- Incomplete combustion generates harmful gases like sulphur dioxide, ethylene, carbon monoxide and nitrous oxides. These gases are responsible for necrosis, flower malformation and senescence if left unchecked, resulting in lower quality products.
- Additional costs required for greenhouse modification. Greenhouses need to be properly sealed to maintain a desirable level of CO2.
- Excess CO2 level can be toxic to plants as well as humans.
- On warmer days it is difficult to maintain desirable higher

CO2 levels because of venting to cool the greenhouses.

Effect of supplemental CO2 on different growing factors CO2-light

The rate of photosynthesis cannot be increased further after certain intensity of light termed as the light saturation point, which is the maximum amount of light a plant can use. However, additional CO2 increases the light intensity required
to obtain the light saturation point, thus increasing the rate
of photosynthesis. Mostly in the winter, photosynthesis is limited by low light intensity, and an additional lighting system will enhance the efficiency of CO2 and increase the rate of photosynthesis and plant growth. Thus, supplemental CO2 integrated with supplemental lighting can decrease the number of days required for crop production.

CO2-water:

Supplemental CO_2 affects the physiology of plants through stomatal regulation. Elevated CO_2 promotes the partial clo- sure of stomatal cells and reduces stomatal conductance.

Stomatal conductance refers to the rate of CO_2 entering and exiting with water vapor from the stomatal cell of a leaf. Because of reduced stomatal conductance, transpiration (loss of water from leaf stomata in the form of water vapor) is minimized and results in an increased water use efficiency (WUE) (ratio of water used in plant metabolism to water lost through transpiration). Lower stomatal conductance, reduced transpiration, increased photosynthesis and an increase in WUE helps plants to perform more efficiently in water-stressed conditions. Supplemental CO_2 reduces water demand and conserves water in water-scarce conditions.

CO2 -temperature

Temperature plays a big role in the rate of plant growth.

Most biological processes increase with increasing tempera- ture, this includes the rate of photosynthesis. But the optimum temperature for maximum photosynthesis depends on the availability of CO_2. The higher the amount of available CO_2 , the higher the optimum temperature requirement of crops (Fig 2). In a greenhouse supplemented with CO_2, a dramatic increase in the growth of plants can be observed with increas- ing temperature. Supplemental CO_2 increases the optimum temperature requirement of a crop. This increases produc- tion even at higher temperature, which is not possible at the ambient CO_2 level.

CO2 -nutrient

A major effect of CO_2 supplementation is the rapid growth of plants because of enhanced root and shoot growth. The enhanced root system allows greater uptake of nutrients from the soil. It is recommended to increase fertilizer rate with increasing CO_2 level. The normal fertilizer rate can be exhausted quickly and plants may show several nutrient deficiency symptoms.

Control and Distribution of CO2

Depending on the size of the greenhouse and type of system installed, the CO_2 level in the greenhouse is controlled manually or through a computer-based system. A CO_2 gas sensor (Fig. 5) gives the level of CO_2 concentration in the greenhouse atmosphere and a generator is manually turned on and off based on the readings of the sensor. The sensor measures temperature and humidity

along with CO_2 and helps in developing a crop management strategy. However, in the case of the computer-based system, sensors signal the current CO_2 level to the control system and a control system turns on and off the generator based on the set points created by the grower.
CO_2 diffuses slowly, so proper air circulation is essential to distribute CO_2 evenly. Generally, a small greenhouse with a single CO_2 generator uses fan jets or horizontal air flow fan for distribution. However, a large connected greenhouse with a flue gas generator generally uses plastic tubes underneath the bench (right below the crop level) and are perforated at different intervals to diffuse CO_2. The main advantage of such tubing is to supply adequate CO_2 to the boundary layer of a leaf even in dense canopy conditions.

ON-LINE MEASUREMENT OF PLANT GROWTH IN THE GREENHOUSE:

- Traditionally, greenhouse environmental control has been relying on feedback from the environmental.
- On-line control and optimization of plant production will require feedback directly from the crop.
- Therefore non-destructive measurements of "plant growth" have been developed and tested.
- For determination of fresh weight and transpiration of plants an electronic balance is used in combination with a hydroponic system.
- The second method, a CCD-camera and an image processing system allows on-line measurement of leaf area.
- An evaluation of the relation between fresh weight and recorded leaf area gives the best accordance with an exponential regression equation.
- The third method is the measurement of net CO_2-uptake using the greenhouse as a cuvette or maintaining inside the greenhouse the same CO_2-concentration as outside.

OUTLINE OF ON-LINE MEASUREMENT OF PLANT GROWTH IN THE GREENHOUSE

- The use of microcomputers allows to control the climate conditions in a greenhouse according to the plant response.
- This requires information about plant reaction and physiological processes, such as photosynthesis, transpiration, fresh weight and leaf area development in short intervals.
- It is likely that control of plant production will require feedback directly from the crop.
- Three kinds of feedback information from the plants are distinguishable:

1. Potentials, such as leaf temperature, turgor pressure, stem diameter or leaf colour.
2. Fluxes, such as transpiration or assimilation rates. –

3. State variables, such as fresh weight, leaf area or height of plants.
   - Unfortunately, direct feedback from the plants is not easy to measure.
   - Especially on-line measurement in greenhouses is difficult because of disturbances

MATERIAL AND METHODS

The following methods have been tested under greenhouse conditions.

1. Image Processing system

- The image processing system consists of the image sensor, the image processing unit and the computer system.
- The plant image is recorded by a CCD-camera and converted to a digital picture with at maximum 64 grey levels.
- These are stored in a buffer memory. Digitization logic, D/A-converter and buffer memory are located on the image processing board in the process computer.
- Mouse and keyboard allow corrections and manipulations of the picture. In the same way it is possible to set the grey level, which is a scale for the brightness of the picture.
- To eliminate disturbances caused by short wave radiation a red filter is used cutting off radiation shorter than 700 nm.
- For small plants a two-dimensional measurement of leaf area is sufficient, whereas for higher plants a three dimensional evaluation is necessary using two cameras with different angles.
- The first tests have shown a high fluctuation of measured leaf area during daytime. With changing radiation intensity, the values increase and decrease, while at constant radiation level. e.g. at night, they are relatively constant.
- It could be observed, that at high radiation level the contrast between soil and plant is decreasing. Because the contrast of the image is influenced by the grey level, this must be changed according to the radiation.
- A linear regression has been used to adapt the grey level to light intensity. Thus, the influence of global radiation on the measurement error could be eliminated.
- The main Tash of image processing is to estimate fresh weight. Several regression models have been tested. The best correlation between fresh weight and leaf area gives an exponential equation, which can be expressed by:

  FG = 1.74 * EXP (0.02 *LF)

  (FG = fresh weight; LF = leaf area)

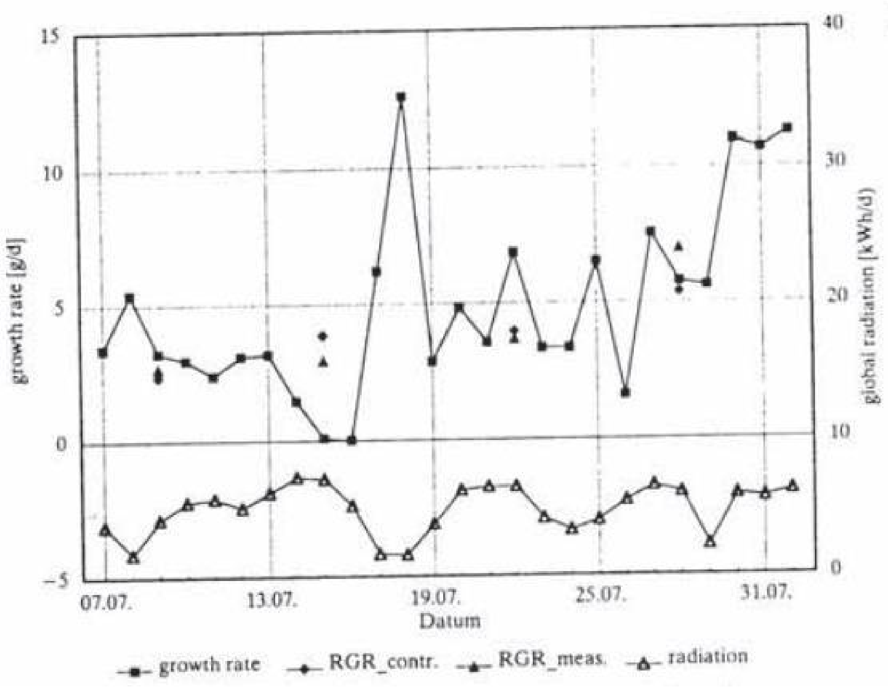

Fig. 1. Growth rate, relative growth rate and solar radiation for the time of 7.7. to 31.7.

- Fig. 1 shows an example for the estimation of growth rate, relative growth rate and solar radiation. The measured growth rate using image processing fits very well into the real growth rate.

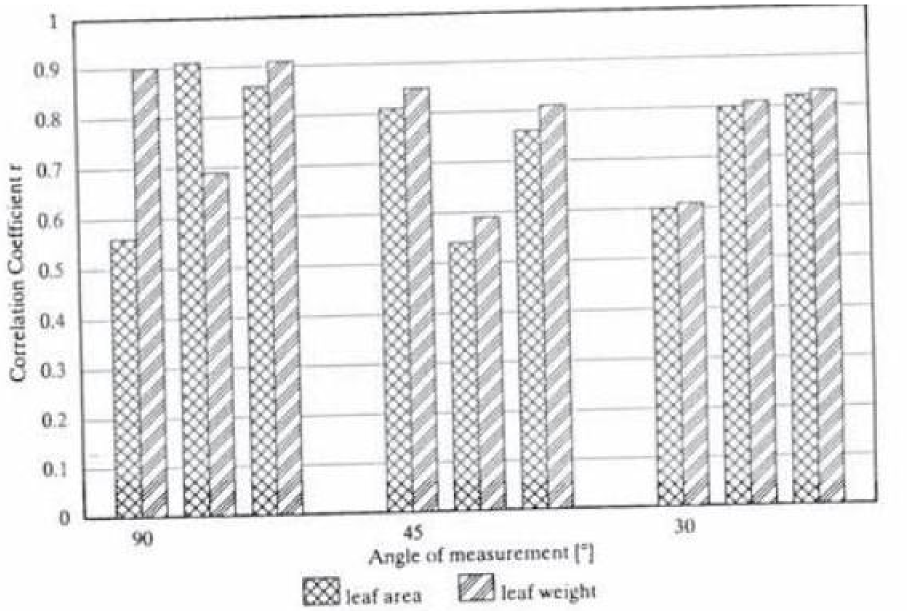

Fig. 2. Correlation coefficients for 1 or 2 cameras and different measurement angles.

- As mentioned earlier, for higher crops (e.g. tomato) a three-dimensional measurement is necessary using two cameras with different angles.
- Fig. 2 shows the correlation coefficient using 1 or 2 cameras and different angles of measurement.

2. Electronic balance and hydroponic system

- This method can be used especially for hydroponic culture.
- The pot with the plant stands on the balance. By means of a controlled inlet nutrient solution is added up to a fixed level.
- At first a run-off system has been used. That means surplus water will be returned ("run-off").
- After a few minutes there is a water balance in the system with always the same defined amount of water.
- For the second period of experiments the system has been changed, using a sensor to detect the level of water in the pot and to switch off the inlet at a fixed level.
- The weight differences between the actual and the preceding adding present the increase of the fresh weight of the plant.
- Until to the next adding the system can be used as a lysimeter and measurements of the evapotranspiration are possible with an interval of one minute.
- The hourly changes of plant fresh weight and evapotranspiration show an antagonistic daily course (Fig. 3).

- The evapotranspiration rate depends mainly on the solar radiation (Fig. 3). That means the minimum is in the night.
- During daytime the evapotranspiration rate increases according to solar radiation. When the transpiration losses exceed the water uptake of the plant, the fresh weight of the plant decreases.
- At night with low transpiration rates the fresh weight increases steadily.

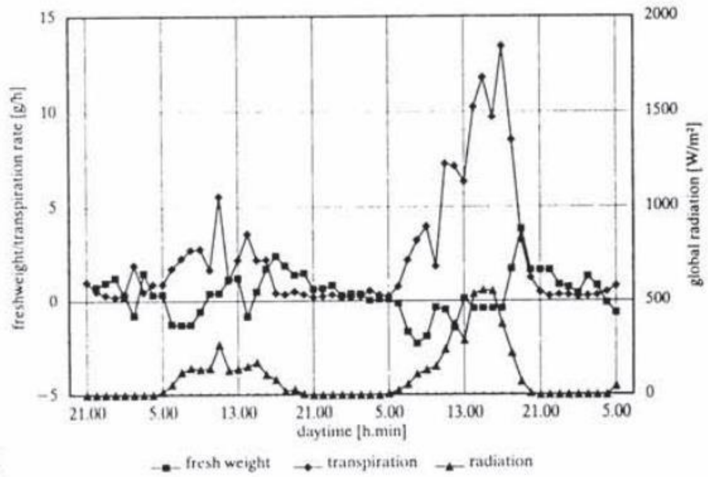

Fig. 3. Daily course of transpiration rate and fresh weight for days with low and high solar radiation

- The experiments have shown that on-line measurement of plant reaction due to a change of climate conditions is possible.
- The described methods allow non-destructive measurements. The accuracy of the

measurements is limited.

- For image processing the grey level must be adapted to light intensity.
- The time interval between measurements has to be selected in accordance to the intensity of plant growth.
- For overlapping leaves, fruit or head development a correction of the regression model is necessary.
- For higher plants a three-dimensional measurement, using 2 cameras gives a better correlation.
- Using the electronic balance the information of short term plant reaction is available directly with a high accuracy.
- **A disadvantage** of this method is that it is limited to hydroponic cultivation system and that only a few plants can be measured which must be representative.

MODELS OF PLANT PRODUCTION AND EXPERT SYSTEMS IN HORTICULTURE.

- Expert Systems are intelligent encoded domain specific expert's computer program solutions. Generalized computerized farm management and Expert System have good scope for managing and coordinating optimal production in agriculture.
- Horticultural crops, by improving the income in the rural areas, play a unique role in Indian economy.
- Though these crops hardly occupy 7% of the area and they contribute over 18% to the GDP in the country.
- Litchi is one of them and is called the Queen of the fruits which play a significant role in our national economy. Horticultural crops are affected by insect-pests and diseases causing destruction if mismanaged.
- It is therefore essential that the identification of pests, diseases and disorders and application of suitable remedies.
- For this purpose, application of ES in the management of horticultural crops can be helpful for minimizing losses and thereby increase productivity

Why we need an Expert System?

- The major problem is scarcity of real experts in a particular field, if available then there may be a problem of inaccessibility.
- Consultation may be expensive, and the expert may feel the repetitive job uninteresting, which may affect efficiency.
- The other major problem faced by experts is the memory limitation affecting processing

of essential knowledge and information required for decision-making.

- Research and developments in every discipline render relevant and accurate advice available from updated experts, which is not an easy task.
- Experts are subject to limitations, and it is impossible to access all the essential factors, while taking decisions.
- Some factors are always missed and unconsidered.
- This necessitates computer-based tools for assistance, like Decision support system, Decision making system or Expert system to update knowledge and render help in making decisions.

SOLUTION:

- In this respect, ES has been a very useful tool. ESs of today support problem solving activities such as decision making, knowledge fusing, designing and planning, forecasting, regulating, controlling, monitoring, identifying, diagnosing, prescribing, interpreting, explaining or training using different techniques, while future expert systems will support many more activities.
- In the beginning, Expert Systems were developed by the end of 1970s and were operating in the medicine, chemical, education, natural resources and science. ES started to gain popularity in the early 1980s.

EXPERT SYSTEM

- Expert Systems (ES) are intelligent computer program encoded, domain specific knowledge and reasoning of experts to produce solution.
- ES derived its knowledge from experts, supported by literature on application. ES differs from conventional computer program in many ways: uses knowledge rather than data for controlling solutions.
- Knowledge is encoded as an entity separate from the control of the program, it can explain how and why a particular solution is obtained, it uses symbolic representation for knowledge (rules, semantic nets or frames), it often reasons with meta knowledge i.e., knowledge about itself and has self-learning capabilities.
- The rule-based expert system has five components:

(i) the knowledge base, (ii) the database, (iii) the inference engine, (iv) the explanation facilities, and (v) the user interface.

- The basic components of rule-based expert system are shown in fig.1.

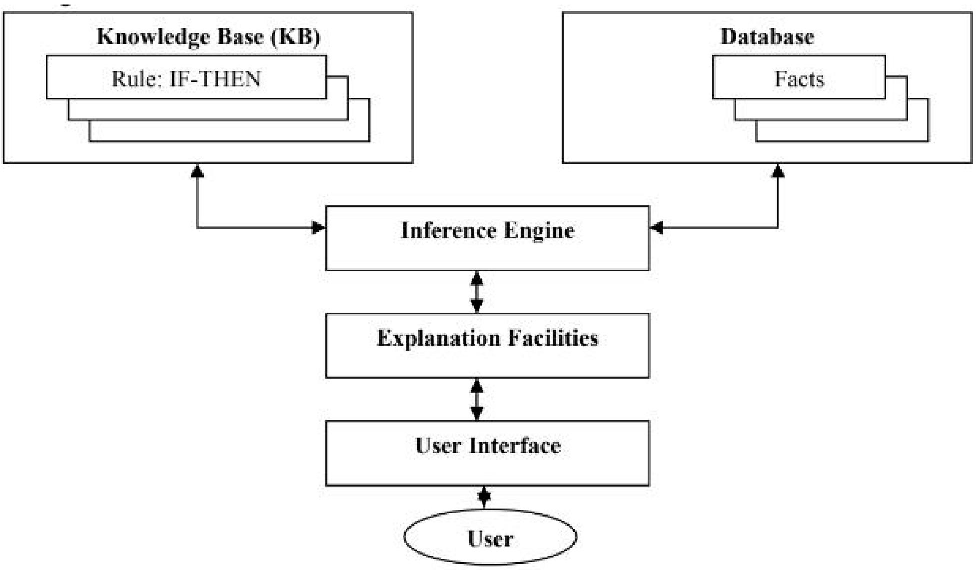

Fig.1 Components of Expert System and User interface

The expert system developed in the Prolog programming language functions as an inference engine in the backward chaining.

(i) **Knowledge Base:** It is a declarative representation of the expertise, often in IF- THEN rules including such things as simple facts about the domain, rules or constraints that describe relation or phenomena in the domain, and possibly also methods, heuristics and ideas for solving problems in this domain.

(ii) **Database:** It is the data or a set of facts which is specific to a problem being solved used to match against the IF (condition) parts of the rules stored in the knowledge base.

(iii)**Inference Engine:** It carries out the reasoning by interplaying the information or facts obtained from the user with the knowledge stored in the knowledge base whereby the expert system reaches a solution.

(iv) **Explanation Facilities**: It explains about how a particular conclusion is reached and why a fact is needed and explains its reasoning and justifies its advice, analysis or conclusion.

(v) **User Interface:** It provides communication between the user and expert system.

APPLICATION OF THE EXPERT SYSTEM IN HORTICULTURE:

- The agricultural practices as performed by farmers are traditionally based and non-scientific. Computer based general farm management and Expert System can be helpful in providing solutions to the problems in horticulture.
- ES can provide a comprehensive management of orchards. It can help in disease, pest and disorder management of plants. Since, plants and fruits are affected by insect-pests and diseases, which cause considerable loss, if not properly managed.
- So, proper management of orchard for diagnostic purposes can be helpful to increase total production and minimizing losses. Computer based general support and ES can be helpful in creating awareness and giving timely preventive suggestions.
- It can also help in insect identification, monitoring, insecticide selection, and disease

management.

- It can be cost effective as users need not wait for experts. By repeated consultations, farmers can develop self- skill and awareness for care-taking and ES can become advisory-cum-training tools.
- The transfer of knowledge from consultants, scientists, researchers and experts to extension workers in any area is very important for the development of agriculture and horticulture.
- The ES technology provides a good platform to facilitate the transfer of knowledge from expert to extension workers or farmers.

- The ES technology around horticulture has been developed especially related with decision-making, pests, diseases, or disorders diagnosis.
- Some of the Expert Systems developed for the horticulture applications are: CUPTEX- for cucumber crop production, TOMATEX- for tomatoes, CITEX- for orange production, LIMEX- for lime production, PLANT/ds- for the disease diagnosis among Soyabean, AMRAPALIKA- for the diagnosis of pests , diseases, and disorders in Indian mango , POMME for apple orchard management
- The application of the ES in horticulture is well justified and many developed countries have developed the expert system for their use.
- Although adoption of this technology in Indian agricultural practices is rather slow in comparison to developed countries, Indian farmers felt the need for such technology to increase agricultural productivity.
- Since, signs and symptoms of the pests, diseases and disorders have due geographical variations, expert system developed for a particular climatic and geographical region does not apply to different geographical region.
- Therefore, it is necessary to develop a new one or modify the existing system for that geographical region. Since, the concept of ES technology in agriculture has enough potential to revolutionize the agricultural practices, its use in India is urgently needed to enhance the productivity.
- ES can also help in finding nutrient status using visual symptoms in the plant and use of proper fertilizers to control the nutrient disorders and preventing damage to that tree.
- The information provided by farmers during consultation can be used to develop database of specific orchard for region-specific agricultural practices and problems. Such database will become valuable research resources in the future.
- In the modern days the concept of agro clinic has come into practice as shown in fig 2. Such clinics are being established near the agricultural land in the rural areas.

Obviously, farmers will seek these clinics to get solutions for problems encountered.

- For this purpose, ES can also be installed for consultation in local agro-clinics or like ATM machines where farmers can have direct access. The person managing this clinic will need expert knowledge to help farmers.
- Under such conditions, ES will be highly useful and will attract farmers to these clinics. The ES available at agro clinics in remote area can be linked with central remote sensing center to make predictions about disease spread and weather conditions, enabling advance planning in caretaking of orchards. Such scheme will be highly helpful in alerting farmers in rural area for taking preventive steps to save crops in adverse weather conditions.

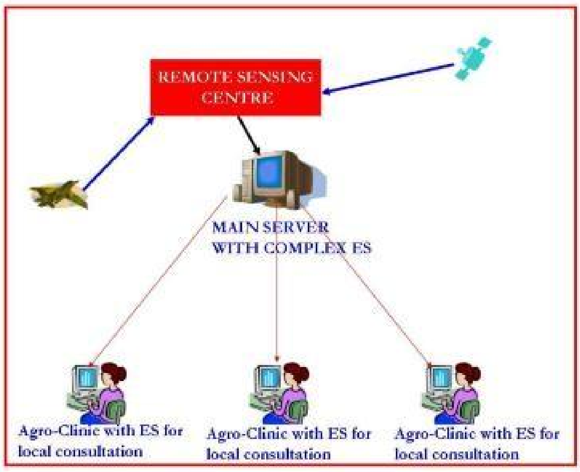

Fig 2. Role of ES in agro-clinics

CASE STUDY

Brief description of horticultural crop 'Litchi'

Horticultural crops play a major role in Indian economy by improving the income of the rural people. Cultivation of crops requires labor generating employment opportunities for the rural population. Fruits and vegetables are also rich source of vitamins, minerals, proteins, and carbohydrates, referred to as protective foods and assumes importance as a nutritional security. 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. It is estimated that all the horticulture crops put together cover nearly 11-6 million hectares area with an annual production of 91 million tons. Though these crops occupy hardly 7% of the area and they contribute over 18% to the GDP in the country. India with more than 28.2 million tons of fruits and 66 million tons of vegetables is the second largest producer in the world, next only to Brazil and China. With the present population level, the annual requirement of fruits and vegetables will be of the order of 32.58 million tons and 83 million tons respectively. However, per capita consumption of fruits and vegetables in India is only around 46 kg and 130 g [Minimum of about 92 g and 300 g recommended by Indian Council of Medical Research (ICMR) and National Institute of

Nutrition (NIN), Hyderabad]. In different agro climatic zones of India, various fruits are grown. Litchi is one of them and is called the Queen of the fruits which play a significant role in our national economy. Litchi (Litchi chinensis Sonn.) is one of the most important evergreen subtropical fruit known for its fragrance and quality aril.

It is an important commercial fruit crop with tremendous export potential. India is the second largest producer of litchi in the world after China. The total production of litchi in India is 4,

33,000 tons from an area of 60,000 ha and productivity level is 7.4 t/ha [3]. The other important growing countries are China, Taiwan, Thailand, Vietnam, Brazil, Malaysia, Myanmar, Mauritius, South Africa, Australia, New Zealand, Madagascar and USA. The area, production and productivity (2002-03) of litchi at global level have been given in table 1.

Table 1: Global production of litchi

Country	Area (ha)	Production (tonnes)	Productivity (t/ha)
China	5,88,000	1,280,000	2.18
Taiwan	12,000	108,000	9.00
Vietnam	30,000	50,000	1.70
Thailand	23,000	81,000	3.50
India	56,200	4,29,000	7.70
Bangladesh	4,800	12,800	2.70
Nepal	2,300	14,000	6.10
South Africa	1,500	8,000	5.30
Madagascar	3,000	20,000	6.67
Israel	300	2,000	6.67
Australia	1,500	5,000	3.33
USA	240	1,000	4.20
Mauritius	1,000	12,000	12.00
Brazil	350	2,120	

n India, commercial cultivation of litchi is restricted in northern part, particularly in foothills of the Himalayas from Tripura to Jammu & Kashmir and Gangetic plains. The major litchi growing states are Bihar, Bengal, Uttrakhand, Jharkhand, Assam, Tripura, Orissa and Punjab. Bihar produces 75% of total litchi production of the country and occupies nearly 54% of the area under litchi plantation. State-wise area, production and productivity of litchi (2004-05) in India have been given in table 2

Table 2: State-wise production of litchi in India

State	Area ('000 ha)	Production ('000tonnes)	Productivity (t/ha)
Bihar	28.4	284.9	10.0
West Bengal	7.2	69.9	9.8
Assam	4.5	22.5	5.0
Jharkhand	1.4	16.5	12.0
Tripura	2.2	12.4	5.6
Punjab	1.3	12.6	10.0
Orissa	3.9	11.9	3.0
Uttrakhand	6.7	8.9	1.3
Himachal Pradesh	3.4	3.6	1.1
Chhattishgarh	0.5	3.4	7.0
Haryana	0.2	1.0	6.2
Others	0.5	1.0	2.0
Total	**60.2**	**448.6**	**7.4**

In India, there are large numbers of varieties (approximately 52 cultivars) grown in different parts under different climates and soil conditions. Approximately 90% of the produce utilized as fresh at various stages and post harvest losses exceed 30% sometimes followed by market glut. Litchi plants and fruits are also affected by insect-pests and diseases, which cause considerable losses, if not properly managed. In general, litchi plants are least affected by diseases but fruits are prone to certain diseases and disorder if not managed properly. So, proper management of litchi orchard can be helpful to increase total production as well as minimizing losses.