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STUDY MATERIAL

on

GREENHOUSE TECHNOLOGY

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GREENHOUSE TECHNOLOGY

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LECTURE 1

INTRODUCTION

After the advent of green revolution, more emphasis is laid on the quality of the product along with the quantity of production to meet the ever- growing food requirements. Both these demands can be met when the environment for the plant growth is suitably controlled. The need to protect the crops against unfavourable environmental conditions led to the development of protected agriculture. 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.

HISTORY

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. 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.

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 on farm can be increased.

LECTURE 2

Contents of lecture: Brief description of types of green houses - greenhouses based on shape, utility, construction, covering materials and cost, shade nets.

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.

GREENHOUSE TYPE BASED ON SHAPE

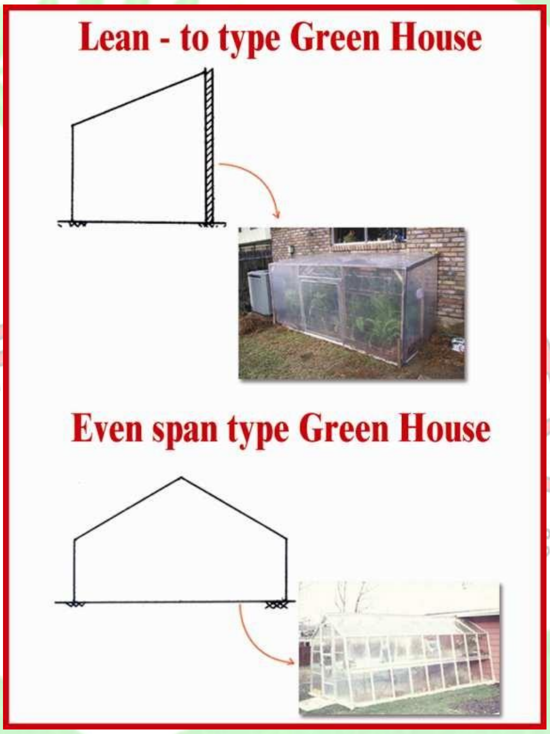
Greenhouses can be classified based on their shape or style. For the purpose of classification, the uniqueness of the cross section of the greenhouses can be considered as a factor. As the longitudinal section tend to be approximately the same for all types, the longitudinal section of the greenhouse 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.

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). 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.



(FIG-1.1) Lean-to-type and Even span type greenhouses

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.2.1). 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.

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. 2.2). This type of greenhouses is seldom used now-a-days as it is not adaptable for automation.

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.1.2). 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.

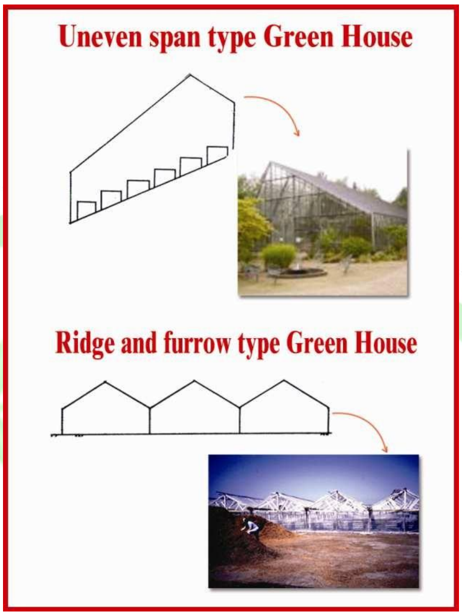


Fig. 2.2. Uneven and Ridge and furrow type greenhouses

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.2.3) develops in a saw- tooth type greenhouse.

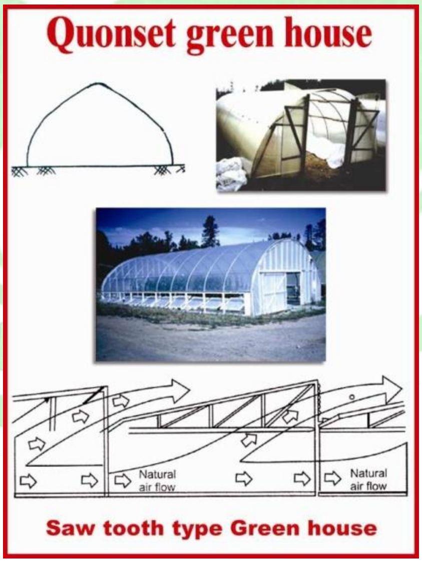


Fig. 2.3. Quonset and Saw tooth type greenhouses

Quonset greenhouse

This is a greenhouse, where the pipe arches or trusses are supported by pipe purling running along the length of the greenhouse (Fig 2.3). In general, the covering material used for this type of greenhouses is polyethylene. Such greenhouses are typically less expensive than the gutter connected greenhouses and are useful when a small isolated cultural area is required. These houses are connected either in free, standing style or arranged in an interlocking ridge and furrow.

In the interlocking type, truss members overlap sufficiently to allow a bed of plants to grow between the overlapping portions of adjacent houses. A single large cultural space thus exists for a set of houses in this type, an arrangement that is better adapted to the automation and movement of labour.

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.

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.

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%.

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. Therefore based on construction, greenhouses can be broadly classified as wooden framed, pipe framed and truss framed structures.

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.

Pipe framed structures

Pipes are used for construction of greenhouses, when the clear span is around 12m (Fig. 2.4). In general, the side posts, columns, cross ties and purlins are constructed using pipes. In this type, the trusses are not used.

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. 2.4). 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 these frames are best suited for pre-fabrication.

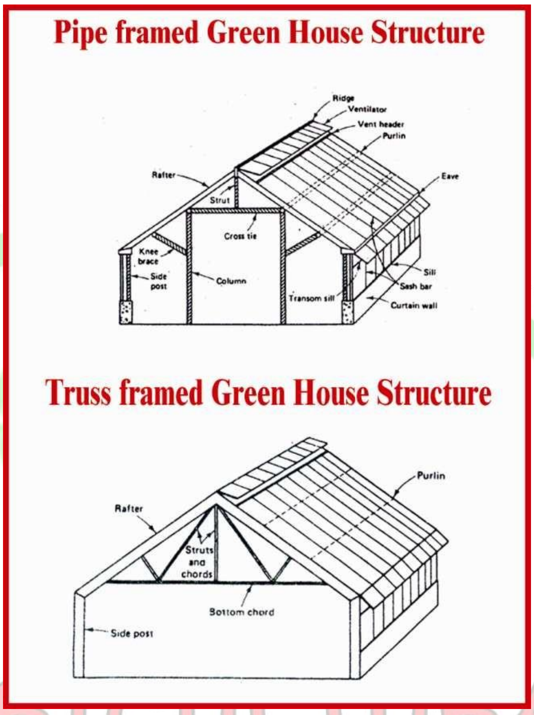


Fig.2.4. Pipe and truss framed greenhouse structures

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.

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.

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.

SHADE 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.

LECTURE 3

Contents of lecture: 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.

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

$$Co_2 + \text{water} + \text{light energy} \xrightarrow[\text{Plant nutrients}]{\text{Chlorophyll}} \text{carbohydrates} + \text{oxygen}$$

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 129.6klux on 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.

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. Photosynthesis is more active in the blue and red spectrum in comparison to green-yellow region. 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.

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^{0}C, carnation and cineraria at 10^{0}C, rose at 16^{0}C, chrysanthemum and poinsettia at 17 to 18^{0}C and African violet at 21 to 22^{0}C.

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.

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^{0}C 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.

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.

LECTURE 4

Contents of lecture: Environmental requirement of agriculture and horticulture crops inside green houses. Light requirement of crops and light control methods, greenhouse shading methods, greenhouse supplemental lighting systems.

ENVIRONMENT

Growing greenhouse vegetables is one of the most exacting and intensive forms of all agriculture enterprises. In the controlled environment of a greenhouse, high yields of excellent quality vegetables can be produced. A successful greenhouse grower should have a good knowledge of agriculture, horticulture, soils, plant pathology, entomology, and plant physiology, as well as the engineering capability to provide an environment best suited for plant growth. The important environmental factors that affect the horticultural crops inside the greenhouse are temperature, light, relative humidity, and CO_2 concentration. Classification of horticultural crops is also made based on the optimum temperature and lighting conditions for better growth. Direct effect of temperature and the differential day and night temperature controls the overall growth of the plants. The components of light that affect the production are intensity, quality, and duration. Relative humidity of air is a measure of the moisture available in air, and it has good correlation to the occurrence of pest and diseases. Enclosure of the growing area makes it easier for the controlling operations in greenhouse than in open field agriculture

TEMPERATURE REQUIREMENTS OF HORTICULTURAL CROPS

Of all the climatic factors affecting the vegetable production, temperature is considered to be the most important factor. Temperature affects the germination, flowering, pollination, fruit-set, quality of produce and seed production. Based on temperature requirements, vegetable crops in general are classified into:

1. Cool season crops that survive at temperatures ranging from 0 to 10°C (beans, carrots, cauliflower, potato, peas, and lettuce).

2. Warm season crops can survive in the temperature range of 15 to 30°C (Cowpea, cucurbits, bell pepper, tomato, chillies, okra, and sweet potato).

Temperature variations affect the development of the economic parts of many crops. The optimum temperature range varies with crop and with its growth stage. Environmental requirements for some of the horticultural and floricultural crops are given in Table 4.1. Plant height can be controlled by adjusting the day-to-night temperature difference (DIF). The term DIF (acronym for the temperature differential) refers to the temperature difference obtained by subtracting the night temperature from the day temperature. The rate of stem internode elongation increases with the increase in day temperatures and with the decrease in night temperatures. Hence, the plants become tall when the DIF value is highly positive. Large reductions in plant height are achieved by reducing DIF from positive to zero values or negative values. The concept of DIF works well when plants are young and their rate of growth is rapid.

LIGHT REQUIREMENTS OF CROPS AND LIGHTING CONTROL METHODS

The performance of crops is influenced by the three aspects of light, namely, intensity, quality, and duration. Light intensity refers to the number of photons falling on a given area or the total amount of light which plants receive. Light intensity is specified in lux for each crop. A range of 32.3 to 86.1 klux is required by crops like cucurbits, capsicum, eggplant, and sweet potato, while cabbage, and sweet potato require 21.5 to 86.1 klux. Light quality refers to the wavelengths of the radiation. Composition of visible light affects the photosynthetic activity of plants. Length of the day is responsible for accumulation of carbohydrates and for flower induction in certain plants. Light duration plays an important role in photoperiodism, which is the response of an organism to the day-night cycle.

The relative length of the light and dark periods governs a number of responses including flowering, leaf shape, stem elongation, bulb formation and pigmentation. Based on the response of the plant to the light periods, plants are classified into long-day plants (requiring 8 to 10 h of continuous dark periods), short-day plants (requiring 10 to 14 h of continuous dark periods) and day-neutral plants (photo insensitive plants). Cucurbits, cowpea, lettuce, radish, pea, turnip, clover, and spinach are long-day plants; certain cultivars of cowpea, beans, onions, coffee, strawberry, and sweet potato are short-day plants; and cucumber, tomato, potato, and rose are day-neutral plants. The optimum light requirement varies with crops based on its classification (Table 4.1). Artificial shading and supplemental lighting systems can effectively control the plant photoperiodism and DIF in the greenhouse, which can be manipulated to the advantage of the growers.

GREENHOUSE SHADING METHODS

There is an established need for reducing light intensity in the bright sunshine months from May to August. Intensity of radiations can be reduced by providing shades (partial or full) over the growing area. 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). It can be done either by spraying a shading compound on the glazed surfaces of greenhouse, or by installing a screen fabric over the greenhouse or inside the greenhouse above head light. Commercial shading compounds can be prepared by mixing white latex paint with water. One part paint in 10 parts or water provides a very heavy shade, while one part paint in 15 to 20 parts water provides a standard shade. The shading compound can be sprayed on from the ground by means of a pesticide sprayer and most of the shading compound will wear off by the end of the next season.

Table 4.1 Environmental Requirements for Some Horticultural and Floricultural Crops

Crop	Season	Temperature (˚C)	Relative humidity (%)	Light (klux)	Remarks
Potato	Sprouting and initial growth	20 to 24	-	-	Above 30^0C
	Growth and tuberation	18 to 20	-	-	No tuber formation
Tomato	Fruit setting	21 to 30	-	-	CO_2 200 ppm
	Colour development (red and yellow)	10 to 30	-	-	-

Bell pepper		21 to 23	-	-	-
Onion	Bulb formation	20 to 22	-	-	-
Carrot	Root development	15 to 21	-	-	-
	Colour development	15 to 22	-	-	-
Cauliflower	Curd formation	17	-	-	-
Garlic Brinjal Pumpkins	-	-	-	-	Cool temperature
Vegetable seeds	Normal storage (Conditions at different Temp. And RH)	26 21 7	5 to 10 7 to 13 9 to 15	- - -	- - -
Mango	-	24 to 27	>80	-	-
Citrus	-	25	-	-	-
Banana	-	20 to 35	-	-	-
Passion fruit	-	20 to 30	-	-	-
Rose	-	13.3 to 21	-	64.6 to 86.1	CO_2, 1200 to 2000 ppm
Orchids	Day	15.5 to 21	>30	25.8 to 38.7	CO_2 500 ppm
	Night	10.0 to 15.5	>80	-	-
Gladiolus	-	15 to 25	15	-	-
Carnation	-	15.5 to 20	60 to 75	-	-
Chrysanthemum	-	8 to 12	-	-	-

When shade is desired only to protect flowers, sheets of screening are sometimes used only where they are needed. Longer lasting synthetic fabrics are more popular today, including such material as polypropylene, polyester, saran, and aluminium coated polyester.The shade values of the polypropylene, polyester, and saran, can vary from 20 to 90%, although 50% is commonly used. The use of UV stabilized plastic covering material is being introduced recently.

The problem with spraying shading compounds or installing a fixed sunscreen in the greenhouse is that the barrier cause periods of inadequate light intensity leading to reduced growth and delayed crops, when the light intensity is low on cloudy days and in early morning or late afternoon on all days. Modern greenhouses have automated equipment to draw sunscreens across the greenhouse in response to photocell sensors. In this way, screening is applied only during the hours when it is needed.

GREENHOUSE SUPPLEMENTAL LIGHTING SYSTEMS

Artificial light affects the plant growth by supplementing the light requirements of the plant. Such lighting is more profitable in high density plantings, such as rooting and seedling beds and the production of young plants. Supplemental lighting is used for most crops but is particularly popular with chrysanthemum and geranium stock plants, Elatior begonia, rose, and plug seedlings. Many types of lamps have been used in the greenhouse. Basically, they fall into three groups:

Incandescent lamps

Incandescent lamps are available in the range of 40-500 W at 115 and 230 V and have only 7 per cent light to energy (lumen/watt) conversion ratio since lamps provide excessive heat to obtain particular light level. They produce a high proportion of red and far-red wavelength spectrum, causing tall and soft growth in the plants. The average service life of these lamps is 750-1,000 h. Tungsten filament incandescent lamps are generally not used for supplemental lighting because of poor light quality and excessive heat production.

Fluorescent lamps

Fluorescent lamps provide a linear light source rather than a point source and have a specific light output of 40-60 lumen/Watt. These lamps give cool white light for plant growth. They convert about 20 per cent electrical energy into light energy and these lamps are most commonly used in crops like cucumber, tomatoes and capsicum grown inside greenhouse. Fluorescent lamps are most commonly used in growing rooms and over small germination areas in the greenhouse.

High-intensity-discharge (HID)

High-intensity-discharge (HID) such as high-pressure mercury, metal halide, low-pressure sodium and high-pressure sodium lamps: Now-a-days, the HID lamps are preferred types for the final stages of the crop growth in the greenhouse. The most commonly used HID system at present utilizes high-pressure sodium lamps. Light intensities of 3.2 to 6.5 klux at plant height are generally used for seedlings and ornamental plants, with 4.3 klux being the most common level. Intensities of 6.5 to 10.8 klux are used for vegetable crops.

LECTURE 5

Contents of lecture: Environmental control inside greenhouse- manual controlling, thermostats, Active summer cooling and winter cooling systems, carbon dioxide enrichment methods

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.

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.5.1). 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.

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.5.1). 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, cooling the air everywhere. As this system does not wet the foliage, there is less scope for disease and pest attack. The plants stay dry throughout the process. This system is equally useful for seed germination and propagation since it eliminates the need for a mist system.

Both types of summer evaporative cooling system can reduce the greenhouse air temperature. The fan-and pad system can lower the temperature of incoming air by about 80% of the difference between the dry and wet bulb temperatures while the fog cooling system can lower the temperature by nearly 100% difference. This is, due to the fact that complete 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.

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 raise 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.

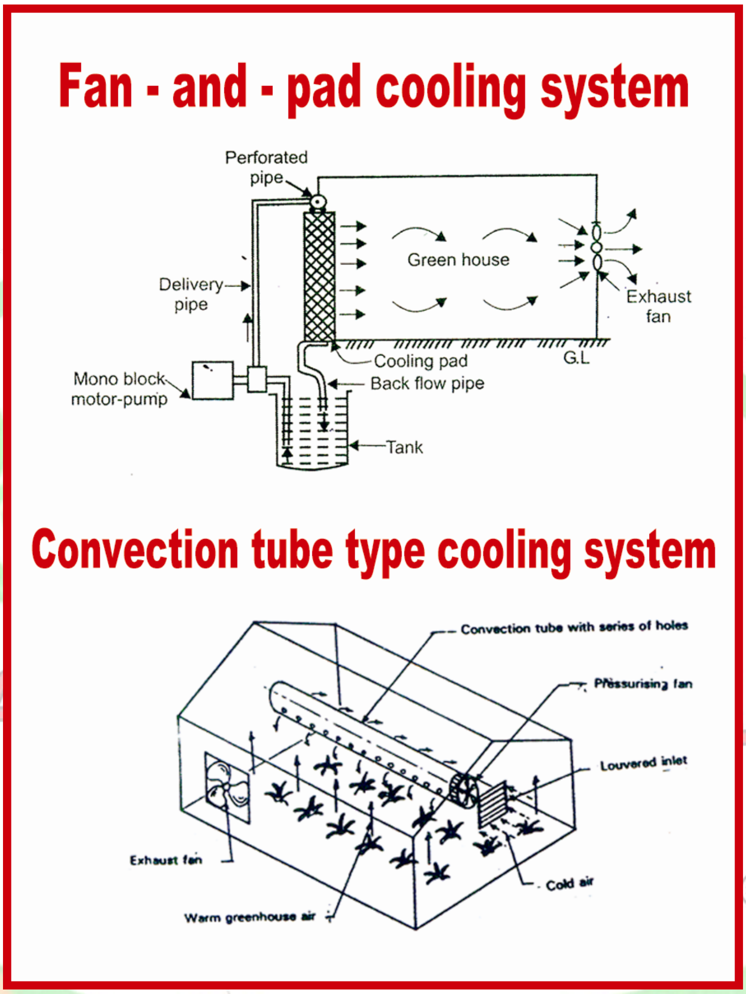


Fig. 5.1 Components of fan-and-pad and Convection tube cooling systems in a greenhouse

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.

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. 5.2). 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.

Similarly to the convection tubes, the HAF fans can be used to distribute heat in the green house When neither cooling nor heating is required, the HAF fans or convection tube can be used to bring warm air down from the upper level of the gable and to provide uniform temperature in the plant zone. It is possible to integrate summer and winter cooling systems with heating arrangements inside a green house for the complete temperature control requirements for certain days of the season.

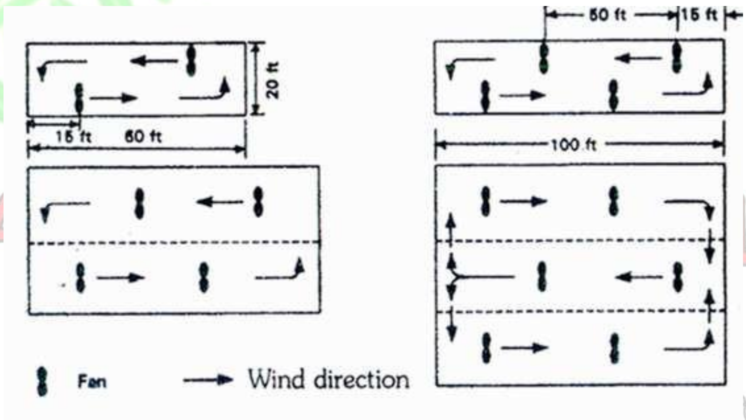


Fig. 5.2. HAF system in different sizes of greenhouses

CARBON DIOXIDE ENRICHMENT METHODS

The carbon dioxide (CO_2) is required in the photosynthesis of individual leave of many species takes place at light intensities around 21.530 klux. As CO_2 increases, the maximum intensity for photosynthesis also increases. The amount of CO_2 required for enrichment is the sum of amount of CO_2 used by plants and loss of CO_2 through infiltration. The amount used by plants varies with the micro climatic parameters, type of crop, and level of nutrition. In general, CO_2 enrichment is carried out in lighting duration and begins at or little after sunrise and continues till one hour before sunset. The CO_2 enrichment is not done during summers unless greenhouse is being cooled with a complete closed loop air circulation system. Depending upon the local climatic conditions, the period of enrichment is generally restricted from October to March. For calculation purpose, the general range varies from 0.6 to 1.2 litres per hr per m^2 of floor area. A low cost CO_2 level indicator is employed to judge the concentration of CO_2 inside greenhouse especially, during enrichment process. The cost of enrichment is estimated from the annual duration of requirement and the amount of fuel burnt per unit time.

Methods

Combustion

A hydrocarbon, such as natural gas, paraffin oil or kerosene, when burnt in the presence of sufficient oxygen, the CO_2 and H_2O (water) is produced. This theory is, generally, applied to enrich greenhouse air with the CO_2. A gas burner fitted with a pressure gauge is fixed in the middle of structure and hang over the head height. A solenoid valve is used to burn liquid petroleum gas (LPG) or natural gas (NG). A small capacity air circulation fans are required for uniform circulation of CO_2 throughout the greenhouse.

Liquid CO_2

When dry carbon dioxide is filled in bottles and tanks under high pressure, it liquefies. The CO_2 gas from these pressurized tanks is released with the help of a set of regulating valves so that gas at low pressure is spread inside the greenhouse. A fine plastic tube of 3 to 6 mm diameter having needle point holes on the periphery at every 30 cm distance is generally used for distribution of CO_2.

Solid CO_2

Carbon Dioxide under pressure and low temperature gets solidified and it is popularly known as 'dry ice'. It can be practised for enrichment of CO_2 in greenhouse system if the quantity required for maintaining a particular level, is known. Also, air circulation system will be required for even distribution of CO_2.

The liquid and solid method of CO_2 enrichment are expensive than combustion which permits commercial greenhouse operator to adopt combustion. However, in certain precise application, such as studying the environmental parameters on each other, solid or liquid CO_2 method could be used.

LECTURE 6

Contents of lecture: Equipment required for controlling green house environment -natural ventilation, forced ventilation, microprocessors, and computers and advantages of computerized control systems.

INTRODUCTION

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.

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.

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. 6.1), 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.

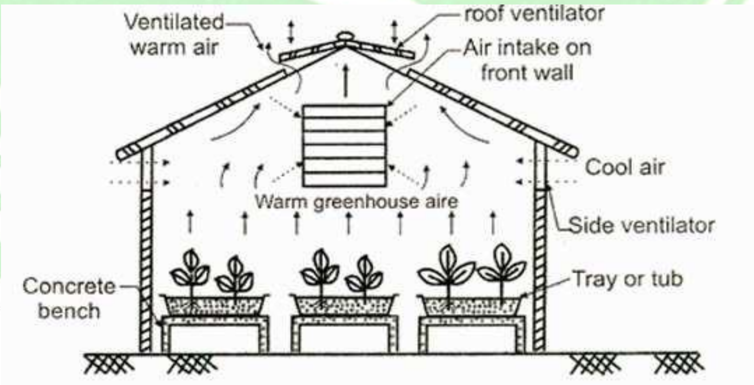


Fig. 6.1. **Chimney effect in general passive ventilation**

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.6.2). 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.

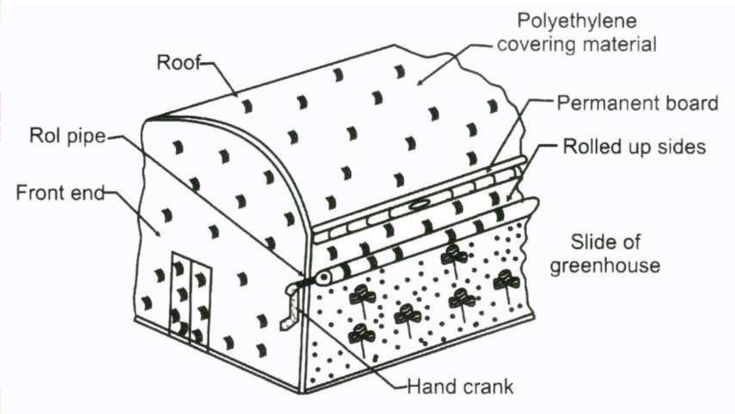


Fig. 6.2. Roll up side passive ventilation

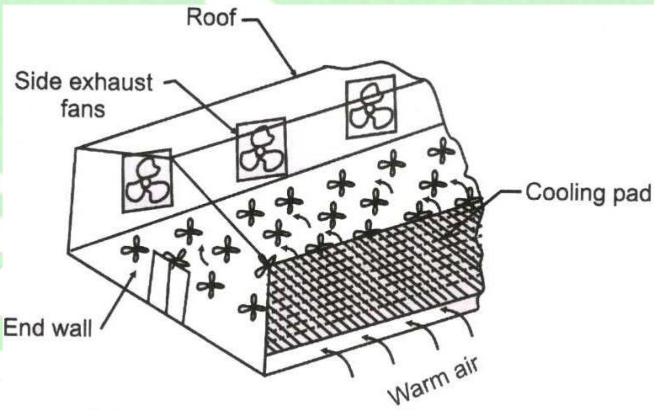


Fig. 6.3. Fan-and-pad cooling system

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.6.3). 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.

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 (Fig.6.3). 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.

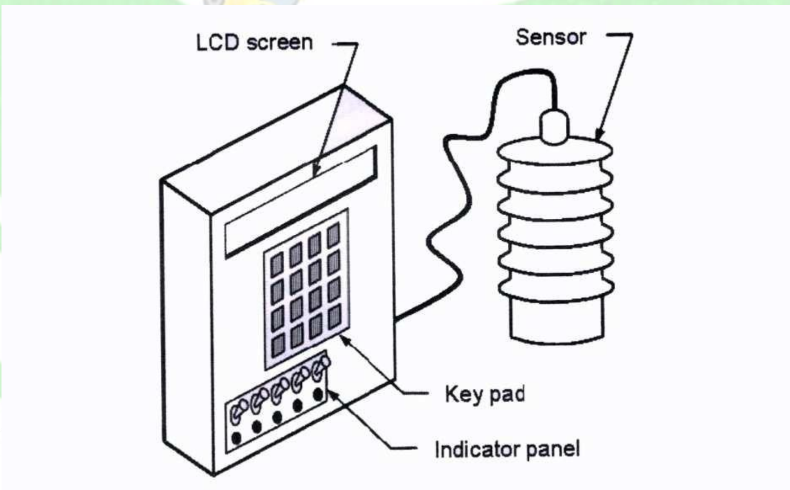


Fig. 6.3. Dedicated microprocessor for controlling greenhouse environment

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.6.4). 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.

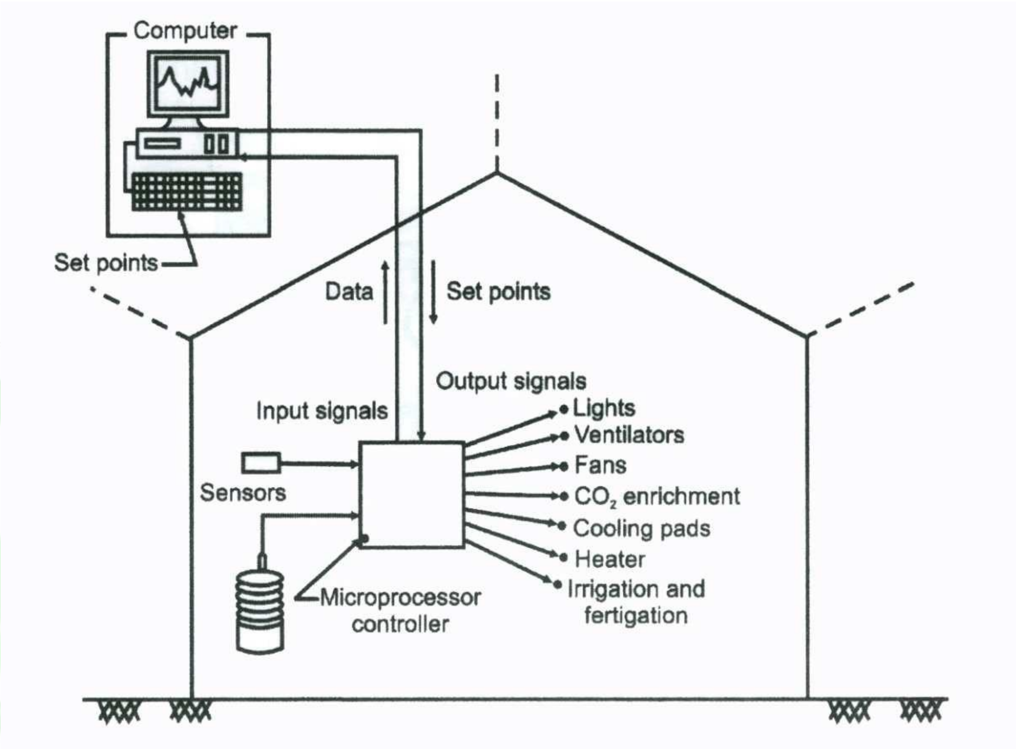


Fig. 6.4. Computerized control system in greenhouse

LECTURE 7

Contents of lecture: Planning of green house facility - site selection and orientation, structural design and covering materials.

A greenhouse, is basically the purpose of providing and maintaining a growing environment that will result in optimum production at maximum yield. The agriculture in the controlled environment is possible in all the regions irrespective of climate and weather.

It is an enclosing structure for growing plants, greenhouse must admit the visible light portion of solar radiation for the plant photosynthesis and, there fore, must be transparent. At the same time, to protect the plants, a greenhouse must be ventilated or cooled during the day because of the heat load from the radiation. The structure must also be heated or insulated during cold nights. A greenhouse acts as a barrier between the plant production areas and the external or the general environment.

SITE SELECTION AND ORIENTATION

A greenhouse is designed to withstand local wind, snow and crop loads for a specific cropping activity. In this way, the structure becomes location and crop specific. The building site should be as level as possible to reduce the cost of grading, and the site should be well aerated and should receive good solar radiation. Provision of a drainage system is always possible. It is also advisable to select a site with a natural windbreak. In regions where snow is expected, trees should be 30.5 m away in order to keep drifts back from the greenhouses. To prevent shadows on the crop, trees located on the east, south, or west sides should be at a distance of 2.5 times their height.

STRUCTURAL DESIGN

The most important function of the greenhouse structure and its covering is the protection of the crop against hostile weather conditions (low and high temperatures, snow, hail, rain and wind), diseases and pests. It is important to develop greenhouses with a maximum intensity of natural light inside. The structural parts that can cast shadows in the greenhouse should be minimized.

The different structural designs of greenhouse based on the types of frames are available. A straight side wall and an arched roof is possibly the most common shape for a greenhouse, but the gable roof is also widely used. Both structures can be free standing or gutter connected with the arch roof greenhouse. The arch roof and hoop style greenhouses are most often constructed of galvanized iron pipe. If tall growing crops are to be grown in a greenhouse or when benches are used, it is best to use a straight side wall structure rather than a hoop style house, this ensures the best operational use of the greenhouse. A hoop type greenhouse is suitable for low growing crops, such as lettuce, or for nursery stock which are housed throughout the winter in greenhouses located in extremely cold regions. A gothic arch frame structure can be designed to provide adequate side wall height without loss of strength to the structure (Fig.7.1).

Loads in designing the greenhouse structures include the weight of the structure itself and, if supported by the structure, loads of the equipment for the heating and ventilation and water lines. Greenhouse structures should be designed to resist a 130 km/h wind velocity. The actual load depends on wind angle, greenhouse shape and size, and the presence or absence of openings and wind breaks.

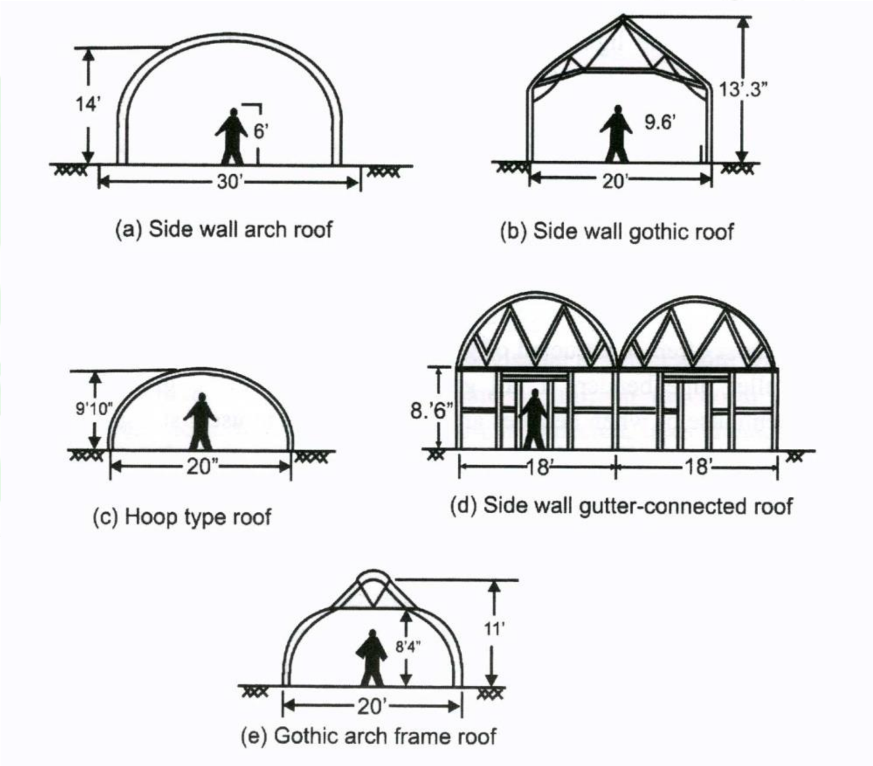


Fig.7.1. Structural designs of different greenhouse frameworks

The ultimate design of a greenhouse depends on the following aspects:

(i) The overall structural design and the properties of the individual structural components.

(ii) The specific mechanical and physical properties which determine the structural behaviour of the covering materials.

(iii) The specific sensitivity of the crop to light and temperature to be grown in the greenhouse.

(iv) The specific requirements relevant to the physical properties of the covering material.

(v) The agronomic requirements of the crop.

COVERING MATERIALS

The following factors are to be considered while selecting the greenhouse covering material i.e., light, transmission, weight, resistant to impact, and durability to outdoor weathering and thermal stability over wide range of temperatures. Before selecting the covering material, two important points should be taken into consideration: the purpose for which greenhouse facility is intended and service life of material. In temperate regions where high temperatures are required, the covering material with high light transmission and far IR absorption must be selected. Also the loss of heat by conduction should be minimum.

Covering material	**Life span**
1. Glass and acrylic sheet	20 years
2. Polycarbonate and fiberglass-reinforced polyester sheet	5-12 years
3. Polyethylene	2-6 months
4. Polyethylene stabilized for UV rays	2-3 years

The ideal greenhouse selective covering material should have the following properties:

(i) It should transmit the visible light portion of the solar radiation which is utilized by plants for photosynthesis.

(ii) It should absorb the small amount of UV in the radiation and convert a portion of it to fluoresce into visible light, useful for plants.

(iii) It should reflect or absorb IR radiation which are not useful to plants and which causes greenhouse interiors to overheat.

(iv) Should be of minimum cost.

(v) Should have usable life of 10 to 20 years.

LECTURE 8

Contents of lecture: Materials for construction of green houses - wood, galvanized iron, glass, polyethylene film, poly vinyl chloride film, Tefzel T^2 film, fiberglass reinforced plastic rigid panel and acrylic and polycarbonate rigid panel.

The following materials commonly used to build frames for greenhouse are (i) Wood, (ii) Bamboo, (iii) Steel, (iv) Galvanized iron pipe, (v) Aluminum and (vi) Reinforced concrete (RCC). The selection of above materials was based on their Specific physical properties, requirements of design strength, life expectancy and cost of construction materials.

WOOD

Wood and bamboo are generally used for low cost polyhouses. In low cost polyhouses, the wood is used for making frames consisting of side posts and columns, over which the polythene sheet is fixed. The commonly used woods are pine and casuarina, which are strong and less expensive. In pipe-framed polyhouses, wooden battens can be used as end frames for fixing the covering material. In tropical areas, bamboo is often used to form the gable roof of a greenhouse structure. Wood must be painted with white colour paint to improve light conditions within the greenhouse. Care should be taken to select a paint that will prevent the growth of mold. Wood must be treated for protection against decay. Chromated copper arsenate and ammonical copper arsenate are water based preservatives that are applied to the wood that may come into contact with the soil. Red wood or cypress (natural decay resistance woods) can be used in desert or tropical regions, but they are expensive.

GALVANISED IRON (GI), ALUMINUM, STEEL AND REINFORCED CEMENT CONCRETE

GI pipes, tubular steel and angle iron are generally used for side posts, columns and purlins in greenhouse structure, as wood is becoming scarce and more expensive. In galvanising operation, the surface of iron or steel is coated with a thin layer of zinc to protect it against corrosion. The commonly followed processes to protect against corrosion are:

(i) Hot dip galvanising (hot process) process: The cleaned member is dipped in molten zinc, which produces a skin of zinc alloy to the steel.

(ii) Electro-galvanising (cold process) process: The cleaned member is zinc plated similar to other forms of electro-plating

The galvanising process makes the iron rust proof, to eliminate the problem of rusting of structural members. Aluminum and hot dipped GI are comparatively maintenance free. In tropical areas, double dipping of steel is required, as single dip galvanising process does not give a complete cover of even thickness to the steel. Aluminum and steel must be protected by painting with bitumen tar**,** to protect these materials from corrosion, while these materials contact with the ground. Now-a-days, the greenhouse construction is of metal type, which is more permanent. RCC is generally limited to foundations and low walls. In permanent bigger greenhouses, floors and benches for growing the crops are made of concrete.

GLASS

Glass has been traditional glazing material all over the world. Widely used glass for greenhouse are: (i) Single drawn or float glass and (ii) Hammered and tempered glass. Single drawn or float glass has the uniform thickness of 3 to 4 mm. Hammered and tempered glass has a thickness of 4 mm. Single drawn glass is made in the traditional way by simply pulling the molten glass either by hand or by mechanical equipment. Float glass is made in modern way by allowing the molten glass to float on the molten tin. Coating with metal oxide with a low emissivity is used for saving of energy with adequate light transmittance. Hammered glass is a cast glass with one face (exterior) smooth and the other one (interior) rough. It is designed to enhance light diffusion. This glass is not transparent, but translucent. Tempered glass is the glass, which is quickly cooled after manufacture, adopting a procedure similar to that used for steel. This kind of processing gives higher impact resistance to the glass, which is generally caused by hail. Glass used as a covering material of greenhouses, is expected to be subjected to rather severe wind loading, snow and hail loading conditions. The strength mainly depends on the length/width ratio of the panel and on the thickness of the panel, but the most widely used thickness is 4 mm.

POLYETHYLENE FILM

Polyethylene is principally used today for two reasons- (i) Plastic film greenhouses with permanent metal frames cost less than glass greenhouses and (ii) Plastic film greenhouses are popular because the cost of heating them is approximately 40% lower compared to single-layer glass or fiberglass-reinforced plastic greenhouses. The disadvantages are : these covering materials are short lived compared to glass and plastic panels. UV light from the sun causes the plastic to darken, thereby lowering transmission of light, also making it brittle, which leads to its breakage due to wind. A thermal screen is installed inside a glass greenhouse that will lower the heat requirement to approximately that of a double-layer plastic film greenhouse, but this increases the cost of the glass greenhouse. Polyethylene film was developed in the late 1930s in England and spread around the middle of this century. Commonly used plastic for greenhouse coverings are thermoplastics. Basic characteristics of thermoplastics are: (i) thermoplastics consists of long chain molecules, soften with heating and harden with cooling and this process is reversible and (ii) thermoplastics constitute a group of material that are attractive to the designer for two main reasons: (a) Thermoplastics have the following specific physical properties- stiffness, robustness and resilience to resist loads and deformations imposed during normal use and (b) It can readily be processed using efficient mass production techniques, result in low labour charge.

The main reason to use polyethylene year round for greenhouse covering is due to presence of UV-inhibitor in it. Otherwise it lasts for only one heating season. UV-inhibited plastic cover may last for a period of 4 to 5 years. UV-grade polyethylene is available in widths up to 15.2 m in flat sheets and up to 7.6 m in tubes. Standard lengths include 30.5, 33.5, 45.7, 61 and 67 m. Some companies provide custom lengths upto a max. of 91.5 m. Condensation on ploythene film is a big problem. Condensation causes disease development, development of water logged condition and oxygen deficient inside the greenhouse. Condensation reduces light intensity within the greenhouse. To avoid this problem, anti-fog surfactant, which discourages condensation, is built into the film or panel. Warm objects, such as plants, the greenhouse frame and soil radiate IR energy to colder bodies at night, which result in loss of heat in greenhouse. Since polyethylene is a poor barrier to radiant heat, it is formulated with IR-blocking chemicals into it during manufacture, will stop about half of the radiant heat loss. On cold and clear nights, as much as 25% of the total heat loss of a greenhouse can be prevented in this way and on cloudy nights only 15% is prevented. UV-stabilised polyethylene, on an average, transmits about 87% of photosynthetically active radiation (PAR) into the greenhouse. IR absorbing polyethylene, reduces radiant heat loss, transmits about 82% of photosynthetically active radiation (PAR) into the greenhouse. The amount of light passing through two layers of a greenhouse covering is approximately the square of the decimal fraction of the amount passing through one layer. Eg. When 87% passes through one layer of UV-inhibited polyethylene, only 76% (0.87 x 0.87) passes through two layers**.** Similarlly, when 82% passes through one layer of IR-absorbing polyethylene, only 67% (0.82 x 0.82) passes through two layers.

POLYVINYL CHLORIDE FILM (PVC FILMS)

PVC films are UV light resistant vinyl films of 0.2 to 0.3 mm and are guaranteed for 4 to 5 years respectively. The cost of 0.3 mm vinyl film is three times that of 0.15 mm polyethylene. Vinyl film is produced in rolls upto 1.27 m wide. Vinyl films tend to hold a static electrical charge, which attracts and holds dust. This in turn reduces light transmittance unless the dust is washed off. Vinyl films are seldom used in the United States. In Japan, 95% of greenhouses are covered with plastic film, out of which 90% are covered with vinyl film.

TEFZEL T^2 FILM

The most recent addition of greenhouse film plastic covering is Tefzel T^2 film (ethylene tetrafluoroethylene). Earlier, this film was used as covering on solar collectors. Anticipated life expectancy is 20 years. The light transmission is 95% and is greater than that of any other greenhouse covering material. A double layer has a light transmission of 90% (0.95 x 0.95). Tefzel T^2 film is more transparent to IR radiation than other film plastics. Hence, less heat is trapped inside the greenhouse during hot weather. As a result, less cooling energy is required. Disadvantage is that, the film is available only in 1.27 m wide rolls. This requires clamping rails on the greenhouse for every 1.2 m. If reasonable width strips become available, the price is not a problem, because a double layer covering will still cost less than a polycarbonate panel covering with its aluminum extrusions, and will last longer, and will have much higher light intensity inside the greenhouse.

POLYVINYL CHLORIDE RIGID-PANEL

Initially, PVC rigid panels showed much promise as an inexpensive covering material (almost 40% of cost of long lasting fiberglass reinforced plastics), has the life of 5 years. After commercial application, these panels indicated that the life expectancy was much shorter, less than 2 years. This is undesirable factor, because the cost of PVC panels was 4 to 5 times that of polyethylene film and they required much more time to install. Now-a-days, PVC rigid panels are not in use.

FIBERGLASS-REINFORCED PLASTIC (FRP) RIGID PANEL

FRP was more popular as a greenhouse covering material in the recent past. Advantage of FRP is that it is more resistant to breakage by factors, such as hail or vandals. Sunlight passing through FRP is scattered by the fibers in the panels, as a result the light intensity is rather uniform throughout the greenhouse in comparison with a glass covering. Disadvantages with these are the panels subjected to etching and pitting by dust abrasion and chemical pollution. Based on the grade, the usable life period of FRP panel varies. Some grades give 5 to 10 years, while better grades can last up to 20 years. FRP panels are flexible enough to conform to the shape of quonset greenhouses, which make FRP a very versatile covering material. FRP can be applied to the inexpensive frames of plastic film greenhouses or to the more elaborate frames of glass type greenhouses. The price of FRP greenhouse lies between that of a plastic film greenhouse and that of a glass greenhouse. But the cost is compensated by the elimination of the need for replacement of film plastic in every year or alternate years. Corrugated panels were used because of their greater strength. Flat panels are used occasionally for the end and side walls, where the load is not great. It is available in 1.3 m width, length up to 7.3 m and in a variety of colours. The total quantity of light transmitted through clear FRP is approximately equivalent to that transmitted through glass, but diminishes in relation its colour. For greenhouse crops in general, only clear FRP permits a satisfactory level of light transmission (88 to 90%). Coloured FRP has found a limited use in greenhouses intended for growing houseplants that require low light intensity and in display greenhouses for holding plants during the sales period. FRP has advantage over glass is that, it cools easily. FRP greenhouses require fewer structural members since sash bars are not needed.

8.9 ACRYLIC AND POLYCARBONATE RIGID-PANEL

These panels have been available for about 15 years for greenhouse use. The panels have been used for glazing the side and end walls of plastic film greenhouses and retrofitting old glass greenhouse. Acrylic panels are highly inflammable, where as polycarbonate panels are non-flammable. Acrylic panels are popular due to their higher light transmission and longer life. Acrylic panels are available in thickness of 16 and 18 mm, and have 83% of PAR light transmission. Acrylic panels cannot be bent, but the thinner panels can be bent to fit curved-proof greenhouses. These panels are also available with a coating to prevent condensation drip. Polycarbonate panels are preferred for commercial greenhouses due to lower price, flame resistance and greater resistance to hail damage. Polycarbonate panels are available in thickness of 4,6, 8, 10 and 16 mm. These panels are also available with a coating to prevent condensation drip and also with an acrylic coating for extra protection from UV light.

LECTURE 9

Contents of lecture: Design criteria and constructional details of greenhouses - construction of pipe framed greenhouses, material requirement, preparation of materials and procedure of erection.

The term greenhouse refers to a structure covered with a transparent material for the purpose of admitting natural light for plant growth. Two or more greenhouses in one location are referred to as a greenhouse range. A building associated with the greenhouses that is used for storage or for operations in support of growing of plants, is referred to as a service building or head house.

DESIGN CRITERIA OF CONSTRUCTION

For locating the greenhouse, a piece of land larger than the grower's immediate need should be acquired. The ultimate size of the greenhouse range should be estimated. Area should then be added to this estimated figure to accommodate service buildings, storage, access drives and a parking lot. The floor area of service buildings required for small firms is about 13% of the greenhouse floor area, and it decreases with the increase in size of the firm. On an average, service buildings occupy 10% of the growing area. The service building is centrally located in a nearly square design of the firm, which minimizes distance of movement of plants and materials. Doors between the service buildings and the greenhouse should be wide enough to facilitate full use of the corridor width. Doors at least 3.1 m wide and 2.7 m high are common. It is good to have the greenhouse gutter at least 3.7 m above the floor to accommodate automation and thermal blanket and still leave the room for future innovations.

CONSTRUCTION OF GLASS GREENHOUSES

Glass greenhouses have an advantage of greater interior light intensity over plastic panel and film plastic covered greenhouses. Glass greenhouses tend to have a higher air infiltration rate, which leads to lower interior humidity, which is advantageous for disease prevention. On the other hand, glass greenhouses have a higher initial cost than double-layer film plastic greenhouses. While comparing the price of a glass greenhouse to a film plastic greenhouse, one needs to take into account the initial purchase price of each as well as the cost of re-covering the film plastic greenhouse every three to four years.

Several types of glass greenhouses are designed to meet specific needs. A lean-to-type design is used when a greenhouse is placed against the side of an existing building. This design makes the best use of sunlight and minimizes the requirements for roof supports. It is found mostly in the retail industry. An even-span greenhouse is one in which the two roof slopes are of equal pitch and width. By comparison, a un-even-span greenhouse has roofs of unequal width, which makes the structure adaptable to the side of a hill. This style is seldom used today because such greenhouses are not adaptable to automation. Finally, a ridge-and-furrow design uses, two or more A- frame greenhouses connected to one another along the length of the eave. The sidewall is eliminated between greenhouses, which results in a structure with a single large interior. Basically, three frame types are used in glass greenhouses, which are wood frames (6.1 m in width), pipe frames (12.2 m in width) and truss frames (15.2 m in width). Latest glass greenhouses are primarily of the truss frame type. Truss frame greenhouses are best suited for prefabrication.

All-metal greenhouses proved cheaper to maintain since they required no painting. At present, virtually all glass greenhouse construction is of the metal type. The structural members of the glass greenhouse cast shadows that reduce plant growth during the dark months of the year. Aluminum sash bars are stronger than wooden ones; hence wider panels of glass can be used with aluminum bars. The reduction in materials and the reflectance of aluminum have given these metal greenhouses a great advantage over wooden greenhouses in terms of higher interior light intensity.

Glass greenhouse construction of today can be categorized as high profile or low profile. The low profile greenhouse is most popular in the Netherlands and is known as the Venlo greenhouse. The low profile greenhouses uses single panels of glass extend from eave to ridge. The low profile greenhouse slightly reduces exposed surface area, thereby reducing the heating cost, but more expensive to cool. The high profile greenhouses require more than single panel to cover the eave to ridge. A problem with this design is the unsealed junction between pieces of glass in the inner layer. Moisture and dust may enter between the layers and reduce light transmission.

CONSTRUCTION OF PIPE FRAMED GREENHOUSES

The choice of construction of pipe framed greenhouses often favours low initial investment and relatively long life. Galvanized mild steel pipe as a structural member in association with wide width UV- stabilized low density polyethylene (LDPE) film is a common option of greenhouse designers.

Material requirement

The structural members of greenhouse are

(a) hoops

(b) foundation

(c) lateral supports

(d) polygrip assembly

(e) end frame

The following materials are required for a greenhouse having 4m × 20 m floor area:

(i) GI pipe class A (25 mm diameter, 85 cm long, 30 m total length)

(ii) GI pipe class B (15 mm diameter, 6.0 m long, 21 No.s)

(iii) GI sheet (20 gauge, size 90 ×24 cm, 4 sheets)

(iv) MS flat (25 × 3 mm size, 4 m length)

(v) Lateral support to end frames (10 mm diameter rod, 10 m length)

(vi) Cement concrete (1: 3: 6 mix, 1.0 m^3)

(vii) UV- stabilized LDPE film (single layer 800 gauge, 5.4 m^2/kg, 154 m^2)

(viii) Polygrip (channel 2000×3.5×4 cm, 2 No.s; Angle 2000×2×2 cm, 2 No.s; both made from the procured 20 gauge GI sheet, key 6 mm diameter, 56 mm length)

(ix) Wooden end frames (5 × 5 cm wood, 0.15 m^3)

(x) Nuts and bolts 9 6 mm diameter, 35 mm long, 70 sets)

(xi) Miscellaneous items like nails, hinges and latches as per requirement

Procedure of erection

(1) A 4m by 20m rectangular area is marked on the site, preferably orienting the longer dimension in east-west direction. This rectangle will act as the floor plan of the greenhouse (Fig.9.1).

(2). Mark four points on the four corners of the rectangle.

(3) Start from one corner point and move along the length of marked rectangle, marking a point every 1.25 m distance until reaching the other corner (16 bays; 17 points). The same procedure is repeated on the other side of the rectangle.

(4). Dig 10 cm diameter holes upto 70 cm depth on all marked points with the help of bucket auger (or) a crowbar. This way a total of 34 holes on both the parallel sides of the greenhouse floor is obtained.

(5) Polygrip sections formed according to the drawing into two 20m length.

(6). Fix the prefabricated polygrip channels to the foundation pipes on 1.25 m spacing with the help of 6 mm diameter bolts.

(7). Set these assemblies on temporary supports between the holes with the foundation pipes hanging vertically in the holes.

(8). Pour cement concrete mix of 1: 3 : 6 around foundation pipes in such a way that the lower 15 cm to 20 cm ends are covered in concrete. The concrete is compacted around the foundation pipes with the help of the crowbar and is allowed to cure for 2-3 days.

(9) After curing, fill the soil around the foundation pipes to the ground level and compact it well.

(10). Position end frames on the two ends. Mark the position of legs and dug holes for fixing of legs. Now install both the end frames.

(11). Put the ringside of lateral support members on adjacent foundation pipe to the corner, and other side is hooked to the end frame.

(12). Put all the hoops in the foundation pipes in such away that straight portion of hoop is inserted into the foundation and rests on the bolt used for fixing of polygrip channel .

(13). Take a 20 m long ridge line by spacing 15 mm diameter pipes together. Put the 20m long pipe at the ridge line of the hoops.

(14) Use cross connectors on the ridge line pipe, in such a way that one half of it remains on the one side of the hoop and the other half on the other side.

(15) Put two bolts of 6 mm diameter in the holes provided in the ends of cross-connector. Tie a few of them with the help of nuts.

(16) Repeat the same procedure for joining all the hoops with ridge line pipe.

(17) While forming cross-connectors, the distance between the cross-connectors or hoops should be maintained 1.25 m center to center. This poly grip mechanism will provide a firm grip of the ridge line pipe and hoops at right angles without allowing for slippage.

(18) Spread polyethylene film over the structure from one end to the other end without wrinkles and keeping the edges together.

(19) Place polyethylene film between the polygrip channel and right angle strip and secure them under pressure with the help of iron rods. The film is stretched gently and fixed on the other parallel side by polygrip. This way the polyethylene is secured on both the longer sides.

(20) On the other two remaining ends, polyethylene is nailed to the end frames using wooden battens and nails.

(21) The remaining portion of the end frames is covered with polyethylene film, which is secured with wooden battens and nails.

(22) Mechanical ventilation, heating and cooling equipment is installed on the frames as per the crop requirement.

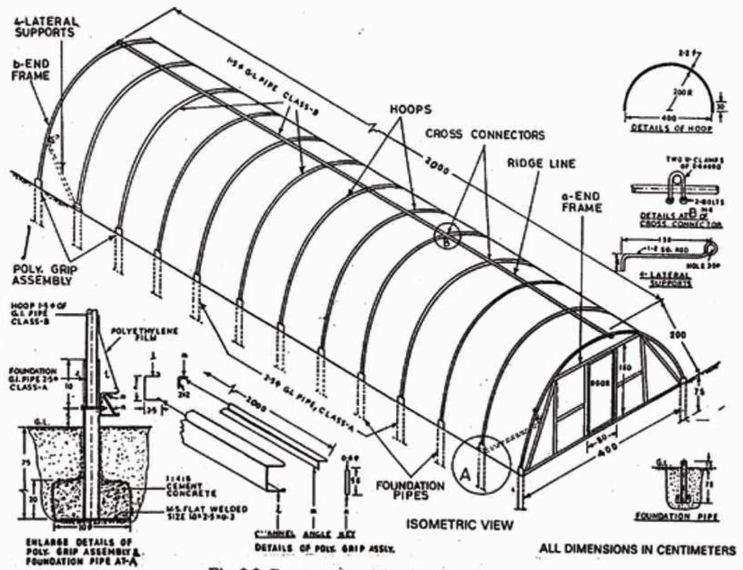


Fig. 9.2 Constructional details of pipe framed greenhouse

Fig.9.1.Constructional details of pipe framed greenhouse

LECTURE 10

Content of lecture: Greenhouse cooling – Design of active summer and winter cooling sytems.

GREENHOUSE COOLING

Ventilation and cooling of greenhouse environment are essential during summer and winter as well. While summer cooling is done using evaporative cooling systems, the winter cooling uses convection-tube with pressurizing fans and exhaust fans. Although the warming phenomenon due to greenhouse effect is desirable inside greenhouse, occasions arise to cool the greenhouse environment to guard the crops from the ill effects of overheating. Green house cooling during summer and winter should be thought essentially of maintaining the desirable temperature and air quality by moving and mixing for efficient crop production. Greenhouse cooling requires that large volume of air to be brought into the greenhouse.

Design of Active Summer Cooling system

The rate of air exchange is measured in cubic meters per minute (cmm). The National Greenhouse Manufacturers Association (NGMA) indicates in its 2004 standards and guidelines for ventilating and cooling greenhouses that a rate of removal of 2.5 cmm/ m^2 of greenhouse floor is sufficient. This apples to a greenhouse under 305 m in elevation, with an interior light intensity not exceeding 53.8 klux and an air temperature rise of 4^0 C from pad to fans. Standard tables of correction factors of the rate of air removal are available to account for any deviation from these standard conditions. Since it is relatively tedious to calculate the air volume using this method, a direct value of 3.4 to 5.2 cmm/m^2 of floor area recommended by Willits (1993) can be used.

The rate of air removal from the greenhouse must increase as the elevation of the greenhouse site increases. The density of air decreases and becomes lighter with increases in elevation. The ability of air to remove solar heat from the greenhouse depends upon its weight and not its volume. Thus, a larger volume of air must be drawn through the greenhouse at high elevations than that is drawn through at low elevations in order to have an equivalent cooling effect. Hence, the values of elevation factor (F_{elev}) are directly proportional to the elevation. The values of elevation factors, used to correct the rate of air removal for a particular elevation are listed in Table 10.1.

Table 10.1. Correction Factors of the Rate of Air Removal for Elevation Above Sea Level.

Elevation above sea level (m)	**<300**	**300**	**600**	**900**	**1200**	**1500**	**1800**	**2100**	**2400**
F_{elev}	1.00	1.04	1.08	1.12	1.16	1.20	1.25	1.30	1.36

Source: National Greenhouse Manufactures Association (2004)

The rate of air removal is also depends upon the light intensity in the greenhouse. As light intensity increases, the heat input from the sun increases, requiring a greater rate of air removal from the greenhouse. Hence, the values of light factor (F_{light}) vary directly with the light intensity. The values of light factors used to adjust the rate of air removal are listed in Table 10.2. In general, an intensity of 53.8 klux is accepted as a desirable level for crops. Any excess light intensity can also be controlled either with a coat of shading compound on the greenhouse covering or with a screen material above the plants in the greenhouse.

Table 10.2. Correction Factors of the Rate of Air Removal for Maximum Light Intensity in the Greenhouse.

Light intensity (Klux)	**43.1**	**48.4**	**53.8**	**59.2**	**64.6**	**70.0**	**75.3**	**80.1**	**86.1**
F_{light}	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60

Source : National Greenhouse Manufacturers Association (2004)

Solar energy warms the air as it passes from the pad to the exhaust fans. Usually, a 4^0C rise in temperature is tolerated across the greenhouse. If it becomes important to have uniform temperature across the greenhouse, it will be necessary to raise the velocity of the air movement through the greenhouse. To maintain less temperature difference across the greenhouse more air is to be circulated. Hence, the temperature factor (F_{temp}) increases as the difference in temperature across pad to fan decreases. The temperature factors used for various possible temperature rises are given in Table 10.3.

Table 10.3. Correction Factors of the Rate of Air Removal for a given Pad- to - Fan Temperature Rises.

Temperature rise (°C)	5.6	5.0	4.4	3.9	3.3	2.8	2.2
F_{temp}	0.70	0.78	0.88	1.00	1.17	1.40	1.75

Source: National Greenhouse Manufactures Association (2004)

The pad and fans should be placed on opposite walls, either end walls or side walls of the greenhouse (Fig.10.1) and the distance between them is important. A distance of 30 to 61 m is the best. The size of the exhaust fan should be selected to achieve proper temperature difference and good circulation. If the pad to fan distance is less, then there is less opportunity time for the flowing air to cool the surroundings; whereas with very large distance uniform cooling is not possible as fans may not pull enough air through the pads. To achieve a given degree of cooling, more amount of air is required when pad to fan distance is less and vice versa. The velocity of incoming air is to be modified accordingly. The velocity factors (F_{vel}) used to compensate for pad to fan distance are listed in Table 5.

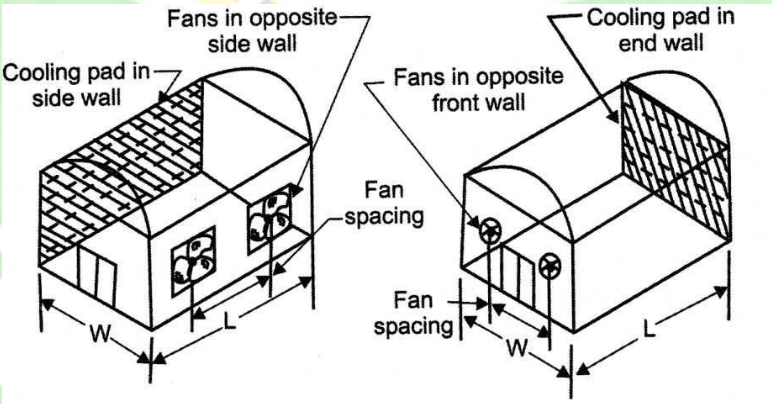


Fig.10.1. Arrangement of fan and pad in active summer cooling system.

The rate of air required for a specific greenhouse can be calculated using the factors given in Table 10.1 through 10.4. Firstly, the rate of air removal required for a greenhouse is determined under standard conditions (Q_{std}) using the following equation:

Q_{std}=LxWx2.5

Where, L is the length and W is the width of greenhouse.

Table 10.4. Correction Factors of the Rate of Air Removal for a given. Pad-to-Fan Distances

Pad-to-fan Distance (m)	6.1	7.6	9.1	10.7	12.2	13.7	15.2	16.8	18.3
F_{vel}	2.24	2.00	1.83	1.69	1.58	1.48	1.41	1.35	1.29
Pad-to-fan distance (m)	19.8	21.3	22.9	24.4	25.9	27.4	29.0	>30.5	
F_{vel}	1.24	1.20	1.16	1.12	1.08	1.05	1.02	1.00	

Now, the standard rate of air removal is adjusted by multiplying it by the larger of the following two factors: F_{house}, or F_{vel}. The value of F_{vel} is read directly from Table 10.4 whereas F_{house} is calculated from the following equation:

$F_{house}= F_{elev} x F_{light} x F_{temp}$

Thus, the final adjusted (Q_{adj}) capacity of the exhaust fans must be

$Q_{adj}= Q_{std}$ x (F_{house} or F_{vel})

The size and number of exhaust fans must be selected next. The collective capacity of the fans should be at least equal to the rate of air removal required at a static water pressure of 30 Pa. If slant wall housing fans are used, which has the fan outside the louvers, the fans should be rated at 15 Pa static water pressure. The static pressure value takes into account the resistance the fans meet in drawing air through the pad and the fan itself. Air-delivery ratings for various sizes of fans are listed in Table 6. Fans should not be spaced more than 7.6 m apart. The required capacity of each fan in this case can be determined by dividing the Q_{adj} by the number of fans required. These fans are selected for the their rated performance levels from the tables and are evenly spaced in the greenhouse, at pant height if possible, to guarantee a uniform flow of air through the plants. The excelsior (wood fiber) pads of 2.5 to 4 cm thick are generally used. These are replaced annually and they support an airflow rate of 45 cmm/m^2. Cross-fluted cellulose pads come in units of 30 cm wide and are 5, 10, 15 or

30 cm thick. They can last up to 10 years, and the commonly used 10 cm thick pad can accommodate an air intake of 75 cmm/m^2. An arrangement of excelsior pad on the end wall and cross fluted cellulose cooling pad on the side is shown in Fig. 10.2 and 10.3 respectively.

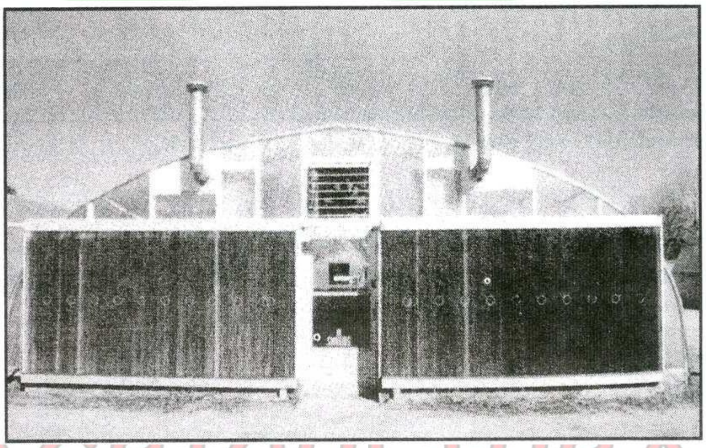


Fig 10.2. Arrangement of excelsior pad on the end wall

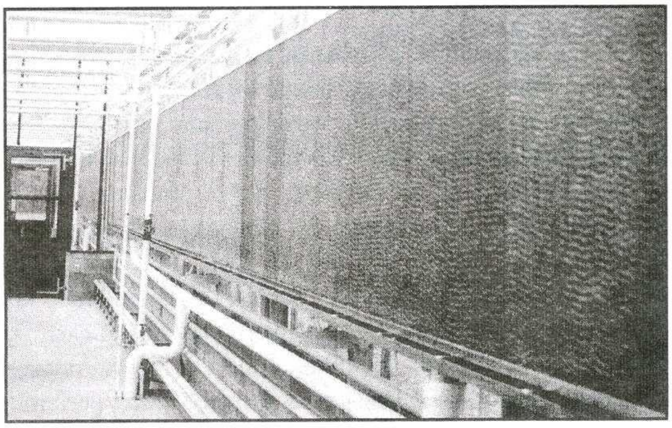


Fig 10.3. Arrangement of cross fluted cellulose cooling pad on the side

The total area of pad required is determined by dividing the volume of air that must be removed from the greenhouse in unit time by the volume of air that can be moved through a square meter of pad or can directly be obtained from Table 10.5.

Water must be delivered to the top of a 10 cm thick cross- fluted cellulose pad at the rate of 6.2 1/min/m of pad, with proper distribution pipes and holes arrangement. The flow rate for a 15 cm pad is 9.3 1/min/m of pad. The sump volume should be 30.5 1/m^2 for 10 cm thick pad, and 40.7 1/m^2 for 15 cm thick pad. These sump volumes are designed for an operating

Table 10.5. Correction Factors of the Rate of Air Removal for a given Pad-to Fan distances.

Fan size (cm)	Horse Power (hp)	Rate at 30 Ps static pressure (cmm)	Pad area per fan (m^2)		
			Excelsior	10 cm Cellulose	15 cm Cellulose
61	0.25	127	2.8	4.5	1.2
	0.33	161	3.5	2.1	1.5
	0.50	184	4.0	2.4	1.8
	0.75	215	4.7	2.8	2.0
76	0.33	209	4.6	2.8	2.0
	0.50	249	5.5	3.3	2.3
	0.75	289	6.3	3.8	2.7
91	0.33	249	5.5	3.3	2.3
	0.50	300	6.6	4.0	2.9
	0.75	359	7.9	4.7	3.4
	1.00	402	8.8	5.3	3.8
107	0.50	354	7.8	4.6	3.3
	0.75	425	9.3	5.6	4.0
	1.0	475	10.4	6.3	4.5
122	0.50	416	9.1	5.5	3.9
	0.75	504	11.1	6.7	4.7
	1.00	555	12.2	7.2	5.2
137	1.00	648	14.2	8.5	6.1
	1.50	730	16.0	9.7	6.9

Source : Acme Engineering and Manufacturing Corporation, Muskogee, OK (1993)

Water level at half the depth of the tank and will provide space to accommodate water returning from the pad when the system is turned off. Water should be delivered to the top of an excelsior pad at the rate of 13.6 1/min/m of pad, regardless of the height of the pad. Since all water will return to the sump when the system is turned off, a sump capacity of 19 1/m of pad is required.

10.2 Design of Active Winter Cooling System

During winter, the outside air temperature will be less than that is inside the greenhouse. Therefore simple mixing of the outside ambient air by convection tubes does the actual winter cooling. In active winter cooling systems, under standard conditions a volume of 0.61 cmm of air should be removed from the greenhouse for each square meter of floor area. The air volume obtained by multiplying the floor area by this value would define the capacity of the exhaust fan.. If a lower inside temperature is desired, cold air must be introduced into the greenhouse at a greater rate. Hence, in active winter cooling, the winter factor ($F_{winter)}$ based on temperature difference between inside and outside air vary inversely with the required temperature difference. The compensating factors to be used in active winter cooling are given in Table 10.6.

Table 10.6. Correction Factors of Standard Rate of Air Removal in a Winter Greenhouse Cooling System based on Temperature Difference.

Temperature Difference (^{0}C)	10.0	9.4	8.9	8.3	7.8	7.2	6.7	6.1	5.6	5.0
F_{winter}	0.83	0.88	0.94	1.00	1.07	1.15	1.25	1.37	1.50	16.7

Source: National Greenhouse Manufacturers Association (2004)

As in the case of summer cooling systems, standard conditions also specify an elevation under 305 m and a maximum interior light intensity of 53.8 klux. If other elevation or light intensity specifications are desired, factors must be selected from Tables 2 and 3 are used to correct the rate of air entry. Convection tubes are conventionally oriented from end to end in the greenhouse (Fig. 5.1). One convection tube placed down the center of the house will cool houses up to 9.1 m in width. Greenhouses 9.1 to 18.3 m wide are cooled by two tubes placed equidistant from the side walls across the greenhouse. Holes along the tube exist in pairs on the opposite vertical sides. The holes vary in size according to the volume of greenhouse to be cooled. The number and diameter of tubes needed to cool a greenhouse can be determined from Table 10.7. If two or more tubes are needed, they should be of equal size and should be spaced evenly across the greenhouse. Recommendations in Table 8 are based on an air flow rate approximately 518 cmm/m^2 of cross sectional area in the tube. When the greenhouse is large and the required number of 76 cm diameter tubes becomes cumbersome, tubes may be installed with air inlets in both ends. These inlets double the amount of cool air that can be brought in through a single tube.

Table 10.7. Air Distribution Tubes Required for Winter Cooling of Greenhouse of Various Sizes.

Greenhouse width (m)	**Number (N) and Diameter (D in cm) of air destitution tubes for different greenhouse lengths)**									
	15 m		**30 m**		**46m**		**61m**		**76m**	
	N	**D**	**N**	**D**	**N**	**D**	**N**	**D**	**N**	**D**
4.6	1	46	1	46	1	61	1	76	1	76
6.1	1	46	1	61	1	76	1	76	2	61
7.6	1	46	1	61	1	76	2	61	2	76
9.1	2	46	2	46	2	61	2	76	2	76
10.7	2	46	2	61	2	76	2	76	3	76
12.2	2	46	2	61	2	76	2	76	3	76
15.2	2	46	2	61	2	76	3	76	3	76

Source National Greenhouse Manufacturers Association (2004)

Note: The problems on design of active summer cooling system and active winter cooling system must be practiced in practical class (Refer page No.92-93 and 96-97 of book titled: Greenhouse Technology and Management, Second Edition by K.Radha Manohar and C. Igathinathane).

LECTURE 11

Content of lecture: Greenhouse heating- modes of heat loss, heating systems, heat distribution systems, solar heating system, water and rock storage, heat conservation practice.

The northern parts of our country experience cold winters, where heating system need to be employed in the greenhouses along with cooling systems for summer. Whereas the southern region greenhouses need only cooling systems since the winter cold effect is not that severe. Greenhouse heating is required in cold weather conditions, if the entrapped heat is not sufficient during the nights. The heat is always lost from the greenhouse when the surroundings are relatively cooler. Heat must be supplied to a greenhouse at the same rate with which it is lost in order to maintain a desired temperature: Heat losses can occur in three different modes of heat transfer, namely conduction, convection, and radiation. Maintenance of desired higher temperature, compared with the surroundings needs heating systems and heat distribution systems. For the purpose of greenhouse heating, apart from conventional systems, solar energy can also be used and the heat can be stored using water and rock storage. Different heat conservation practices are available to effectively utilize the heat energy.

MODES OF HEAT LOSS

The heating systems, in a continuous process, should supply the heat just enough to compensate which is lost. Most heat is lost by conduction through the covering materials of the greenhouse. Different materials, such as aluminum sash bars, glass polyethylene, and cement partition walls, vary in conduction according to the rate at which each conducts heat from the warm interior to the colder exterior. A good conductor of heat looses more heat in a shorter time than a bad conductor and vice versa. There are only limited ways of insulating the covering material without blocking the light transmission. A dead air space between two coverings appears to be the best system. A saving of 40% of the heat requirement can be achieved when a second covering in applied. For example greenhouse covered with one layer of polyethylene loses, 6.8 W of heat through each square meter of covering every hour when the outside temperature is 1^{oC} lower than the inside. When second layer of polyethylene is added, only 3.97 W/m^2 is lost (40% reduction).

A second mode of heat loss is that of convection (air infiltration). Spaces between panes of glass or FRP and ventilators and doors permit the passage of warm air outward and cold air inward. A general assumption holds that the volume of air held in a greenhouse can be lost as often as once very 60 minutes in a double layer film plastic or polycarbonate panel greenhouse, every 40 minutes in a FROP or a new glass greenhouse every 30 minutes in an old well maintained glass greenhouse, and every 15 minutes in an old poorly maintained glass greenhouse. About 10% of total heat loss from a structurally tight glass greenhouse occurs through infiltration loss.

A third mode of heat loss from a greenhouse is that of radiation. Warm objects emit radiant energy, which passes through air to colder objects without warming the air significantly. The colder objects become warmer. Glass, vinyl plastic, FRP, and water are relatively opaque to radiant energy, whereas polyethylene is not. Polyethylene, greenhouses can lose considerable amounts of heat through radiation to colder objects outside, unless a film of moisture forms on the polyethylene to provide a barrier.

HEATING SYSTEMS

The heating system must provide heat to the greenhouse at the same rate at which it is lost by co0nductin, infiltration, and radiation. There are three popular types of heating systems for greenhouses. The most common and least expensive is the unit heater system. In this system, warm air is blown from unit heaters that have self contained fireboxes. These heaters consist of three functional parts. Fuel is combusted in a firebox to provide heat. The heat is initially contained in the exhaust, which rises through the inside of a set of thin walled metal tubes on it way to the exhaust stack. The warm exhaust transfers heat to the cooler metal walls of the tubes. Much of the heat is removed from the exhaust by the time it reaches the stack through which it leaves the greenhouse. A fan in the back of the unit heater draws in greenhouse air, passing it over the exterior side of the tubes and then out from the heater to the greenhouse environment again. The cool air passing over hot metal tubes is warmed and the air is circulated.

A second type of system is central heating system, which consists of a central boiler than produces steam or hot water, plus a radiating mechanism in the greenhouse to dissipate the heat. A central heating system can be more efficient than unit heaters, especially in large greenhouse ranges. In this system, two or more large boilers are in a single location. Heat is transported in the form of hot water or steam through pipe mains to be growing area, and the heat is exchanged from the hot water in a pipe coil located across the greenhouse or an in-bed pipe coil located in the plant zone. Some greenhouses have a third pipe coil embedded in a concrete floor. A set of unit heaters can be used in the place of the overhead pipe coil, obtaining heat from hot water or steam from the central boiler.

The third type of system is radiation heating system. In this system, gas is burned within pipes suspended overhead in the greenhouse. The warm pipes supply heat to the plants. Low intensity infrared radiant heaters can save 30% or more, of fuel compared to conventional heaters. Several of these heaters are installed in tandem in the greenhouse. Lower air temperatures are possible since only the plants and root substrate are heated directly by this mode of heating.

The fourth possible type of system is the solar heating system, but it is still too expensive to be a viable option. Solar heating systems are found in hobby greenhouses and small commercial firms. Both water and rock energy storage systems are used in combination with solar energy. The high cost of solar heating systems discourages any significant use by the greenhouse industries.

Heat distribution systems

Heat is distributed from the unit heaters by one of two common methods. In the convection tube method, warm air from unit heaters are distributed through a transparent polyethylene tube running through the length of the greenhouse. Heat escapes from the tube through holes on either side of the tube in small jet streams, which rapidly mix with the surrounding air and set up a circulation pattern to minimize temperature gradients.

The second method of heat distribution is horizontal airflow. In this system, the greenhouse may be visualized as a large box containing air, and it uses small horizontal fans for moving the air mass. The fans are located above plant height and are spaced about 15 m (50 ft) apart in two rows. Their arrangement is tha, the heat originating at one corner of the greenhouse is directed from one side of the greenhouse to the opposite end and then back along the other side of the greenhouse. Proper arrangement of fans is necessary for effective distribution in horizontal airflow system for various greenhouse sizes. Both of these distribution systems can also be used for general circulation of air and for introducing cold outside air during winter cooling.

Solar heating system

Solar heating is often used as a partial or total alternative to fossil fuel heating systems. Few solar heating systems exist in greenhouses today. The general components of solar heating system (Fig. 11.1) are collector, heat storage facility, exchange to transfer the solar derived heat to the greenhouse air, backup heater to take over when solar heating does not suffice and set of controls.

Various solar heat collectors are in existence, but the flat plate collector has received greatest attention. This consists of a flat black plate (rigid plastic, film plastic, sheet metal, or board) for absorbing solar energy. The plate is covered on the sun side by two or more transparent glass or plastic layers and on the backside by insulation. The enclosing layers serve to hold the collected heat within the collector. Water or air is passed through the copper tubes placed over the black plate and absorb the entrapped heat and carry it to the storage facility. A greenhouse itself can be considered as a solar collector. Some of its collected heat is stored in the soil, plants, greenhouse frame, floor, and so on. The remaining heat is excessive for plant growth and is therefore vented to the outside. The excess vented heat could just as well be directed to a rock bed for storage and subsequent use during a period of heating. Collection of heat by flat-plate collection is most efficient when the collector is positioned perpendicular to the sun at solar noon. Based on the locations, the heat derived can provide 20 to 50% of the heat requirement.

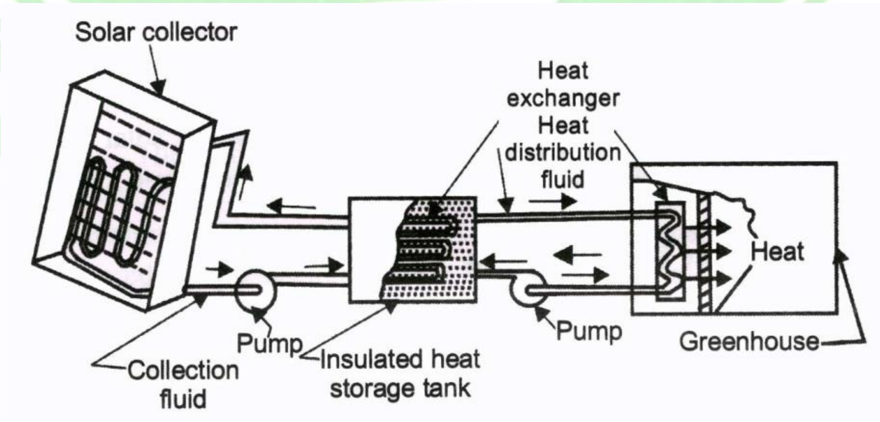


Fig.11.1. A typical solar heating system for greenhouse

WATER AND ROCK STORAGE

Water and rocks are the two most common materials for the storage of heat in the greenhouse. One kg of water can hold 4.23 kJ of heat for each 1^{o}C rise in temperature. Rocks can store about 0.83 kJ for each 1^{o}C. To store equivalent amounts of heat, a rock bed would have to be three times as large as a water tank. A water storage system is well adapted to a water collector and a greenhouse heating system which consists of a pipe coil or a unit heater which contains a water coil. Heated water from the collector is pumped to the storage tank during the day. As and when heat is required, warm water is pumped form the storage tank to a hot water or steam boiler or into the hot water coil within a unit heater. Although the solar heated water will be cooler than the thermostat setting on the boiler, heat can be saved, since the temperature of this water need be raised as high as to reach the output temperature of water or steam from the boiler. A temperature rise of 17^{o}C above the ambient condition is expected during the daytime in solar storage units. Each kilogram of water can supply 71.1 kJ of heat, and each kilogram of rock can supply14.2 kJ of heat, as it cools by 17^{o}C.

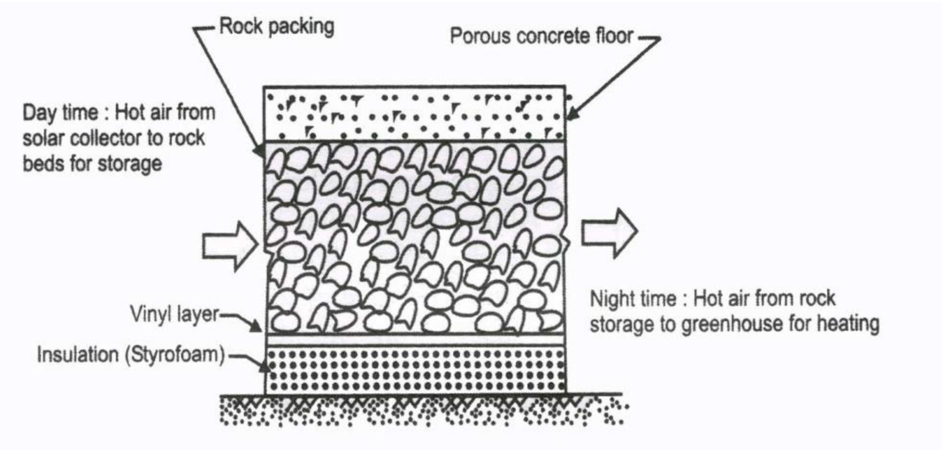


Fig.11.2. Cross section of a typical rock storage unit

A rock storage bed can be used with an air-collector and forced air heating system. In this case, heated air form the collector, along with air excessively heated inside the greenhouse during the day, is forced through a bed of rocks (Fig. 11.2). The rocks absorb much of the heat. The rock bed may be located beneath the floor of the greenhouse or outside the greenhouse, and it should be well insulated against heat loss. During the night, when heat is required in the greenhouse, cool air from inside the greenhouse is forced through the rocks, where it is warmed and the passed back into the greenhouse. A clear polyethylene tube with holes along either side serves well to distribute the warm air uniformly along the length of the greenhouse. Conventional convection tubes can be used for distributing solar heated air. The water or rock storage unit occupies a large amount of space and a considerable amount of insulation is provided if the unit is placed outside. Placing it inside the greenhouse offers an advantage in that escaping heat is beneficial during heating periods, but it is detrimental when heating is not required. Rock beds can pose a problem in that they must remain relatively dry. Water evaporating from these beds will remove considerable heat.

LECTURE 12

Content of lecture: Irrigation system used in greenhouses-rules of watering, hand watering, perimeter watering, overhead sprinklers, boom watering and drip irrigation.

A well-designed irrigation system will supply the precise amount of water needed each day throughout the year. The quantity of water needed would depend on the growing area, the crop, weather conditions, the time of year and whether the heating or ventilation system is operating. Water needs are also dependent on the type of soil or soil mix and the size and type of the container or bed. Watering in the green house most frequently accounts for loss in crop quality. Though the operation appears to be the simple, proper decision should be taken on how, when and what quantity to be given to the plants after continuous inspection and assessment .Since under watering (less frequent) and over watering (more frequent) will be injurious to the crops, the rules of watering should be strictly adhered to. Several irrigation water application systems, such as hand writing, perimeter watering, overhead sprinklers, boom watering and drip irrigation, over sprinklers, boom watering and drip irrigation which are currently in use.

RULES OF WATERING

The following are the important rules of application of irrigation.

Rule 1: Use a well drained substrate with good structure

If the root substrate is not well drained and aerated, proper watering can not be achieved. Hence substrates with ample moisture retention along with good aeration are indispensable for proper growth of the plants. The desired combination of coarse texture and highly stable structure can be obtained from the formulated substrates and not from field soil alone.

Rule 2: Water thoroughly each time

Partial watering of the substrates should be avoided; the supplied water should flow from the bottom in case of containers, and the root zone is wetted thoroughly in case of beds. As a rule, 10 to 15% excess of water is supplied. In general, the water requirement for soil based substrates is at a rate of 20 l/m^2 of bench, 0.3 to 0.35 litres per 16.5 cm diameter pot.

Rule 3: Water just before initial moisture stress occurs

Since over watering reduces the aeration and root development, water should be applied just before the plant enters the early symptoms of water stress. The foliar symptoms, such as texture, colour and turbidity can be used to determine the moisture stress, but vary with crops. For crops that do not show any symptoms, colour, feel and weight of the substrates are used for assessment.

HAND WATERING

The most traditional method of irrigation is hand watering and in present days is uneconomical. Growers can afford hand watering only where a crop is still at a high density, such as in seed beds, or when they are watered at a few selected pots or areas that have dried sooner than others. In all cases, the labour saved will pay for the automatic system in less than one year. It soon will become apparent that this cost is too high. In addition to this deterrent to hand watering, there is great risk of applying too little water or of waiting too long between waterings. Hand watering requires considerable time and is very boring. It is usually performed by inexperienced employees, who may be tempted to speed up the job or put it off to another time. Automatic watering is rapid and easy and is performed by the grower it self. Where hand watering is practiced, a water breaker should be used on the end of the hose. Such a device breaks the force of the water, permitting a higher flow rate without washing the root substrate out of the bench or pot. It also lessens the risk of disrupting the structure of the substrate surface.

PERIMETER WATERING

Perimeter watering system can be used for crop production in benches or beds. A typical system consists of a plastic pipe around the perimeter of a bench with nozzles that spray water over the substrate surface below the foliage (Fig.12.1).

Either polythene or PVC pipe can be used. While PVC pipe has the advantage of being very stationery, polythene pipe tends to roll if it is not anchored firmly to the side of the bench. This causes nozzles to rise or fall from proper orientation to the substrate surface. Nozzles are made of nylon or a hard plastic and are available to put out a spray are of 180°, 90° or 45°. Regardless of the types of nozzles used, they are staggered across the benches so that each nozzle projects out between two other nozzles on the opposite side. Perimeter watering systems with 180° nozzles require one water valve for benches up to 30.5 m in length.

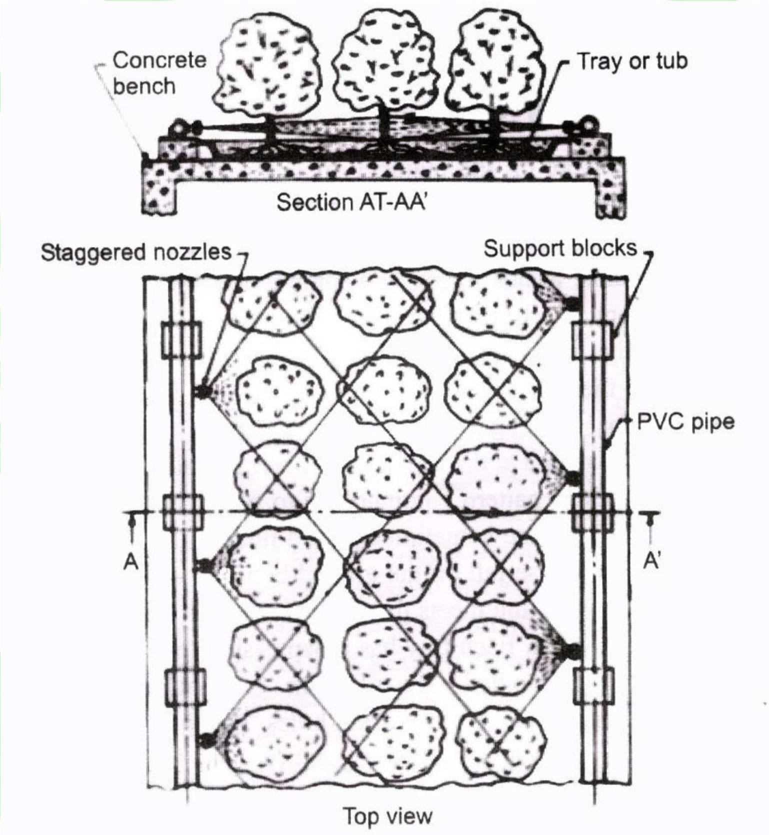


Fig. 12.1. Schematic diagram of perimeter watering system

OVERHEAD SPRINKLERS

While the foliage on the majority of crops should be kept dry for disease control purposes, a few crops do tolerate wet foliage. These few crops can most easily and cheaply be irrigated from overhead. Bedding plants, azalea liners, and some green plants are crops commonly watered from overhead. A pipe is installed along the middle of a bed. Riser pipes are installed periodically to a height well above the final height of the crop (Fig.12.2).

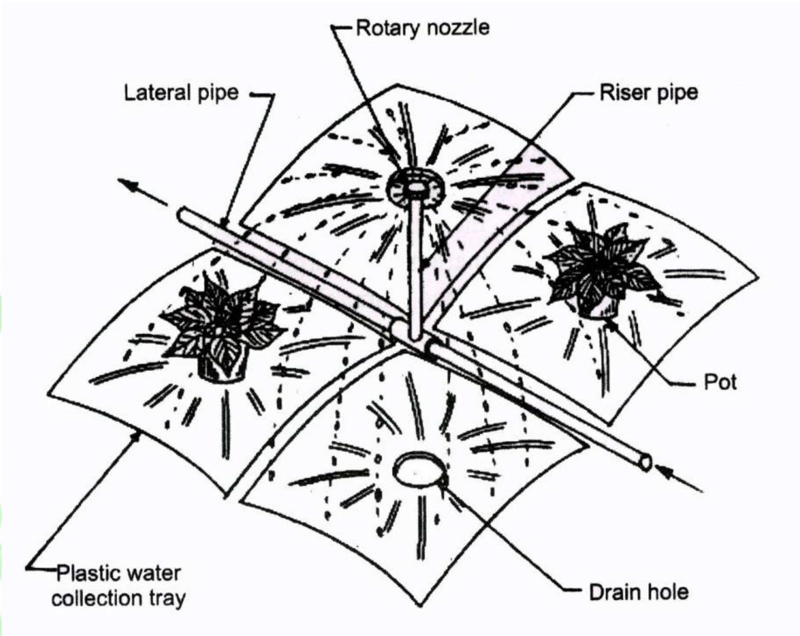


Fig. 12.2. Schematic diagram of overhead sprinkler watering system

A total height of 0.6 m is sufficient for bedding plants flats and 1.8 m for fresh flowers. A nozzle is installed at the top of each riser. Nozzles vary from those that throw a 360° pattern continuously to types that rotate around a 360° circle. Trays are sometimes placed under pots to collect water that would otherwise fall on the ground between pots and wasted. Each tray is square and meets the adjacent tray. In this way nearly all water is intercepted. Each tray has a depression to accommodate the pot and is then angled upward from the pot toward the tray perimeter. The trays also have drain holes, which allow drainage of excess water and store certain quantity, which is subsequently absorbed by the substrate.

BOOM WATERING

Boom watering can function either as open or a closed system, and is used often for the production of seedlings grown in plug trays. Plug trays are plastic trays that have width and length dimensions of approximately 30 × 61 cm, a depth of 13 to 38 mm, and contain about 100 to 800 cells. Each seedling grown in its own individual cell. Precision of watering is extremely important during the 2 to 8 week production time of plug seedlings.

A boom watering system generally consists of a water pipe boom that extends from one side of a greenhouse bay to the other. The pipe is fitted with nozzles that can spray either water or fertilizer solution down onto the crop. The boom is attached at its center point to a carriage that rides along rails, often suspended above the centre walk of the greenhouse bay. In this way, the boom can pass from one end of the bay to the other. The boom is propelled by an electric motor. The quantity of water delivered per unit area of plants is adjusted by the speed at which the boom travels.

DRIP IRRIGATION

Drip irrigation, often referred to as trickle irrigation, consists of laying plastic tubes of small diameter on the surface or subsurface of the field or greenhouse beside or beneath the plants. Water is delivered to the plants at frequent intervals through small holes or emitters located along the tube. Drip irrigation systems are commonly used in combination with protected agriculture, as an integral and essential part of the comprehensive design. When using plastic mulches, row covers, or greenhouses, drip irrigation is the only means of applying uniform water and fertilizer to the plants. Drip irrigation provides maximum control over environment variability; it assures optimum production with minimal use of water, while conserving soil and fertilizer nutrients; and controls water, fertilizer, labour and machinery costs. Drip irrigation is the best means of water conservation. In general, the application efficiency is 90 to 95%, compared with sprinkler at 70% and furrow irrigation at 60 to 80%, depending on soil type, level of field and how water is applied to the furrows. Drip irrigation is not only recommended for protected agriculture but also for open field crop production, especially in arid and semi-arid regions of the world. One of the disadvantages of drip irrigation is the initial cost of equipment per acre, which may be higher than other systems of irrigation. However, these costs must be evaluated through comparison with the expense of land preparation and maintenance often required by surface irrigation. Basic equipment for irrigation consists of a pump, a main line, delivery pipes, manifold, and drip tape laterals or emitters as shown in Fig 12.2.

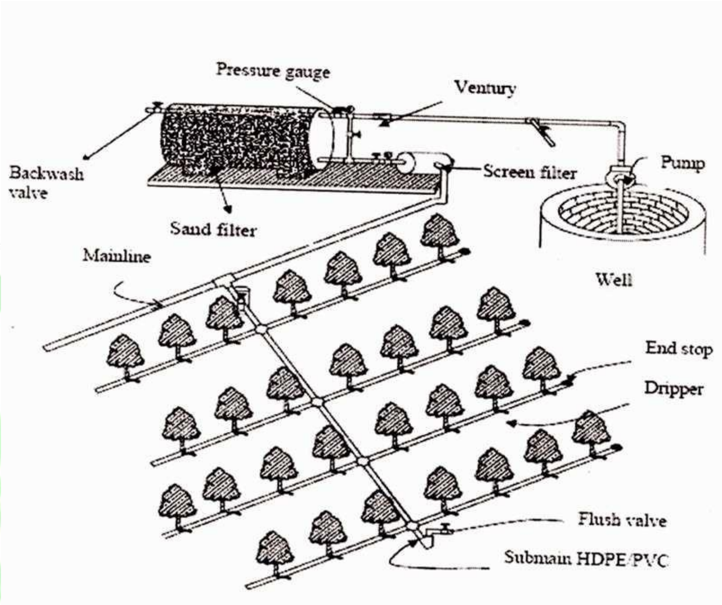


Fig.12.2. Diagram of drip irrigation system for greenhouse

The head, between the pump and the pipeline network, usually consists of control valves, couplings, filters, time clocks, fertilizer injectors, pressure regulators, flow meters, and gauges. Since the water passes through very small outlets in emitters, it is an absolute necessity that it should be screened, filtered, or both, before it is distributed in the pipe system. The initial field positioning and layout of a drip system is influenced by the topography of the land and the cost of various system configurations.

LECTURE 13

Content of lecture: Greenhouse utilization in off-season, drying of agricultural produce and curing of tobacco.

GREENHOUSE UTILIZATION IN OFF-SEASON

Drying is traditional method for preserving the food. It also helps in easy transport since the dried food becomes lighter because of moisture evaporation. Drying of seed prevents germination and growth of fungi and bacteria. The traditional practice of drying agricultural produce in the developing countries is sun drying, which is seasonal, intermittent, slow, and unhygienic. To overcome the problems of sun drying, mechanical drying is introduced with the following advantages: (i) fast drying, (ii) large volumes of produce can be handled (iii) drying parameters can be controlled and quality of the produce can be maintained. The energy demand of conventional mechanical dryers is met by electricity, fossil fuels, and firewood are becoming scarce. Solar energy can be an alternative source for drying of food and solar dryers are employed for the purpose. The use of the greenhouse as a dryer is the latest development. The drying capabilities of the greenhouse can be utilized for curing tobacco leaves, while guarding the harvest from rain damage.

The greenhouse solar drying system is a multipurpose structure combining a greenhouse outer shell and drying chambers. Outer shell acts as the collector glazing whereas drying chambers inside act as the heat absorber.

Drying of agricultural produce

In an efficiently managed greenhouse CEA, there will not be any time gap between crops. However, for some other management reasons, if crops are not grown in a particular period, the greenhouse can be utilized as a solar dryer. A small amount of 15 to 30% of the incoming solar radiation is reflected back from the surface of the greenhouse, with the remainder is transmitted into the interior. Most of this transmitted radiation is absorbed by plants, soil and other internal surfaces, the rest being reflected. The greenhouse solar drying systems were successful in advocating the year round utilization of the greenhouse facility and thus reducing the operation cost per unit output. In general, the produce is spread as thin layers in trays covering the greenhouse area. The trays can be fabricated with sheet metal and wire mesh. Trays should be arranged horizontally on existing growing benches or frames. For better operation, proper ventilation should be provided by either forced or natural ventilation, to remove the moisture liberating from the produce and to control the air temperature inside the greenhouse. The natural ventilation can be enhanced by using a black LDPE chimney connected to the greenhouse.

Curing of tobacco

Tobacco is an important foreign exchange earning commercial crop of India, which provides employment opportunities to lakhs of people. Curing of tobacco is a delicate and vital process in producing good quality leaves. Tobacco curing essentially refers to drying of the harvested fresh tobacco leaves under controlled temperature, humidity and ventilation in order to initiate the essential bio-chemical processes. The success of curing also depends on the condition of the harvested leaves and their degree of maturity. The usual curing methods are flue, air, pit, fire and sun curing. The open field sun curing is the cheapest method of curing. The drying capabilities of greenhouse can be successfully utilized for curing the tobacco. Different stages of tobacco curing require specific environmental conditions for the best product, which can be maintained easily in a greenhouse. The harvested tobacco leaves are made into bunches of few leaves by knots and arranged serially to form a string with free ends left for fixing it. Scaffoldings should be erected inside the greenhouse and the string of leaves is tied to them, for the tobacco curing process. To increase the capacity, the strings are tied with judicious gap between them and also put in tiers. As curing progresses, the leaves loose moisture and the string will become lighter and the initial sag in the strings can be corrected. For maintaining uniform product quality, the strings can be cycled among the tiers in a specified sequence. Humidity and temperature control by proper ventilation and frequent inspection is important in tobacco curing operations.

The greenhouse solar system basically consists of transparent exterior and removable or interchangeable inner chambers. Figures 13.1 and 13.2 respectively show the tobacco bulk curing mode and grain or peanut drying mode setup. The system is equipped with oil and gas furnace unit with temperature, humidity, air flow controls and a gravel solar collector/energy storage system. Black internal surfaces provide efficient solar energy absorption. Parallel-corrugated slotted ducts embedded under earth the gravel beds provide uniform airflow throughout the gravel for effective energy storage. North-south orientation of the structure allows its multidirectional collection surface to maximize solar energy collection. Fig. 13.3 illustrates the tobacco-curing mode at right side of the greenhouse symmetrical centerline and grain-drying mode at left. When the structure is not used as curing and drying facility, it can be converted to a greenhouse. Solar energy is then used for plant growth and space heating in a controlled environment.

Solar energy can be used as energy source in all stages of tobacco curing mode to supplement the energy requirement for bulk curing of tobacco. In coming air for the furnace is preheated during the daytime by solar heat absorber and at night by the stored energy accumulated in the gravel during the day. It is based on the airflow configuration for various stages of curing and drying.

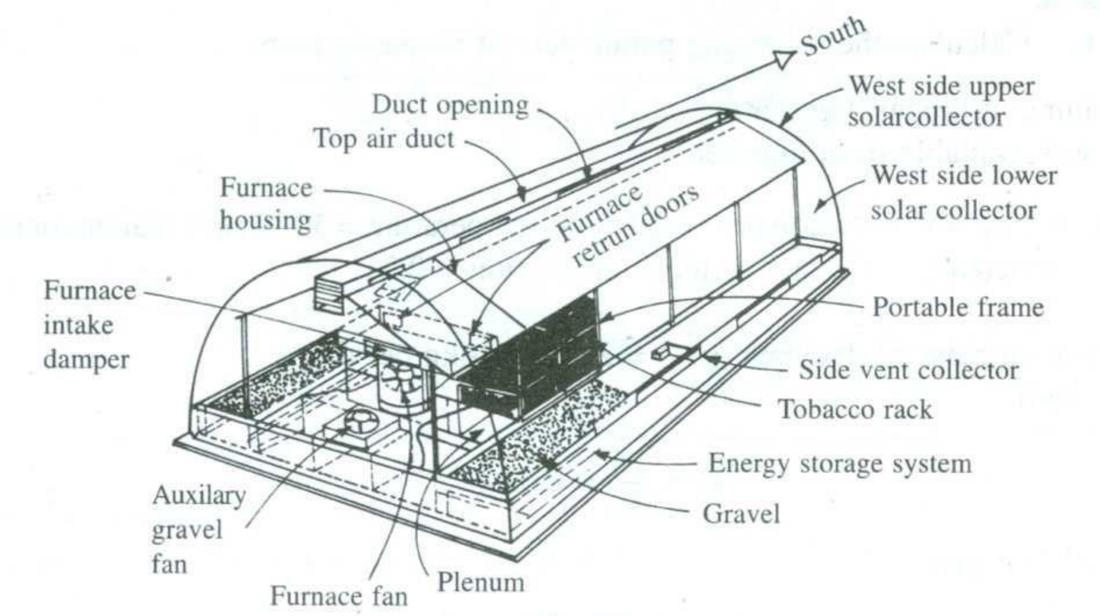


Fig.13.1. A view of Greenhouse Structure used for Grain Drying

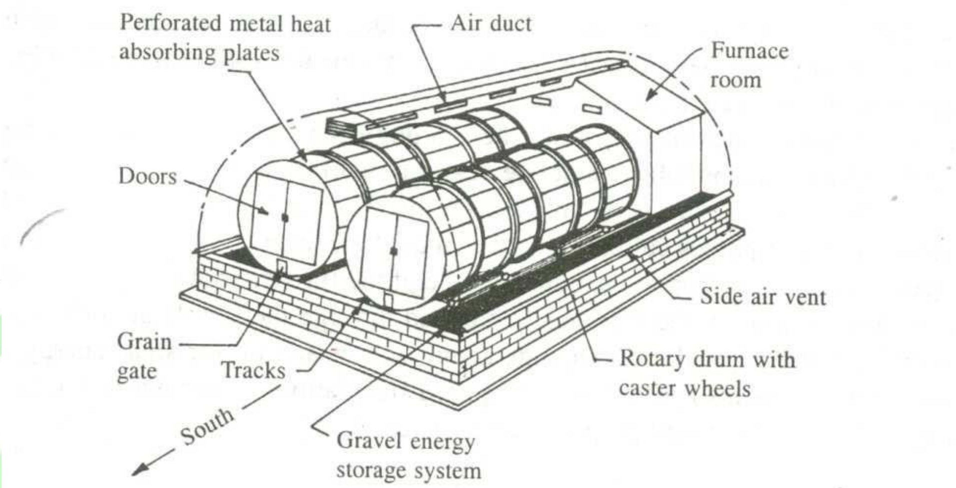


Fig.13.2. A view of Greenhouse Structure used for Curing and Drying

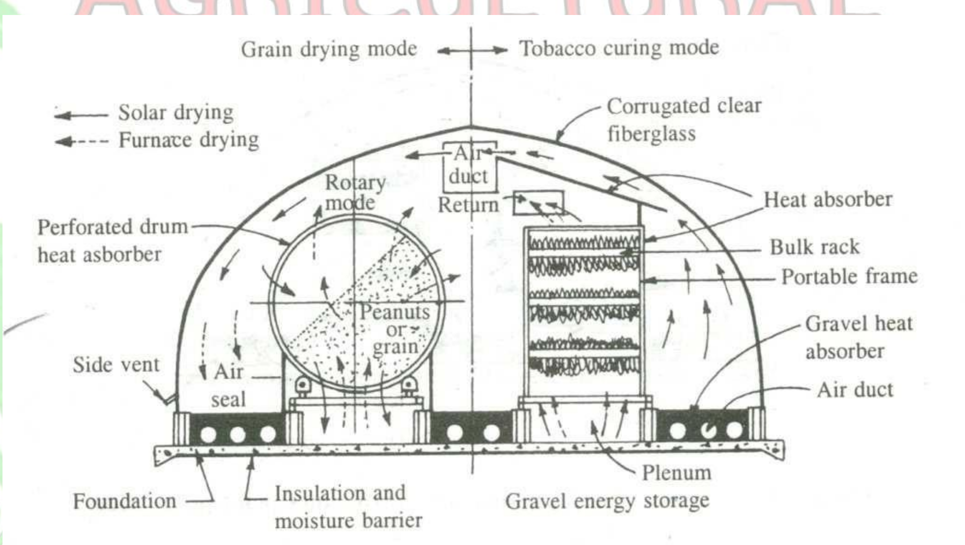


Fig.13.3. Greenhouse System Utilizing Portable Frames and Rotary Drums for Seedling Production

For grain or peanut drying mode four rotary drums consisting of structural frames and perforated sheet metal surfaces are used. Further, these drums are placed inside the transparent shell structure to form an integrated solar collector system during operation. The drum rotates slowly and intermittently or about 60° rotation in 2 minute every 30 minute in order to maintain uniform drying of grains or peanut. The cylindrical surface perforation is

2.97 mm diameter holes staggered on 3.97 mm center (47 holes per square inch) with 51% open area to permit the hot air from the chamber to enter the drum. The flow through grain or peanuts inside the drum is, then, either exhausted into the outside atmosphere or recirculated within the structure. The black surface of the drum partly acts as a solar heat absorber because it is heated by the absorption of solar radiation and dissipates the heat both into the air in the structure and to the grain or peanuts.

During the daytime, the drum and other internal surfaces to heat the air flowing through th-.: material being dried continuously collect solar energy. When the solar energy is minimal or no: available, reverse flow furnace duct is utilized.

LECTURE 14

Content of lecture: Simplified protected agricultural techniques- row covers, perforated plastic tunnels, Slitted row covers, air supported row covers, floating row covers

ROW COVERS

Row covers have become an important method of protected agriculture since the mid fifties. Row cover is a piece of clear plastic stretched over low hoops and secured along the sides of the plant row by burying the edges and ends with soil. Row covers, or plastic tunnels, protect crops from frost and create favourable conditions for plants to achieve early production. PVC and polyethylene films are the common row covers used presently.

Although row covers are permeable to vapour, under certain conditions of temperature and humidity, moisture condenses on their inside surfaces. This condensation releases heat which increases the air temperature. The water droplets formed from the moisture on the inside of the covers act as good heat sinks. They store this heat and radiate it to the crop at night. The covers thus increase the relative humidity of the air inside and reduce water losses by transpiration or evaporation. They enhance seed germination by maintaining higher soil moisture at the surface, and prevent crusting. The covers can also modify gas concentrations around the plant. They increase CO_2 level when the decomposing organic matter is present in the soil. They modify light, thereby influencing photosynthesis, flowering and plant growth. This chapter deals with different types of row covers.

Perforated Plastic Tunnels

High winds remain always a problem with every method of ventilation. A technique has been developed in France whereby the plastic is perforated in order to facilitate ventilation, instead of the conventional method of opening and closing the tunnels daily (Fig. 14.1). There is only a slight difference between temperatures with the perforated and the non-perforated tunnel. They produce similar results in early harvest and yield. The perforated plastic tunnels are less labour intensive, since solid plastic tunnels require considerable time to ensure ample ventilation in the morning and evening during an eight week period. Moreover only little condensation occurs under the perforated film. It was found that the perforated plastic sheets reduced tunnel temperatures by 5 to 6°C in comparison to unventilated solid plastic tunnels. Besides, the perforation in the plastic reduced the need for manual ventilation. Perforation can be produced by drilling the polyethylene sheet while it is still on the roll, with a low speed twist drill, aiming the drill at the center of the core. Excessively rapid drilling should be avoided as it increases the temperature, which melts and fuses the film. The perforations are approximately 6.25 mm in diameter, spaced 80 mm on the center in each direction.

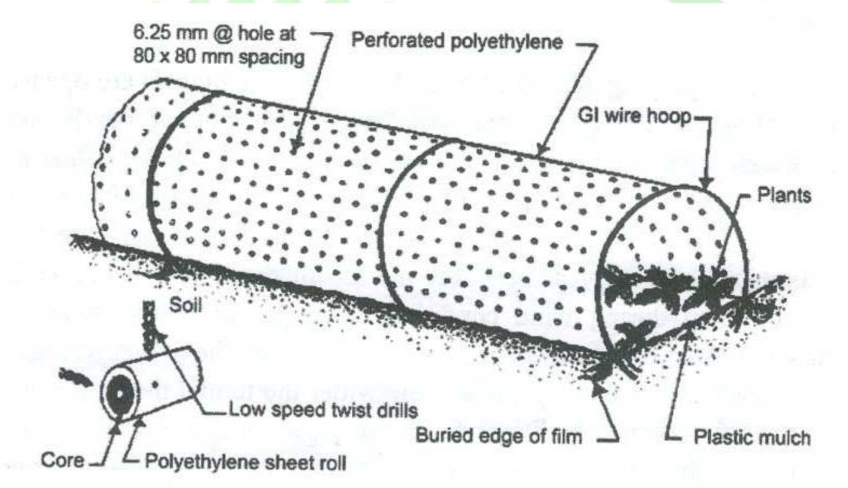


Fig.14.1. Perforated Plastic Tunnels

Slitted Row Covers

Slitted row covers have a series of crosswise slits in specific number of rows along the length, which provide ventilation on sunny days. Without these slits, plastic covers have to be manually opened and closed to provide ventilation during the day and protection from cold during night. To achieve ventilation, row covers are constructed from a single sheet of plastic, 1.5 m wide, 38 gm thick, with two rows of continuous slits, 19 mm apart and 127 mm long (Fig. 14.2). Wire hoops are buried 0.15 m deep in the soil. The procedure for installation of sheet is the same as with any row covers. Slitted row covers are generally used in combination with black polyethylene mulch. The slitted one-piece row covers show about 80% reduction in installation labour. They are self-ventilating, eliminating daily manual opening and closing of the covers and are able to withstand very gusty winds. Since the weeds are controlled by the use of black plastic mulch, the slitted row covers are free from trouble from the time of installation until the time of removal. Frost protection with the slitted covers is similar to that of the perforated polyethylene covers but is inferior to solid covers. **The maximum increase in temperature inside slitted row covers is only 1.0 to 2.0°C above open field temperatures**, **whereas an increase of 2.5 to 4°C can be achieved with solid covers**. **The slitted row covers provide a reasonable compromise between maximum frost protection and a saving in labour**. Crops like muskmelons, cucumbers, tomatoes, and peppers can be grown effectively under slitted row covers in combination with the black plastic mulch.

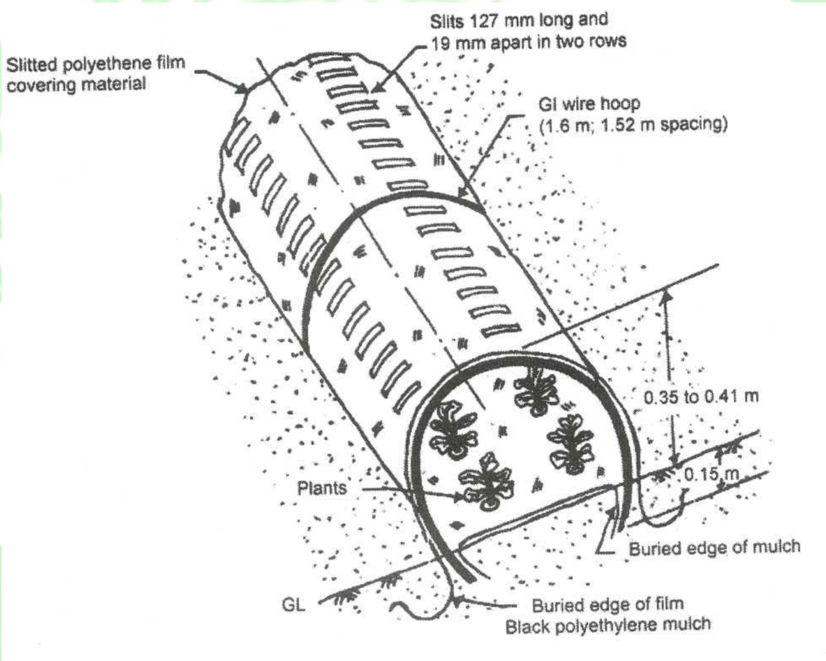


Fig.14.2 Slitted Row Covers

Air Supported Row Covers

To achieve a greater degree of frost protection to the crops, artificial heat in plastic tunnels is provided. The air supported row covers system consists of heating system, distribution chamber and air supported row cover tunnels (Fig. 14.3). The tunnels where the crops are grown, are attached continuously to the distribution chamber. Each tunnel is provided with a door at the opposite end for regulating the air flow. The fan draws the air through the air inlet and feed it to the distribution chamber, which in turn diverts the air to different tunnels. This continuous flow of diverted air will provide support to the row covers without the help of hoops. Crops such as tomatoes, cucumbers and muskmelons were grown under air supported row covers.

During hot weather, ventilation or air movement through the tunnel is increased by increasing the fan speed or by increasing the opening at the end of the tunnel or both. During cold weather, heat is added to the air stream by using heating system and distributed to the tunnels. In warm sunny days, the temperature built up inside the tunnels can be achieved by providing a smaller door opening, which in turn reduces the air movement through the tunnels. If the door opening is large, then the air movement will be more and temperature built up will be less. When the door is opened completely the temperature inside the tunnel will be approximately equal to the outside temperature.

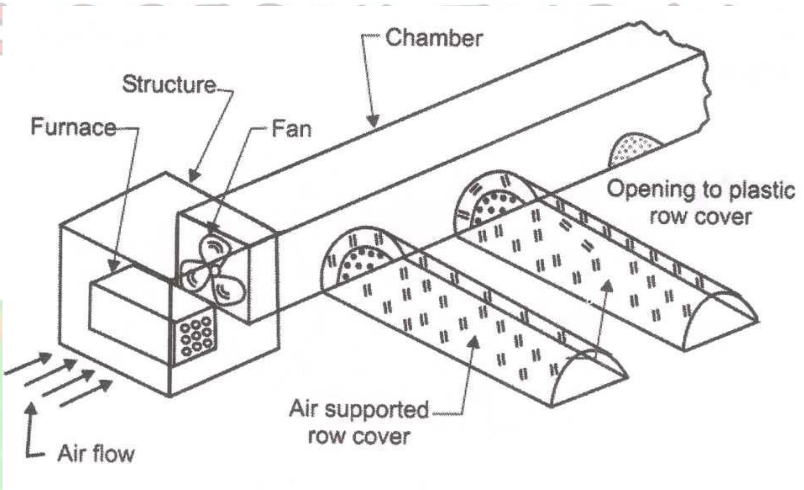


Fig.14.3. Air Supported Row Covers

Air temperature decreases along the length when hot air is supplied to the tunnels. In order to achieve uniform distribution of heat, a small opening is provided at the end of the tunnel. By injecting chemical dust into the fan intake, even distribution of the chemical throughout the planting can be accomplished, and pest and diseases can be controlled. If the air supported row covers are kept rigid, they can withstand the weight of the snow better than those supported by wire hoops. In these tunnels, when the heat is supplied, the harvesting of crops can be advanced up to 2 weeks. The investment for fan and other equipment is quite high and the high expenditure is compensated by higher returns in the market.

Floating Row Covers

Floating row covers are wide sheets of clear, perforated, polyethylene or non-woven porous plastic, not supported by hoops but by the plants. Floating row covers can offer protection to both cool and warm season crops. The simplest form of row cover is the fabric or floating row cover, without wire or cane hoops. Floating row covers are made of spunbonded or non-woven fabrics such as polypropylene, polyamide or polyester. Polypropylene and polyester are the most commonly available fabrics. These covers are made by melting the appropriate plastic, or combination of plastics and produces fabric. Fabric can be made into very wide pieces, ranging from 1 to 10 m in width and varying lengths.

The covers can be applied over a single row either by hand or by using a modified mulch applicator. Also a number of plant rows can be covered with one single large cover. For transplanted seedlings on a single row, the floating row covers can be laid after applying the plastic mulch (Fig. 14.4).

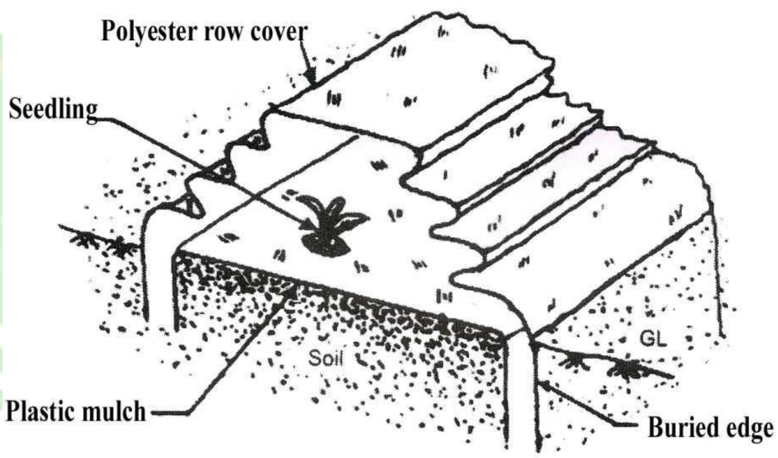


Fig. 14.4. Row cover for transplanted crop

If the single row is seeded, the floating row covers can be laid directly without plastic mulch application (Fig. 14.5) as the mulch may hinder the development of the seedlings. In the case of light weight covers, the edges are securely buried by putting additional weights on the soil thereby permitting safe and free flow of wind. Using a combination of mechanical and manual method of applying the widest covers to a field, a team of three people can cover nearly half hectare in 40 minutes. Heavy fabrics can be reused once or more times. The lightest covers, of about 10 g/m^2 are used as insect barriers. They offer protection against viruses and feeding damage from insects such as aphids, loopers, and beetles. They also prevent or discourage feeding by birds and small animals. However, these fabrics are easily damaged by livestock and other animals. They have minimal effect on temperature and light transmission.

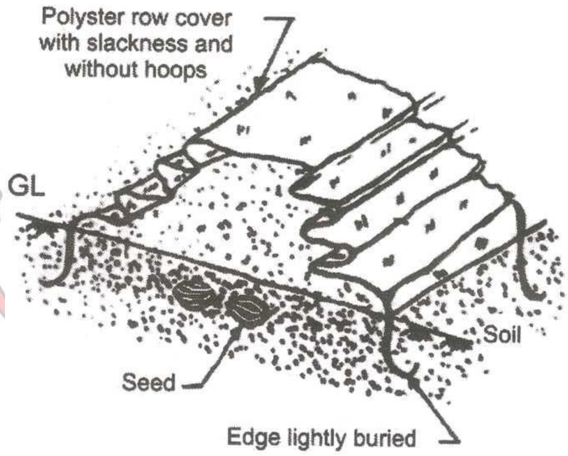


Fig. 14.5. Row cover for seeded crop

LECTURE 15

Content of lecture: Advanced protected agricultural systems- Hydroponic system, functions, advantages and disadvantages and nutrient film technique.

HYDROPONIC SYSTEM

Hydroponics is a technology for growing plants in nutrient solutions with or without the use of an artificial medium, such as sand, gravel, vermiculite, rock wool, peat moss and sawdust to provide mechanical support. Liquid hydroponic systems have no other supporting medium for the plant roots, whereas aggregate systems have a solid medium for support. Hydroponic systems are further categorized as open system when the nutrient solution is delivered to the plant roots and is not reused and closed system when the surplus solution is recovered, replenished, and recycled.

Hydroponic culture is possibly the most intensive method of crop production in today's agricultural industry. In combination with greenhouses or protective covers, it is highly technology oriented and capital intensive. It is also highly productive, conservative of water and land, and protective of the environment. Since regulating the aerial and root environment is a major concern in such agricultural systems, production takes place inside enclosures designed to control air and root temperatures, light, water, plant nutrition, and adverse climate. During the last 12 years, there has been increasing interest in hydroponics or soilless techniques for producing greenhouse horticultural crops. The future growth of hydroponics depends greatly on the development of production systems that are cost competitive with open field agriculture. There are many types of hydroponics systems, as well as many designs for greenhouse structures and many methods of control of the environment, every system is not cost effective in a particular location.

Virtually all hydroponic systems in temperate regions of the world are enclosed in greenhouse type structures. The following are the functions of the general hydroponic system:

(i) It should provide temperature control

(ii) Reduce water loss by evaporation.

(iii) Reduce disease and pest infestation

(iv) It should protect crops against the elements of weather such, as wind and rain.

While hydroponics and CEA are not synonymous, CEA usually accompanies hydroponics. The principal advantages of hydroponic CEA are:

(i) High density.

(ii) Maximum crop yield.

(iii) Crop production where no suitable soil exists.

(iv) Virtual independence to ambient temperature and seasonality.

(v) More efficient use of water and fertilizers.

(vi) Minimal use of land area.

(vii) Suitability for mechanization.

(viii) Effective disease control.

A major advantage of hydroponics, as compared to the open field agriculture (OFA), is the isolation of the crop from the underlyng soil, which often has problems of disease, salinity, poor structure and drainage. The costly and time-consuming tasks of soil sterilization and cultivation are not necessary in hydroponic systems and a rapid production of crops is readily achieved. Because of the precise control over the environment and balanced supply of plant nutrients, the maximum potential yield is assured in hydroponic culture.

The principal disadvantages of hydroponics relative to conventional OFA are the high costs of capital and energy inputs, and the high degree of management skills required for successful production. Capital costs may be especially excessive if the structures are artificially heated and evaporatively cooled by fan and pad systems, and have systems of environmental control that are not always needed in the tropics. Workers must be highly competent in plant science and engineering skills. Because of its higher costs, successful application of hydroponic technology is limited to crops of high economic value, to specific regions and often confined to specific seasons of the year, when OFA is not feasible. Because capital costs are much higher for CEA than for OFA, it is economical to grow only a few food crops, where field crops are totally inappropriate. Studies of prices have shown that only high quality, garden type vegetables, such as tomatoes, cucumbers, and specially lettuce can provide break even or better revenues in hydroponic systems. Besides these vegetables, eggplant, peppers, melons, strawberries and herbs are grown commercially under hydroponic systems in Europe and Japan.

15.1.1 Nutrient film technique

Nutrient film technique (NFT) is a form of hydroponics in which plants are grown in narrow, sloped channels. A thin film of recalculating nutrient solution flows through the roots in the channels. The walls of the channels are flexible, which permit the solution to flow around the base of each plant prohibiting light and preventing evaporation. Nutrient solution is pumped to the higher end of each channel and flows past the plant roots by gravity to catchment pipes and a sump (Fig.15.1). The solution is monitored for replenishment of nutrient salts and water before it is recycled. Capillary material in the channel prevents young plants from drying out, and the roots soon grow into a tangled mat.

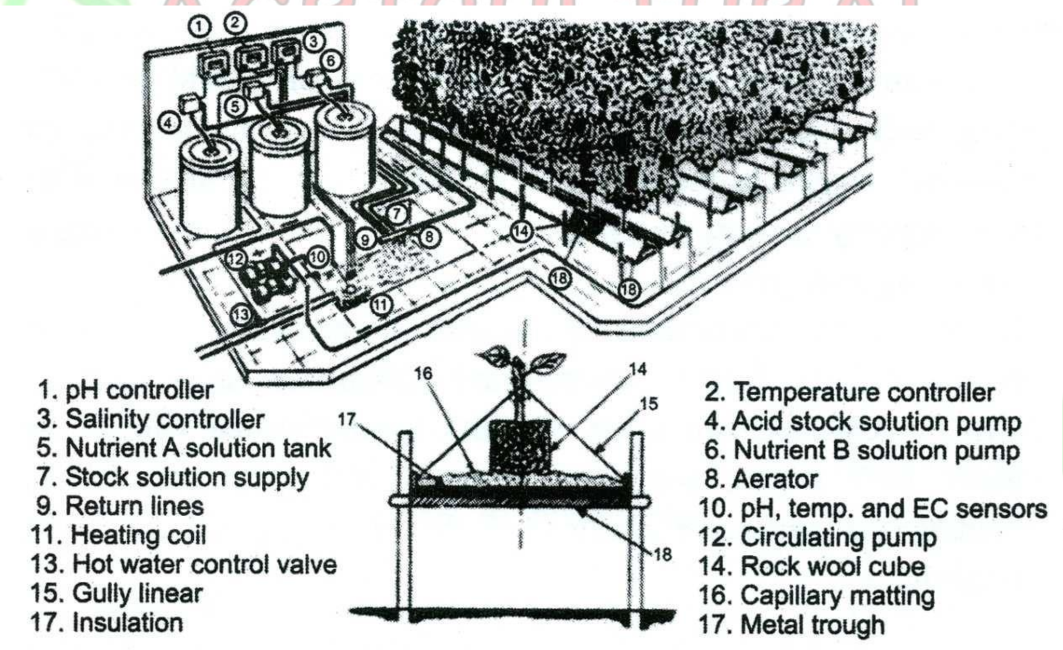


Fig.15.1. Typical features of NFT hydroponic system

A principal advantage of the NFT System in comparison with others is that it requires very less nutrient solution. It is therefore easier to heat the solution during winter months, to obtain optimum temperatures for root growth, and to cool it during hot summers in arid or tropical regions, thereby avoiding the bolting (formation of seed stalk) of lettuce and other undesirable plant responses. If it is necessary to treat the nutrient solution for disease control, small volumes are easier to work with.

The channels should not be greater than 15 to 20 m in length. In a level greenhouse, as the recommended slope of the channel is 1 in 50 to 1 in 75, long channels can restrict the height available for plant growth. To assure good aeration, the nutrient solution could be introduced into channels at two or three points along the length. The flow of nutrient solution into each channel should be 2 to 3 lpm, depending on the oxygen content of the solution. The maximum temperature of the nutrient solution should be 30^0 C. Temperature above 30^0C will adversely affect the amount of dissolved oxygen in the solution. The O_2 concentration should be approximately 5 ppm or more, especially in the nutrient solution flowing over the root mat in the channel. NFT system permits economical cooling of plant roots, avoiding the expensive cooling of the entire greenhouse aerial temperature. Aeration is not a problem with NFT, as in the classical hydroponic systems, because the nutrient solution is confined to a depth of 3 mm. Sterile rock wool can be used as a rooting medium in NFT.

LECTURE 16

Content of lecture: Economic analysis of greenhouse production - capital requirement, economics of production and conditions influencing returns.

ECONOMICS OF GREENHOUSE PRODUCTION

Regardless of the type, protected agricultural systems are extremely expensive. The equipment and production cost may be more than compensated by the significantly higher productivity of protected agricultural systems as compared with open field agriculture. The cost and returns of protected agriculture vary greatly, depending on the system used, the location and the crop grown. By design, all protected agricultural systems of cropping are intensive in use of land, labour, and capital. Greenhouse agriculture is the most intensive system of all. The intensity of land use is greatly dependent upon the system of protected agriculture. Year-round greenhouse crop production is therefore much more intensive than seasonal use of mulches and row covers. Coinciding with intensity are yields, which are normally far greater per ha from year round than from seasonal systems. The normal benefit of higher yields of CEA over the open field agriculture depends on the system used and the region of production.

Capital requirements

The capital requirements differ greatly among the various systems of protected agriculture. Mulching is least expensive while greenhouses require the most capital per unit of land. Total cost involved in the production is the sum of fixed cost and operating cost (Fig.27). The fixed capital costs include land, fixed and mobile equipment, and structures like grading, packing and office. Fixed costs also include taxes and maintenance. The fixed capital costs for greenhouses clearly exceed those of other systems of protected agriculture, but vary in expense according to type of structure, and environmental control and growing systems. Operating costs include labour, fuel, utilities, farm chemicals and packaging materials. The operating or variable costs and fixed costs are annual expenditures and these can be substantial. Annual costs may correlate to some extent with capital investment. The flow diagram of capital requirements of production is shown in figure.

In estimating the capital requirements, the farmer must include the cost of the entire system as well as the mulch. While greenhouse production systems may be far more expensive than open field systems of equal land area, open field systems of protected agriculture are normally more expensive in field area than in greenhouse production. Greenhouses are expensive, especially if the environment is controlled by the use of heaters, fan and pad cooling systems and computer controls.

Economics of production

Production economics considers the various components of fixed and variable costs, compares them with the income and evaluates the net return, on unit area basis. On an average basis, wages account for approximately 85% of the total variable cost. Wages are the greatest expenditure in greenhouse production, followed by amortization costs and then energy costs, and energy expenditure, when heating is necessary. About two-fifths of the expenses are fixed costs and about three-fifths are variable costs. Depreciation and interest on investment accounts for most of the fixed costs.

Conditions influencing returns

A number of variables which may not show up in the yearly financial balance sheet influence the returns to green house operators, such as economics of scale, physical facilities, cropping patterns and government incentives. The size of any system of protected agriculture will depend on the market objectives of the farmer. Most protected agricultural endeavors are family operated. Often the products are retailed directly to the consumer through a road side market at the farm site. In the developed world, greenhouse operations tend to be a size that can be operated by one family (0.4 to 0.8 ha).A unit of 0.4 ha can be operated by two to three labourers, with additional help at periods of peak activity. The labour wages can usually be provided by the owner and his family. Moreover, the owner will pay close attention to management, which is the most important factor. Labour costs may rise significantly if it is necessary to recruit labour from outside the family. Green house owners who hire a highly qualified manager may have to operate a larger greenhouse than family size greenhouses in order to offset the additional salary paid.

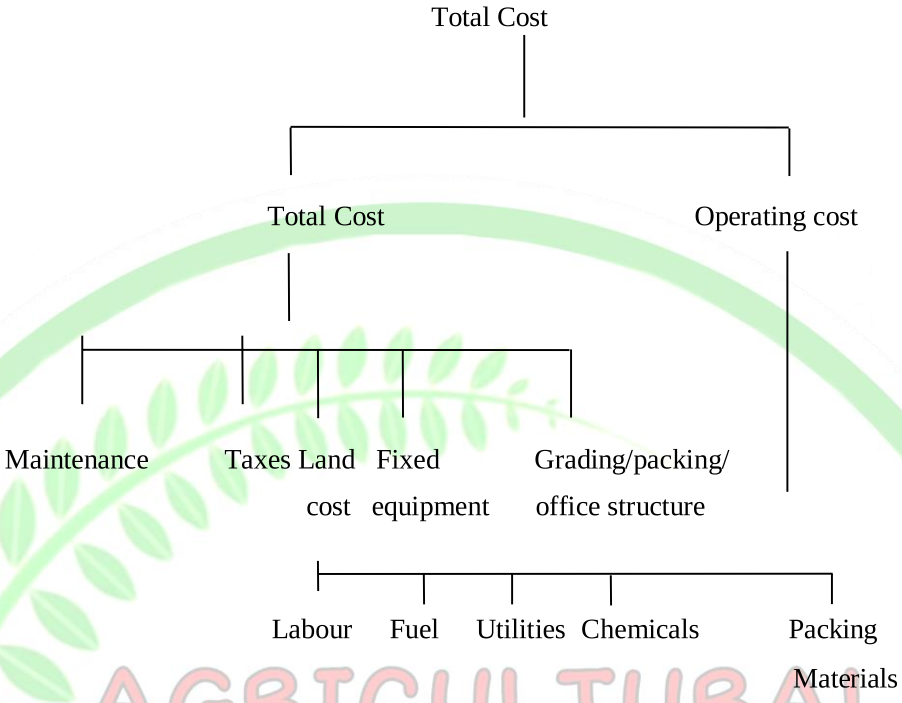


Fig. 16.1 Flow Diagram of Capital Requirements Of Production.

The green house system economy can be improved with increased size when:

(i) There is a unique opportunity to mechanize certain operations.

(ii) Labour can be more efficiently utilized.

(iii) Low cost capital is available.

(iv) There are economics in the purchase of packaging materials and in marketing.

(v) Some special management skills are available.

The physical facilities and location of the green house influence the economics. Another variable that influence the profits from the green house is intensity of production, which is determined by the structures with complete environmental control system facilities year round production and early harvest, thus enabling the grower to realize higher profits. Year round production offers year round employment to the laborers. It is found that the environmentally controlled green house produced only one- third more revenue than high tunnel structure. With the improved transportation facilities, the new areas of production in combination with the following factors contribute to the lower costs.

(i) High sun light intensity undiminished by air pollution.

(ii) Mild winter temperatures.

(iii) Infrequent violent weather conditions.

(iv) Low humidity during the summer for cooling.

(v) Availability of water with low salinity levels.

Cropping pattern will have bearing on the green house structure. A high –tunnel structure or any structure not fitted with environmental controlled equipment for heating and cooling will be used only on a seasonal basis. It is common to switch over from green house vegetable production to flower production, especially in structures with more elaborate environmental control systems. Growers through out the world are currently experimenting with alternative crops, such as herbs. As eating habits change, with times and as the consumers are becoming increasingly conscious of diet and the nutritional value of fruits and vegetables, growers must continually look for alternative to existing cropping patterns. Government policies also influence the financial returns from the crops. Government may provide grants or low interest loans, subsidies towards construction costs, fuels, and use of plastics, such as drip irrigation systems, mulches, row covers and covering materials. Such incentives from the Government encourage the growers and stimulate the green house industry.