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## Abstract

The purpose of growing crops under greenhouse conditions is to extend their cropping season and to protect them from adverse environmental conditions, such as extreme temperatures and precipitation, and from diseases and pests. Greenhouse production normally requires a high level of technology to obtain adequate economic returns on investments. Quality is a high priority for greenhouse crops, requiring much care in pest and disease management, not only to secure yields but also to obtain a high cosmetic standard. Agroclimate, types of glazing materials, types of greenhouses, and greenhouse environmental control are some of the topics discussed in this chapter.

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## Keywords

Greenhouse production • Agroclimate • Glazing materials • Greenhouse • Environmental control

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## 2.1 Introduction

Greenhouse technology implies production of plants for economic use in a covered structure that allows rapid harvesting of solar radiation and modification of agroclimatic conditions conducive for plant growth and development. The technology embraces infrastructure modeling, selection of plants for adaptation, production economics, agronomic management and commercial potential, etc.

“A greenhouse is a framed or an inflated structure covered with a transparent or translucent material which permits at least partial control of plant environment and which are large enough to permit a person to carry out cultural operations” (Chandra and Panwar 1987). While full advantage is taken of the available sunshine for crop production by way of selecting proper covering materials, the enclosure provides an opportunity to control the other environmental parameters. As a result, greenhouse crop productivity is

largely independent on outdoor environmental conditions.

The purpose of growing crops under greenhouse conditions is to extend their cropping season and to protect them from adverse environmental conditions, such as extreme temperatures and precipitation, and from diseases and pests (Hanan et al. 1978). Greenhouse structures are essentially light scaffolding covered by sheet glass, fiberglass, or plastic. Such materials have a range of energy-capturing characteristics, all designed to maximize light transmission and heat retention. Crops may be grown in ground bed soil, usually amended with peat or farmyard manure, in benches, in pots containing soil or soil mixtures or soil substitutes, and in hydroponic systems, such as sand or rock wool cultures and flowing nutrient systems, without a matrix for the roots.

Modern technology has given the grower some powerful management tools for production. Generally, added-value crops are grown under protection. Most of them are labor intensive and energy demanding during cold weather. Greenhouse production therefore normally requires a high level of technology to obtain adequate economic returns on investments. Quality is a high priority for greenhouse crops, requiring much care in pest and disease management, not only to secure yields but also to obtain a high cosmetic standard. Although technological changes are ultimately intended to reduce production costs and maximize profits, precise environmental and nutritional control push plants to new limits of growth and productivity. This can generate chronic stress conditions, which are difficult to measure but apparently conducive to some pests and diseases. Historically, not enough attention has been paid to exploiting and amending production technology for the control of pests and diseases. This makes the control of pests and diseases in protected crops even more challenging, with many important problems being unresolved and new ones arising as the industry undergoes more changes in production systems.

Growing of vegetable and floriculture crops under protected cultivation is receiving utmost attention and gaining popularity among farming community across India. The government of India launched the Horticulture Technology Mission Project, and under this program, a large number of polyhouses in the states of Kerala, Himachal Pradesh, Karnataka, Maharashtra, the northeastern hill region, Haryana, Gujarat, Tamil Nadu, Andhra Pradesh, and the NCR region have come up in a big way. The protected cultivation has shown promise in respect of higher crop productivity both in terms of quality and quantity of the produce.

Haryana Agricultural University, Hisar, has achieved the productivity of 302 t/ha in tomato, 211 t/ha in bell pepper, and 151 t/ha in cucumber per crop cycle.

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## 2.2 Agroclimate

There are several climatic factors that need care in the management of a greenhouse. The following factors are important for greenhouse cultivation.

### 2.2.1 Sunlight

The direction of the greenhouse should be such that it receives sunlight for maximum hours. In hilly regions, greenhouse should face the south-east direction and its location should not be under shade. However, under the tropical condition, temperature retention can be reduced by choosing a less sunny site. Sunlight is essential for augmentation of the process of photosynthesis and minimum sun requirement of crop should be kept in mind. In addition, sunlight also provides requisite thermal environment for various other physiological processes including photosynthesis. Hilly regions receive clear sunny days in winter so sunlight as such may not be a limiting factor, but its tapping and conservation could be a major concern for further investigation.

### 2.2.2 Temperature

Sunlight is the major rather than the sole source of temperature. Examples of providing external heat source other than sunlight are rare in hilly regions. Temperature during night hours may drop down to below 0 °C and heat obtained from trapped solar radiation is not properly conserved. The following steps are advantageous to maintain a thermal environment of the greenhouse:

- Blackening of internal surface of brick wall and soil bed surface
- Providing insulation by doubling the brick wall
- Covering polyethylene or glass external surface with multilayer covering during night hours
- Mud plastering in the case of stone walls
- Placing of black-colored stones in the greenhouses
- Keeping containers filled with water

### 2.2.3 Relative Humidity

The minimum limit of relative humidity for normal physiological functioning of the plants is 50 %. Extreme xeric conditions hardly allow relative humidity to rise to this level in the outer environment, but inside the greenhouse, sufficient water application and restricted air circulation gear up and maintain relative humidity at higher level. It may be increased by keeping pan evaporation. A mechanical device automatically controls relative humidity by periodical sprinkling of water. Cooling pads are usually installed in low-humidity and tropical areas.

### 2.2.4 Carbon Dioxide Enrichment

Carbon dioxide (CO<sub>2</sub>) is the basic ingredient required for manufacturing of organic matter by process of photosynthesis. In cold arid regions, CO<sub>2</sub> concentration is below normal (NAEDB

1992), and in the closed structures like greenhouses, it may drop down further because of its consumption by the plants. At relatively high sunlight intensities and temperature, photosynthetic rate is directly proportional to CO<sub>2</sub> concentration up to 2400 ppm. Hence supplementary application of CO<sub>2</sub> will boost plant productivity inside the greenhouse. Under the hilly region situation, appropriate air circulation is a better and economic means to prevent undesirable lowering of CO<sub>2</sub>, while for conservation of CO<sub>2</sub> produced at night, a tightly closed greenhouse is a prerequisite.

### 2.2.5 Soil

Soil serves as growth medium for plants. Sandy loam soil is the best choice. It should be supplemented with well-rotten FYM, compost, or bio-fertilizers. Inorganic fertilizers need to be used as per recommendations. Continuous cultivation inside the greenhouse may give rise to buildup of pathogens. To destroy pathogens, pasteurization of soil is recommended (steam aeration) before every crop and soil replacement is recommended after every 3 years. Steam aeration temperature of 60 °C for 30 min is good enough to accomplish the task. Chemical fumigation can also be used but steam is the best as it is not selective thus attacking all sort of pathogens.

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## 2.3 Types of Glazing Materials

### 2.3.1 Glass

Glass has been the preferred covering material for greenhouses worldwide because of its light transmissivity characteristics. Transmissivity of 40–50-year-old glass differs a little from that of new glass. Temperature retention in a glasshouse is pretty good. However, high installation cost is a major limitation. Moreover, due to transportation of materials and frequent damage of glasses due to high wind velocity, a glasshouse is discouraged.

### 2.3.2 Polyethylene

Plastic polyethylene is the most widely used greenhouse film around the globe. It is produced by mixing homopolymers of ethylene with or without an ultraviolet (UV) inhibitor package, but only a UV-stabilized polyethylene sheet is recommended because non-UV inhibitor package-added polyethylene will break down after 3–5 months due to photochemical reactions. Polyethylene film is tough, flexible, and relatively inexpensive. It can withstand as low as  $-50^{\circ}\text{C}$  but  $80\text{--}90^{\circ}\text{C}$  temperature will cause it to melt. Above  $60^{\circ}\text{C}$ , it loses much of its strength and may stretch markedly. The life of UV-stabilized polyethylene film is 1–3 years. However, Rigidex polyethylene sheet may be used for 5–6 years on a trench.

### 2.3.3 Fiberglass-Reinforced Panel (FRP)

These panels consist of fiberglass-reinforced polyester. The panels have been very popular in areas of high light intensity such as Southern USA, but about 10–15 % heat loss due to increased exposed area makes it unfit for most of the Indian region. Further, with its age under use, the transparency gets reduced due to yellowing.

### 2.3.4 Polycarbonate Panels

The panels are available in double-skinned sheets. SDP polycarbonate sheets are similar in physical dimension to the SDP acrylite but are stronger and have a lower light transmissivity. Its price is approximately 25 % higher than SDP acrylite.

## 2.4 Types of Greenhouses

Various types of greenhouses are also seen in India. The brief description of each type is being discussed below.

### 2.4.1 Glasshouse

As its name indicates, glass is used as glazing material (Fig. 2.1) in this greenhouse. Perhaps this is the first and oldest among all types of greenhouse structures. Glass panels are fitted with the help of a wooden or metal frame. It can be of any shape and size and it is pretty effective for winter cultivation, but due to increase in day temperature in summer, it becomes unfit for cultivation during summer. High initial cost, difficulty in construction, and frequent damage of glass panels by strong winds are other discouraging factors. In hilly regions, only a few of such structures are found for research.

### 2.4.2 Polyhouse

Ideal features of polyethylene have increased the use of polyhouses (Fig. 2.2) in place of the glasshouse throughout the globe. It has not only reduced the initial cost but also increased the popularity of the greenhouse by simplifying the installation technology. Generally, there are two types of polyhouses in the hilly region.

#### 2.4.2.1 Prefabricated Polyhouses

A prefabricated metal structure of convenient size is installed and a polyethylene film is covered over it. This structure is not recommended at all for the hilly region because of poor temperature retention, low crop yield, and high installation cost (Singh et al. 1998a).

#### 2.4.2.2 Ladakh Polyhouse

This is one of the innovative and low-cost greenhouses of the Ladakh region. It is similar to normal, but the only difference is its surrounding mud brick wall in place of polyethylene sheets which not only cuts down the installation cost but also reduces the adverse effects of strong winds and also increases temperature retention and ultimately increases net profit. This is generally the lean type and has three sides made of mud bricks. The back wall is 7 ft in height, while the front has no wall. The length is 32 ft with a width of 16 ft

**Fig.2.1** Glasshouse**Fig.2.2** Polyhouse

(Singh et al. 2000). The polyethylene is supported on wooden poles and sidewalls. The two sidewalls are descending toward the front. Jammu and Kashmir State Department of Agriculture/ Horticulture provides cash subsidy besides the 32×16-ft polyethylene sheet. This has brought a boost to the greenhouse revolution in Ladakh.

### 2.4.3 Trench (Underground Greenhouse)

This is a unique, innovative, very simple, cheap, and useful underground greenhouse structure for the hilly region and thus has unlimited potential in the region. This may be of any convenient dimension. However, a trench of 30×10×3-ft size is ideal. In this pit type of structure, wooden poles are used to hold UV-stabilized polyethyl-

ene film. The polyethylene is also covered by an additional or woolen or cotton sheet polyethylene film during night to reduce the heat loss during extreme winter. The damage of blowing off the polyethylene film by strong winds is minimized by putting stones along the sides. Cultural practices and other operations are done by removing the polyethylene sheet from the top of the trench. The structure does not require much skill in its construction and management. Its cost is lowest among all other greenhouses, and being an underground structure, heat loss is minimal and temperature retention is high (Singh and Dhaulakhandi 1998) and thus yields good crop. Strong winds do not affect polyethylene cover much and hence it is long lasting. This structure is therefore being recommended as the most suitable greenhouse for the hilly region (Singh et al. 1998, 2000).



**Fig. 2.3** Nylon netting single-bed tunnels



#### 2.4.4 Plastic Low Tunnel

It is a small semi-spherical structure frame made of metal, wood, or plastic and covered with polyethylene or fiber-reinforced plastics to create a protected environment (Fig. 2.3). Plastic low tunnels are flexible transparent coverings that are installed over rows of individual beds of transplanted vegetables to enhance the plant growth by warming the air around the plants (microclimate) in open field during winters. These help in warming the soil and protect the crop against the hails and snow and advance the crop by 30–60 days than their normal season. This low-cost technology is very simple and highly profitable for off-season cultivation and catching the early market. Generally galvanized iron arches are fixed manually 1.5–2.0 m apart to support the plastic tunnel. Width and height is kept about 45–60 cm to cover the plant as per the crop requirement. Transparent non-perforated plastic of 30–50 thickness is sufficient. It partly reflects infrared radiation to keep the temperature of the low tunnel higher than outside. Small vents can be made at the side of the tunnel to facilitate proper aeration in tunnel. These structures serve as a mini greenhouse. This is a temporary structure which can easily be shifted to any place. However, a major problem in tunnels is faced in watering, weeding, and harvesting which involves removal of cover and again putting them back.

#### 2.4.5 Double-Wall Polyench

This structure is designed by the Forest Research Laboratory (FRL), Leh, to harness the soil and solar heat for growing the vegetables especially during winter months. The polyench refers to a polyhouse erected over a trench where back walls and sidewalls are made up of mud bricks. The sidewalls are provided with double walls filled with insulating material available locally, i.e., sawdust for better retention of heat inside the polyench. The inner walls are painted black to absorb more solar radiation during morning hours. The structure is also like gable uneven span with modified roof having a polythene sheet toward the sun-facing side and grass thatch support over a wooden frame opposite to the sun-facing side with provision of ventilators in the roof. Since locally available material has been used in this greenhouse, the cost is reduced drastically compared to a normal greenhouse with better efficiency of temperature retention than the trench and polyhouse. Considering the wear and tear that occurred due to high wind velocity in the hilly regions, the polythene sheet has been replaced with FRL sheets to increase the life span of the structure. The structure has been accepted by the Ladakh Autonomous Hill Development Council (LAHDC), and the state government is providing a subsidy of 50% to the farmers for promoting the protected cultivation in the Ladakh region.

**Fig. 2.4** Net houses

### 2.4.6 Multipurpose Nets

Shade nets are used to reduce the adverse effect of scorching sun and heavy rain (Fig. 2.4). Shade houses are becoming popular for growing crops and nursery during summer season. Net houses are used for raising vegetables/fruits/flowers/medicinal plants in high-rainfall regions. The roof of the structure is covered with suitable cladding material, mostly HDPE, which does not absorb moisture. Slides are made of wire mesh of different gauges 25–90% shade depending upon requirements. Such structures are popular in the northeastern region of the country. Similarly weed nets are made of HDPE and covered on the ground to control the weeds by reducing light on the soil. Insect-proof nets are effective to reduce the incidence of a number of pests and viral diseases in crops. These nets are used like a mosquito net around the crops, having 40–50-mesh size. Other similar nets include bird protection nets to control the bird damage of plants/crops, hail protection nets, reflector nets, etc.

## 2.5 Greenhouse Environmental Control

A greenhouse is essentially meant to permit at least a partial control of microclimate within it. The control of greenhouse environment means the control of temperature, light, air composition, and nature of the root medium. Obviously, a con-

trol over all these parameters makes a greenhouse a completely controlled structure.

### 2.5.1 Ventilation

A greenhouse is ventilated for either reducing the very high greenhouse air temperatures or for replenishing carbon dioxide supply or for moderating the relative humidity in the greenhouse. It is quite possible to bring greenhouse air temperature down during spring and autumn seasons by providing adequate ventilation for the greenhouse. The ventilation in a greenhouse could either be natural or forced. In the case of a small greenhouse (less than 6 m wide), natural ventilation could be quite effective during spring and autumn seasons. However, fan ventilation is essential to have precise control over air temperatures, humidity, and carbon dioxide levels. Orientation of the greenhouse is another important factor. An east–west-oriented freestanding greenhouse maintains better winter light level as compared to a north–south-oriented greenhouse. Therefore, in northern India, a greenhouse should be oriented in the east–west direction. Gutter-connected greenhouse should be oriented north–south to avoid continuous shading of certain portions of the greenhouse due to structural members.

A greenhouse structure has three distinct segments, i.e., frame, glazing material, and control/monitoring equipment. All the three components

have different designed life periods. Whereas a metallic greenhouse frame is designed for a service period of 15–25 years, glazing materials have a life span of 2–20 years. Control and monitoring equipment normally wear out in 5–10 years. In the prevailing economic conditions, where capital is a scarce input, the choice often favors a low-initial-investment greenhouse. Galvanized mild steel pipe as a structural member in association with wide-width UV-stabilized polyethylene film is a common option selected by greenhouse designers.

A 600–800-gauge-thick polyethylene film can safely withstand normal wind loads prevailing in most parts of the country. A single-piece polyethylene film to cover a greenhouse is preferred due to material economy, easy handling, and improved environmental control. An 800-gauge-thick polyethylene film costs approximately Rs. 60–80/m<sup>2</sup> and has a service span of 2–5 years.

The selection of greenhouse equipment depends on local climate conditions and the crops to be grown. A heating unit is a must in cold regions and a cooling unit is required in almost all climates in India.

## 2.5.2 Cooling Systems

While ventilation may be used for cooling during autumn and spring seasons, other methods have to be employed for cooling during summers. Roof shading helps in cooling the greenhouses. The amount of solar radiant energy entering the greenhouse can be reduced by applying opaque coatings directly to the glazing or by placing wood or aluminum over the glazing. Commercial shading compounds or mixtures prepared with paint pigments are preferred for this purpose. White compounds are preferred for they reflect a maximum amount of sunlight, 83 % versus 43 % for green and 25 % for blue or purple.

### 2.5.2.1 Water Film on the Greenhouse Cover

To absorb infrared radiation, a water layer must be at least 1.0 cm thick. But on a sloping green-

house roof, it is limited to about 0.05 cm which is not thick enough. Cooling is most effective when cold water is used in the water film.

### 2.5.2.2 Evaporative Cooling (EC)

The degree of cooling obtained from an evaporative system is directly related to the wet-bulb depression that occurs with a given set of climate conditions. EC systems are most effective in areas where a consistently low relative humidity exists.

### 2.5.2.3 Fan and Pad System (F & P)

It is adaptable to both large and small greenhouses. In this system, low-velocity and large-volume fans draw air through wet fibrous pads mounted on the opposite side or end wall of the greenhouse. The outside air is cooled by evaporation to 20 °C of the wet-bulb temperature. Either vertical or horizontal pads can be used in the F & P systems. However, vertical pads accumulate salts and sag and; thus, they create openings that allow hot air to enter the greenhouse. Various materials, viz., gravel, pine bark, straw, burlap, aspen wood fiber (shredded *Populus tremuloides* mats), honeycomb paper, etc., can be used for the pad. However, pumice and volcanic rock (1–4 cm in diameter) are reported to function very satisfactorily.

### 2.5.2.4 High-Pressure Mist System

Water is sprayed into the air above the plants at pressures of 35–70 kg/cm<sup>2</sup> from low-capacity nozzles (1.8–2.8 L/h). Although most of the mist evaporates before reaching the plant level, some of the water settles on the foliage where it reduces leaf temperatures.

### 2.5.2.5 Low-Pressure Mist System

Misting with water pressure at less than 7 kg/cm<sup>2</sup> has achieved an air temperature that is 5 °C cooler in a greenhouse compared to natural ventilation. The water droplets from a low-pressure misting system are quite large and do not evaporate quickly. Leaching of nutrients from the foliage and the soil is a serious drawback of using this technique.



### 2.5.3 Humidity Control

For most crops, the acceptable range of relative humidity is between 50 % and 80 %. However, for plant propagation work, relative humidity up to 90 % may be desirable. Humidification in summers can be achieved in conjunction with greenhouse cooling by employing appropriate evaporative cooling methods, such as fan-pad and fogging systems. Sometimes during winters, when sensible heat is being added to raise the greenhouse air temperature during nights, the relative humidity level might fall below the acceptable limit.

### 2.5.4 Greenhouse Heating

There are essentially three main categories of efforts needed to maintain desirable greenhouse temperatures during winter:

- Design of energy-efficient greenhouse with passive solar heating components.
- Design of active heating systems based on renewable energy sources such as solar and biogas.
- Design of an active heating system based on conventional fuels.
- While the conventional fuel-based heating systems are many and dependable, the other two categories of efforts are still evolving.

#### 2.5.4.1 Heating Systems Based on Conventional Fuels

Traditionally, glass greenhouses have been heated by hot water systems. Most of the larger commercial greenhouses are heated with some type of boiler system. Gas-fired unit heaters for greenhouse heating deliver heat at approximately half of the cost of the steam/hot water systems. The hot air is distributed through a perforated polytube running along the greenhouse length. Electric heaters, both radiative and convective, are simple and convenient to control. But, the nonavailability of electricity and its high cost limit its use to small and/or experimental green-

house. The heating systems should not only raise the greenhouse temperatures but should also achieve uniformity of temperature distribution. Therefore, placement of heating units and the type of distribution system to be selected are important.

#### 2.5.4.2 Heating Systems Based on Nonconventional Energy Sources

A number of active solar heating have been developed for the greenhouse during the last two decades in order to reduce the dependence of the greenhouse industry on conventional fuels. The normal components of a solar heating system are solar collector, heat transfer medium, heat exchanger, and heat storage. Biogas, generated from agricultural wastes/residues, can also be used for greenhouse heating.

#### 2.5.4.3 Design of Passive Solar Greenhouse

A passive solar greenhouse is one which not only attempts to capture maximum solar energy but also minimizes the unwanted thermal exchange between the greenhouse and the surroundings in order to maintain desirable temperatures. The following points summarize the useful results so far:

- A greenhouse should be oriented east-west.
- The north side of a greenhouse structure should be thermally insulated.
- The north side of a greenhouse facing the crop should be covered with a reflective surface so that the sunlight incident on it from the south side is reflected on to the crops.

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## 2.6 Future Thrusts

Greenhouse technology development has made good progress in India during the last two decades, and steps necessary for promoting greenhouse cultivation of flower and vegetable crops have been started. Energy-efficient greenhouse cultivation continues to be an area of active

research and development, and this is sought to be achieved through precision equipment and protocols. While the gap between the demand and supply of most horticultural crops remains wide and the country plans to double the production of horticultural crops by 2012, the protected cultivation technology holds the key to meet the targets. It clearly emerges that greenhouse technology has multipurpose application for sustainable development of a hilly zone. During harsh winter which otherwise threatens the survival of human beings in these remote hilly areas, popularization and further improvements in greenhouse management could provide a sign of relief in solitude of white snow cover. Thrust areas for future research are enumerated below:

- Conservation of more thermal radiation in winter.
- Durable infrastructure modeling.
- Development of successful commercial models.
- Modernization of polygreenhouse to permit agroclimatic manipulations of higher magnitude.
- Identification of new crops/varieties suitable for cultivation inside the greenhouse.
- Socioeconomic impacts of polygreenhouse technology in hilly region/cold arid zone.
- Plastic films of suitable grades need to be made available in adequate quantity.
- Development of area-specific suitable greenhouse designs.
- Standardization of package of practices for growing various crops in greenhouse for specific regions.
- Varieties suitable for greenhouse cultivation need to be made available to enhance the productivity.

- Vocational training to the unemployed youth and greenhouse practitioners in remote areas to update their skills in this technology.
- Financial assistance such as low-interest loans should be made available for poor farmers to adopt this technology.
- Insurance of greenhouse structure and crop to protect the farmers against the loss caused by natural calamities.
- Rigorous extension program to disseminate the technology information to the poorest of the society.

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