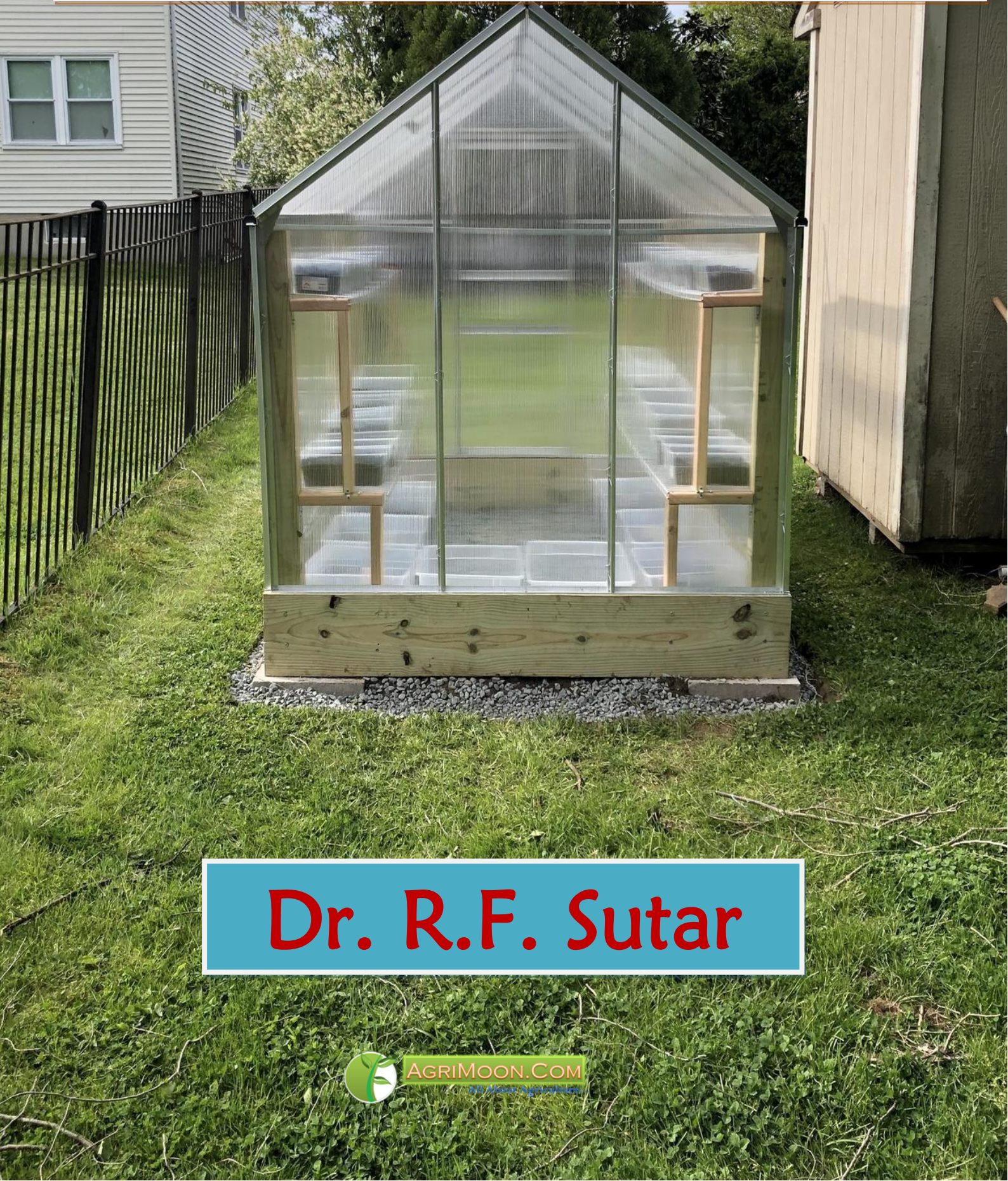


Design and Maintenance of Green House



Dr. R.F. Sutar



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Module 1. History and types of greenhouse

Lesson 1 History and Types of Greenhouse

1.1 INTRODUCTION:

What is Greenhouse Technology?

Today about 92% of plants, raised by man, are grown in the open field. Since the beginning of agriculture, farmers have had to cope with the growing conditions given to them by Mother Nature. In some of the temperate regions where the climatic conditions are extremely adverse and no crops can be grown, man has developed technological methods of growing some high value crops by providing protection from the excessive cold and excessive heat. This is called Greenhouse Technology. **“Greenhouse Technology is the science of providing favourable environment conditions to the plants”**. It also protects the plants from the adverse climatic conditions such as wind, cold, precipitation, excessive radiation, extreme temperature, insects and diseases. An ideal micro climate can be created around the plants. Greenhouses are framed or inflated structures covered with transparent or translucent material large enough to grow crops under partial or full controlled environmental conditions to get optimum growth and productivity.

1.2 HISTORICAL BACKGROUND OF GREENHOUSES

Before the 20th century - Agriculture production inside protected structures was initiated in France and Netherlands in the 19th century. This method was applied in simple, low, glass structures, which provided climate protection, and were used mainly for the growth of ornamental plants.

Modern Times - By the beginning of the 20th century, mostly after the end of 2nd world war, the technology of greenhouse construction accelerated its development, especially in Western Europe cold countries, Netherlands leading the course. Agro-technical systems, aeration solutions and accompanying accessories were gradually added to the structures, while the structure foundations improved to the known, traditional heavy steel constructions covered by rigid glass boards.

New Materials - By the end of the fifties of the 20th century the greenhouses technology flowed to the north and center of Europe, extending its influence and benefits to Israel, where a wave of experiments and research in the field had begun. The sixties revealed a new kind of structure covering sheets. They were the flexible, low priced polyethylene sheets, which caused a conceptual revolution in the field of greenhouses. Simultaneously appeared other types of good light transition coverings, such as polycarbonate (a kind of covering made of plastic polymers) leaving behind the traditional glass covering.

New Technologies - The method of modular structures (Lego-like method) leads to the development of growth technologies suitable for most types of crops, thus creating

customized structure projects, customer-tailored according to specific needs. This new trend caused the breakdown of the traditional, conservative Dutch hegemony ruling until then in the field of greenhouses. Nowadays, light-weighted structures with covering made of flexible polyethylene or stiff-flexible polycarbonate are more common and widespread than the mythological rigid glass greenhouses.

1.3 TYPES OF GREENHOUSES

Greenhouse structures of various types are used for crop production. Although there are advantages in each type for a particular application, in general there is no single type of greenhouse, which can be constituted as the best. Different types of greenhouses are designed to meet the specific needs. The different types of greenhouses based on shape, utility, material and construction are briefly given below:

1.3.1. Greenhouse Type Based On Shape:

For the purpose of classification, the uniqueness of cross section of the greenhouses can be considered as a factor. The commonly followed types of greenhouses based on shape are:

- Lean to type greenhouse.
- Even span type greenhouse.
- Uneven span type greenhouse.
- Ridge and furrow type.
- Saw tooth type.
- Quonset greenhouse.
- Interlocking ridges and furrow type Quonset greenhouse.
- Ground to ground greenhouse.

1.3.1.1 Lean-to type greenhouse

A lean-to design is used when a greenhouse is placed against the side of an existing building. It is built against a building, using the existing structure for one or more of its sides (Fig.1.3.1). It is usually attached to a house, but may be attached to other buildings. The roof of the building is extended with appropriate greenhouse covering material and the area is properly enclosed. It is typically facing south side. The lean-to type greenhouse is limited to single or double-row plant benches with a total width of 7 to 12 feet. It can be as long as the building it is attached to. It should face the best direction for adequate sun exposure.

The advantages of the lean-to type greenhouse are;

- It is usually close to available electricity, water, and heat.
- It is a least expensive structure.

Design and Maintenance of Green House

- This design makes the best use of sunlight and minimizes the requirement of roof supports.

Disadvantages of the lean-to type greenhouse are;

1. Limited space, limited light, limited ventilation and temperature control.
2. The height of the supporting wall limits the potential size of the design.
3. 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.

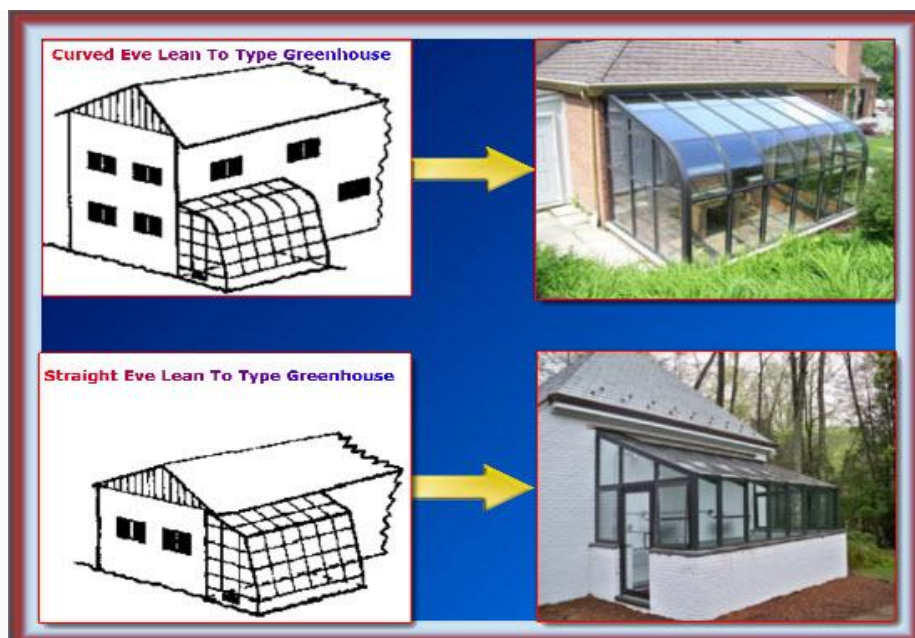


Fig. 1.3.1. Lean-to-type type greenhouses

(source: www.howtobuild-a-greenhouse.org, www.small-greenhouses.com.)

1.3.1.2 Even span type greenhouse

The even-span is the standard type and full-size structure, the two roof slopes are of equal pitch and width (Fig.1.3.2). 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.



Fig 1.3.2. Even Span Type Greenhouse

(source: www.arcadiaglasshouse.com.)

1.3.1.3 Uneven span type greenhouse

This type of greenhouse is constructed on hilly terrain. The roofs are of unequal width; make the structure adaptable to the side slopes of hill (Fig.1.3.3). This type of greenhouses is seldom used now-a-days as it is not adaptable for automation.

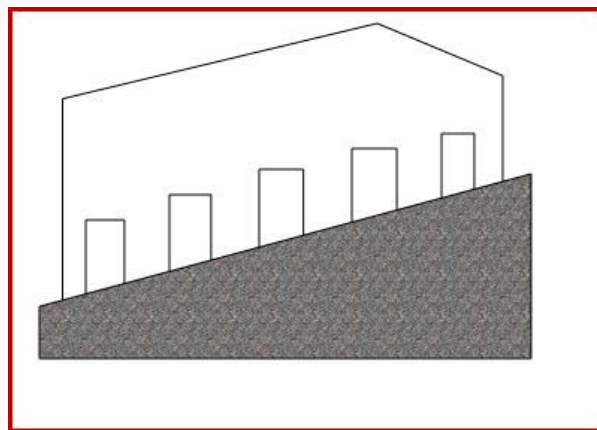


Fig 1.3.3. Uneven Span Type Greenhouse

1.3.1.4 Ridge and furrow type greenhouse

Designs of this type use two or more A-frame greenhouses connected to one another along the length of the eave (Fig. 1.3.4). 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. 1.3.4. Ridge and furrow type greenhouses

(Source: www.nafis.go.ke)

1.3.1.5 Saw tooth type Greenhouse

These are also similar to ridge and furrow type greenhouses except that, there is provision for natural ventilation in this type. Specific natural ventilation flow path (Fig. 5) develops in a saw- tooth type greenhouse.



Fig. 5. Saw tooth type greenhouses

(Source: www.netafim.com)

1.3.1.6 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. 1.3.6). 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.



Fig. 1.3.6 Quonset Type Greenhouse

(source: www.gothicarchgreenhouses.com)

1.3.2. Greenhouse Type Based on Utility

Classification can be made depending on the functions or utilities. Of the different utilities, artificial cooling and heating are more expensive and elaborate. Hence based on this, they are classified in to two types.

- Greenhouses for active heating.
- Greenhouses for active cooling.

1.3.2.1 Greenhouses for active heating

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

1.3.2.2 Greenhouses for active cooling

During summer season, it is desirable to reduce the temperatures of greenhouse than the ambient temperatures, for effective crop growth. Hence suitable modifications are made in

the green house so that large volumes of cooled air is drawn into greenhouse, This type of greenhouse either consists of evaporative cooling pad with fan or fog cooling . This greenhouse is designed in such a way that it permits a roof opening of 40% and in some cases nearly 100%.

1.3.3. Greenhouse Type Based on Construction

The type of construction predominantly is influenced by structural material, though the covering material also influences the type. Higher the span, stronger should be the material and more structural members are used to make sturdy tissues. For smaller spans, simple designs like hoops can be followed. So based on construction, greenhouses can be classified as

- Wooden framed structure.
- Pipe framed structure.
- Truss framed structure.

1.3.3.1 Wooden framed structures

In general, for the greenhouses with span less than 6 m, only wooden framed structures are used. Side posts and columns are constructed of wood without the use of a truss (Fig1.3.7) 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.



Fig 1.3.7. Wooden Framed Greenhouses

(Source: www.mcgreenhouses.com, www.greenhouseandsunrooms.com)

1.3.3.2 Pipe framed structures

Pipes are used for construction of greenhouses, when the clear span is around 12m (Fig. 1.3.8). In general, the side posts, columns, cross ties and purlins are constructed using pipes. In this type, the trusses are not used.



Fig1.3.8. Pipe Framed Greenhouse Structures

(Source: www.angrau.ac.in, www.hiddenvalleyhibiscus.com, www.albertahomegagardening.com)

1.3.3.3 Truss framed structures

If the greenhouse span is greater than or equal to 15m, truss frames are used. Flat steel, tubular steel or angular iron is welded together to form a truss encompassing rafters, chords and struts (Fig. 1.3.9). 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.

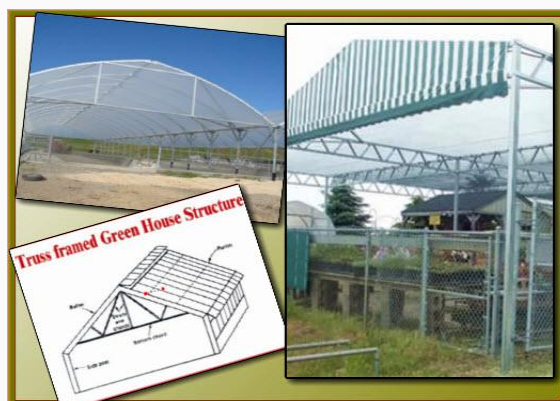


Fig 1.3. 9. Truss Framed Greenhouse Structures

(Source: www.angrau.ac.in, www.gothicarchgreenhouses.com , www.redpath.co.nz)

1.3.4. Greenhouse Type Based on Covering Material

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.

1.3. 4.1 Glass greenhouses

Only glass greenhouses with glass as the covering material existed prior to 1950. Glass as covering material (**Fig.1.3.10**) 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.



Fig.1.3.10 Glass Greenhouse

(source: www.gothicarchgreenhouses.com)

1.3.4.2 Plastic film greenhouses

Flexible plastic films including polyethylene (Fig. 1.3.11), 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.



Fig.1.3.11 Polyethylene film greenhouse

(Source: www.poly-ag.com)

1.3.4.3 Rigid panel greenhouses

Polyvinyl chloride rigid panels, fibre glass-reinforced plastic, acrylic and polycarbonate rigid panels (Fig.1.3.12) 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.



Fig.1.3.12 Polycarbonate Covering

(Source: www.advancegreenhouses.com)

1.3.5 Greenhouse Type Based on Cost of Construction

Based on the cost of construction involved;

1. High cost Green House
2. Medium cost Green House
3. Low cost Green House

1.3.6 Shading Nets

There are a great number of types and varieties of plants that grow naturally in the most diverse climate conditions that have been transferred by modern agriculture from their natural habitats to controlled crop conditions. Therefore, conditions similar to the natural ones must be created for each type and variety of plant. Each type of cultivated plant must be given the specific type of shade required for the diverse phases of its development. The shading nets fulfil 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 fulfil 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 (fig 1.3.13) is available in the market which is defined on the basis of the percentage of shade they deliver to the plant growing under them.



Fig 1.3.13 Shading net

Module 2.Function and features of greenhouse

Lesson-2 Function and Features of Greenhouse

2.1. FUNCTIONS OF GREENHOUSE:

Greenhouses are framed or inflated structures covered with transparent or translucent material large enough to grow crops under partial or fully controlled environmental conditions to get optimum growth and productivity.

- The yield may be 10-12 times higher than that of outdoor cultivation depending upon the type of greenhouse, type of crop, environmental control facilities.
- Reliability of crop increases under greenhouse cultivation.
- Ideally suited for vegetables and flower crops.
- Year round production of floricultural crops.
- Off-season production of vegetable and fruit crops.
- Disease-free and genetically superior transplants can be produced continuously.
- Efficient utilization of chemicals, pesticides to control pest and diseases.
- Water requirement of crops very limited and easy to control.
- Maintenance of stock plants, cultivating grafted plant-lets and micro propagated plant-lets.
- Hardening of tissue cultured plants
- Production of quality produce free of blemishes.
- Most useful in monitoring and controlling the instability of various ecological system.
- Modern techniques of Hydroponic (Soil less culture), Aeroponics and Nutrient film techniques are possible only under greenhouse cultivation.

2.2. GREENHOUSE FEATURES

Although greenhouses look like simple structures, there's more to them than meets the eye. A reliable frame, covering, flooring and ventilation are all necessary for basic operation. To sustain the environment, a heating system and some automated processes, like irrigation via a dedicated water supply, may also be necessary.

2.2.1 The Frame:

A sturdy frame is necessary to maintain the plastic or glass panels that let in precious light and capture heat in the greenhouse. Larger greenhouses also need a foundation. The frame can be made of any number of materials, the most common of which are aluminum, wood, rigid PVC and galvanized steel. Aluminum lets in more light and can also support clip-on panels, making it the most common choice.

2.2.2 The Coverings:

Often referred to as glazing, the panels that cover greenhouses are specially designed to let in as much of the sun's radiation as possible. Ideally, they also provide insulation, are impervious to deterioration from ultraviolet radiation and are shatterproof. The panels can be made of heavy glass or any of a number of synthetic materials designed to maximize light exposure and help reduce heat loss. Glass lets in about 90 percent of the sun's radiation, helping to retain heat and hold up to ultraviolet light. Synthetics, while cheaper and sometimes stronger than glass, let in less of the sun's rays.

2.2.3 The Flooring:

Greenhouse floors need to have excellent drainage. Floors can be made of concrete, stone slabs, brick, sand or even dirt. Gravel floors provide excellent drainage and can be used in conjunction with a weed barrier to keep weeds from growing up through the rocks.

2.2.4 Greenhouse ventilation:

Ventilation is one of the most important components in a successful greenhouse. If there is no proper ventilation, greenhouses and their plants can become prone to problems. The main purpose of ventilation is to regulate the temperature to the optimal level, and to ensure movement of air and thus prevent build-up of plant pathogens (such as *Botrytis cinerea*) that prefer still air conditions. Ventilation also ensures a supply of fresh air for photosynthesis and plant respiration, and may enable important pollinators to access the greenhouse crop. Ventilation can be achieved via use of vents - often controlled automatically - and recirculation fans.

2.2.5 Greenhouse heating:

Heating is one of the most considerable factors in the operation of greenhouses across the globe, especially in colder climates. The main problem with heating a greenhouse as opposed to a building that has solid opaque walls is the amount of heat lost through the greenhouse covering. Since the coverings need to allow light to filter into the structure, they conversely cannot insulate very well. With traditional plastic greenhouse coverings having an R-Value of around 2, a great amount of money is therefore spent to continually replace the heat lost. Most greenhouses, when supplemental heat is needed use natural gas or electrical furnaces.

Passive heating methods exist which seek heat using low energy input. Solar energy can be captured from periods of relative abundance (day time/ summer), and released boost the temperature during cooler periods (night time/ winter). Waste heat from livestock can also be

used to heat greenhouses; e.g. placing a chicken coop inside a greenhouse recovers the heat generated by the chickens, which would otherwise be wasted.

Electronic controllers are often used to monitor the temperature and adjust the furnace operation to the conditions. This can be as simple as a basic thermostat, but can be more complicated in larger greenhouse operations.

2.2.6 Automated Watering System used in greenhouse:

Water is the most important element for plant growth. Without it, plant cannot survive. The manual system to watering is inefficient. When we water manually, the possibility to over watering is high. Some plant can drown when we supply too much water to them.

In order to overcome this problem, automatic greenhouse watering system is used. Sensors such as temperature sensor and soil moisture detector are used to control the watering system in a greenhouse

The system also has the capability to control the water level. In Drought prone area, a tank is used that acts as a reservoir tank in case of water problem. In this tank a sensor is used to ensure that water level is at its maximum level.



Module 3.Scope and development of greenhouse technology

Lesson 3 Scope and Development of Greenhouse Technology

3.1. A SCOPE ON GREENHOUSES AROUND THE WORLD

There are more than 55 countries now in the world where cultivation of crops is undertaken on a commercial scale under cover and it is continuously growing at a fast rate internationally.

The United States of America has a total area of about 15,000 ha under greenhouses mostly used for floriculture with a turnover of more than 3.4 billion US \$ per annum and the area under greenhouses is expected to go up considerably, if the cost of transportation of vegetables from neighbouring countries continues to rise.

Spain has been estimated to be around 28,000 ha and Italy 19,500 ha used mostly for growing vegetable crops like watermelon, capsicum, strawberries, beans, cucumbers and tomatoes. In Spain simple tunnel type greenhouses are generally used without any elaborate environmental control equipment mostly using UV stabilized polyethylene film as cladding material.

In Canada the greenhouse industry caters both to the flower and off-season vegetable markets. The main vegetable crops grown in Canadian greenhouses are tomato, cucumbers and capsicum. Hydroponically grown greenhouse vegetables in Canada find greater preference with the consumers and could be priced as much as twice the regular greenhouse produce.

The Netherlands is the traditional exporter of greenhouse grown flowers and vegetables all over the world. With about 89,600 ha under cover, the Dutch greenhouse industry is probably the most advanced in the world. Dutch greenhouse industry however relies heavily on glass framed greenhouses, in order to cope up with very cloudy conditions prevalent all the year round. A very strong research and development component has kept the Dutch industry in the forefront.

The development of greenhouses in Gulf countries is primarily due to the extremity in the prevailing climatic conditions. Israel is the largest exporter of cut flowers and has wide range of crops under greenhouses (18,000 ha) and Turkey has an area of 12,000 ha under cover for cultivation of cut flowers and vegetables.

In Saudi Arabia cucumbers and tomatoes are the most important crops contributing more than 94% of the total production. The most common cooling method employed in these areas is evaporative cooling.

Egypt has about 1400 ha greenhouses consisting mainly of plastic covered tunnel type structures. Arrangements for natural ventilation are made for regulation of temperature and

humidity conditions. The main crops grown in these greenhouses are tomatoes, cucumbers, peppers, melons and nursery plant material.

In Asia, China and Japan are the largest users of greenhouses. The development of greenhouse technology in China has been faster than in any other country in the world. With a modest beginning in late seventies, the area under greenhouses in China has increased to 51, 000 ha. Out of this 11,000 ha is under fruits like grapes, cherry, Japanese persimmon, fig, loquat, lemon and mango. The majority of greenhouses use local materials for the frame and flexible plastic films for glazing. Most of the greenhouses in China are reported to be unheated and the use of straw mats to improve the heat retention characteristics.

Japan has more than 40,000 ha under greenhouse cultivation of which nearly 7500 ha is devoted to only fruit orchards. Greenhouses in Japan are used to grow a wide range of vegetable and flowers with a considerable share of vegetable demand being met from greenhouse production.

Even a country like South Korea has more than 21,000 ha under greenhouse for the production of flowers and fruits. Thus, greenhouses permit crop production in areas where winters are severe and extremely cold such as Canada and Russia. It also permits production in areas where summers are extremely intolerable as in Israel, United Arab Emirates, Kuwait.

In the Philippines greenhouses make it possible to grow crops despite excessive rains. Thus in essence greenhouse cultivation is being practiced and possible in all type of climatic conditions.

While greenhouses have existed for more than one and a half centuries in various parts of the world, in India the use of greenhouse technology started only during 1980's and it was mainly used for research activities. This may be because the emphasis had been on achieving self-sufficiency in food grain production. However, in recent years in view of the globalization of international markets and shortages of food a tremendous boost is given to export of the agricultural produce in India, this has now created a spurt in the demand for greenhouse technology.

If India wants to emerge as an economic power in the world, agricultural productivity should equal those countries, which are currently rated as economic power of the world. The greenhouse system may be one key element to sustain food for growing Indian population/economy.

3.2 DEVELOPMENT OF GREENHOUSE TECHNOLOGY IN INDIA

The National Committee on the use of Plastics in Agriculture (NCPA-1982) has recommended location specific trials of greenhouse technology for adoption in various regions of the country. Greenhouses are being built in the Ladakh region for extending the growing season of vegetables from 3 to 8 months. In the North-East, greenhouses are being constructed essentially as rain shelters to permit off-season vegetable production. In the Northern plains, seedlings of vegetables and flowers are being raised in the greenhouses either for capturing the early markets or to improve the quality of the seedlings. Propagation of difficult-to-root tree species has also been found to be very encouraging. Several

commercial floriculture ventures are coming up in Maharashtra, Tamil Nadu and Karnataka states to meet the demands of both domestic and export markets.

The commercial utilization of greenhouses started from 1988 onwards and now with the introduction of Government's liberalization policies and developmental initiatives, several corporate houses have entered to set up 100% export oriented units. In just four years, since implementation of the new policies in 1991, 103 projects with foreign investment of more than Rs.80 crores have been approved to be set up in the country at an estimated cost of more than Rs.1000 crores around Pune, Bangalore, Hyderabad and Delhi. Thus the area under climatically controlled greenhouses of these projects is estimated to be around 300 ha. Out of which many have already commenced exports and have received very encouraging results in terms of the acceptance of the quality in major markets abroad and the price obtained.



Module 4. Location, planning and various components of greenhouse

Lesson 4 Location, Planning and Various Components of Greenhouse

4.1 INTRODUCTION

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, therefore, 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.

4.2 LOCATION OF GREENHOUSE

Selecting a “good” site for the location of a greenhouse is crucial. But what constitutes a “good” site? There are several things that should and must be considered in order to increase the chances of a successful operation and business.

4.2.1 Things to Consider While Selecting a Greenhouse Site:

1. Solar Radiation – Plants require sunlight for photosynthesis. When plants experience cloudy days their photosynthetic rates, and therefore their ability to grow and yield a product, such as tomatoes, cucumbers, peppers, etc., will be reduced. Therefore, a region and location with high light intensity year-round is desired.

2. Water – Water quantity and quality is crucial. Water will be needed for irrigation (maximum of 1 gal/plant/day for tomatoes). Water will be needed for the evaporative cooling system and can equal or exceed the irrigation water amounts (10,000 – 15,000 gal/acre/day). In the past, excess irrigation and bleed-off water from the evaporative cooling system was allowed to “run off” onto the ground adjacent to the greenhouse (with a rec. minimum percolation rate into the soil of 1"/hr.)

However, due to more strict regulations and a desire to avoid ground water contamination with high concentrations of salts, large greenhouses are now recirculating the nutrient solution. Recirculating the nutrient solution also saves water, nutrients & money.

Therefore, excess nutrient solution should be recycled and/or mixed with the cooler bleed-off water and redirected into designated areas, such as grass, shrubs, trees/windbreaks, etc.

3. Elevation – will affect the summer maximum and the winter minimum temperatures. Choosing an appropriate elevation will minimize heating costs in the winter and cooling costs in the summer.

4. Microclimate –

- **Latitude** – Unless the global climate changes drastically, sea level at the poles will be colder than sea level in the tropics. Hence, latitude makes a difference!
- **Large bodies of water** – will tend to moderate the temperature (e.g., coastal areas tend to have smaller day/night temperature differences than inland areas).
- **Trees, mountains or other obstructions** – may cast shadows on the greenhouse, especially in the morning or afternoon hours. Mountains can also effect wind and/or storm patterns.
- **Clouds and fog** – Note that certain areas (e.g., on the lee side of certain mountain ranges, or near coastal regions) may develop clouds or fog during certain times of the day or year that will reduce potential sunlight.
- **High Wind Areas** – High winds can “suck” heat away from the greenhouse and therefore increase the heating energy needed to maintain the temperature inside. High winds can also cause structural damage to greenhouses.
- **Blowing dust/sand** – High winds can “kick up dust or sand”, especially in desert regions, which can damage some greenhouse glazing.
- **Snow** – The weight of heavy, wet snow on a greenhouse could crush it. However, high winds in snow areas can also blow snow up against the greenhouse structure (snow drifts) and cause damage to it. This danger can be reduced by using windbreaks (trees, snow fences, etc.).

5. Pest Pressure – Choose a site away from existing agriculture production areas which could harbor insect pests in the fields. Insect pests of concern include white flies, aphids, spider mites and thrips.

6. Level and Stable Ground – The ground upon which the greenhouse will sit must be:

- Graded for routing surface water to a drainage system or a holding pond. (Typical grade = ½ % or a 6 inch drop over a distance of 100 feet.)
- Compacted so there will be no settling after the greenhouse has been constructed.

7. Utilities – Availability of utilities should include telephone service, three-phase electricity and fuel for heating and carbon dioxide generation. Note that, when compared to propane, electricity or fuel oil, natural gas is a fairly economical heating energy source. However, as fossil fuel costs increase, alternative energies may become more cost effective.

8. Roads – Need access to good roads to transport the “product”. Good roads close to a large population center or to a brokerage center aids wholesale and retail marketing.

9. Greenhouse Orientation –

- In Free Standing greenhouse more sunlight is available in winter in East-West oriented greenhouse.
- In multi-span greenhouses, gutter should be oriented North South.
- In Naturally ventilated greenhouse, the ventilator should open on the leeward side.
- A free standing greenhouse should have its long axis perpendicular to the wind direction.

10. Capability of Expansion – Purchase more land than you anticipate using in the beginning so that you have the ability to expand your operation. Locate the initial greenhouses such that future expansion will utilize the land area most efficiently.

11. Availability of Labour – The grower needs people who will want to work as labourers and who are “trainable” to become a retainable workforce. Such skills included pruning/training the plants and harvesting/packing the fruit. Speciality labour will include people with additional training in such fields as plant production, plant nutrition, plant protection (insects and diseases) computers, labour management, marketing, etc. These may or may not be part of the regular workers, but may be called on as consultants as needed.

12. Management residence – The grower/manager residences should be close to the greenhouse so that they can get to the greenhouse quickly in case of emergencies.

13. Community profile: Prior to selecting a site for greenhouse construction the grower should obtain a “Community Profile” for potential locations. These are available at the city or area Chamber of Commerce and contain Community background information:

- Location, elevation, history and weather.
- Population, employment structure and labour force information
- Growth indicators, principal economic activities and property tax information
- Available properties, financing, transportation, communications and utilities
- Government, medical and educational services

4.3 Various Components of Greenhouse / Poly-house

The greenhouse is a structure made by assembling different parts or components. Each part has specific role in greenhouse structure. It is covered with a transparent material for admitting natural light for plant growth. The main components of greenhouse like structure, covering/glazing and temperature control systems need proper design for healthy growth of plants.

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Freestanding (single) or ridge and furrow (gutter connected) greenhouses are two common styles of commercial greenhouses. The freestanding style is often a Quonset, which will accommodate many growing situations but presents height

restrictions near the side walls. Another freestanding style is the single gable greenhouse and its many variations. The ridge and furrow or gutter connected greenhouses are joined at the eave by a common gutter. When several of these buildings are joined they are often referred to as a greenhouse range (Figure 4.3.1).

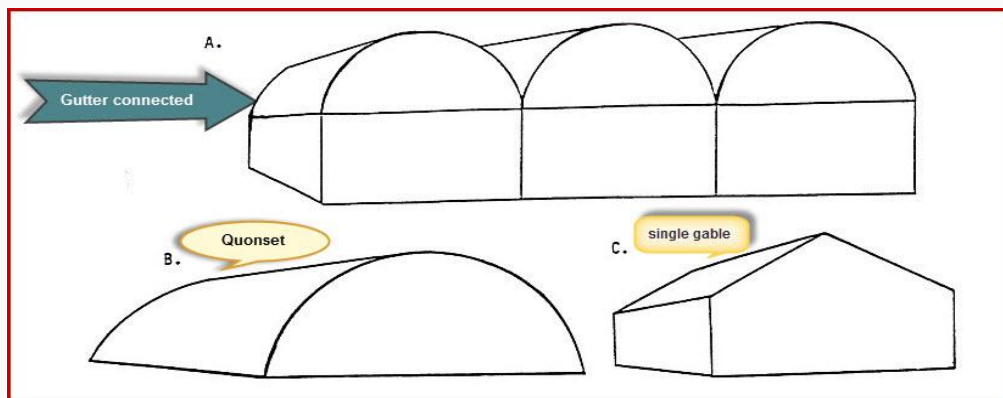


Fig.4.3.1 Commercial greenhouse structures: A) gutter connected, B) Quonset, and C) single gable.

(Source: <http://pods.dasnr.okstate.edu>)

4.3.1 Foundation:

The foundation must resist overturning and vertical pressure from structural loads and snow, and should extend below the frost line. Concrete is the most appropriate material for permanent structures. A 2,500 PSI or greater mix should be chosen when ready-mix concrete is used.

Unless the grower is constructing a greenhouse without the use of a manufacturer, specific recommendations are usually provided for adequate durability of the foundation. The foundation stage of construction is critical and consulting with appropriate personnel, such as experienced builders, is highly recommended.

The foundation can be 60 cm x 60 cm x 60 cm or 30 cm diameter and one meter depth in PCC of 1:4:8 ratios. The vertical poles should also be covered to the height of 60 cm by PCC with a thickness of 5 cm. This avoids the rusting of the poles.

4.3.2 Structural Components:

(Refer Fig 4.3.2)

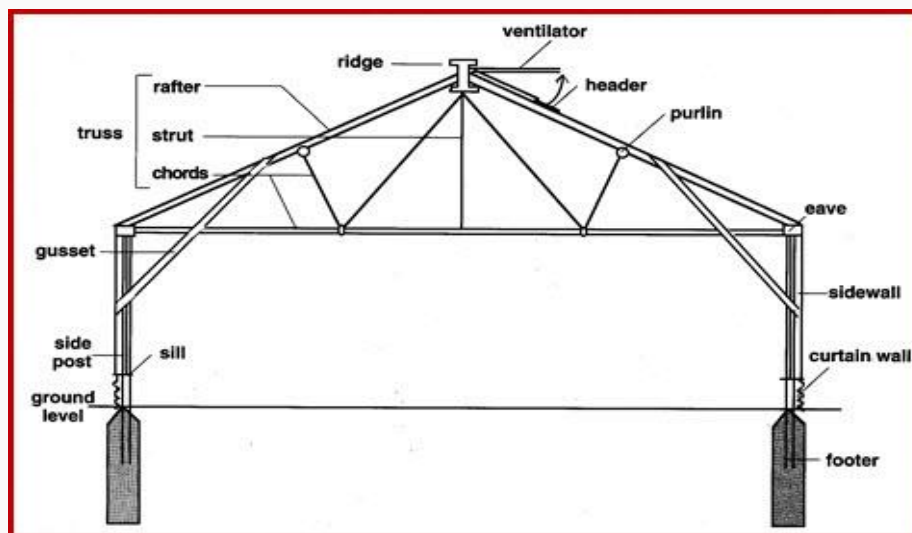


Fig 4.3.2 Basic Structural components of greenhouse

(Source: www.kirkwood.edu)

4.3.2.1 Side Wall:

- It supports the trusses and bears the weight of the greenhouse.
- Set in concrete footings
- Typically spaced 10 feet apart

4.3.2.2 Curtain Wall:

- The first several feet of sidewall above the soil line.
- Usually made of some solid building material such as poured concrete, concrete blocks, bricks, or treated lumber.

4.3.2.3 Sill: It is top of the curtain wall.

4.3.2.4 Eave:

- Where the sides of the greenhouse join the roof of the greenhouse.
- The “top” of the sides of the greenhouse.

4.3.2.5 Truss:

- Structural component that supports the weight of the greenhouse roof.
- Consists of rafters, struts, and chords.

4.3.2.6 Purlin :

- Purlins run along the length of the greenhouse.
- Keep the roof trusses aligned.

4.3.2.7 Ridge :

- Where the roofs come together at the top of the greenhouse.
- Many greenhouses have a ridge vent(s).

4.3.2.8 Side posts and columns:

These are vertical supports that dictate the height of the production area. These range from one to ten feet in height and should be given serious consideration since they directly influence efficiency (Figure 4.3.2).

4.3.2.9 Sash Bar:

Refer Fig 4.3.3

- Run perpendicular to the purlins.
- Attached to the purlins.
- Hold the glazing in place.
- Sometimes built with a drip groove or channel to catch condensation that forms on the inside of the glass panels

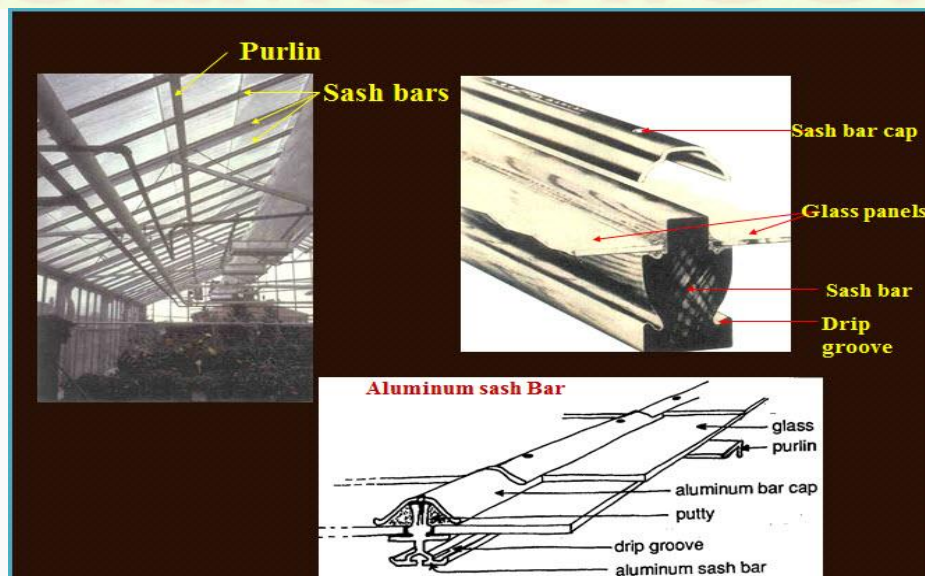


Fig 4.3.3 Sash Bars

(Source: www.kirkwood.edu)

4.3.4 Framing Materials

Aluminum is the most economical material for constructing the greenhouse frame. It can be shaped as needed to form various structural components of the greenhouse and needs no maintenance after installation. Aluminum framing also has the longest life span and allows for light reflectance.

Steel is commonly used but must be painted or galvanized to resist high moisture conditions within the greenhouse. Steel needs more maintenance than aluminum and is heavier, requiring additional support.

Wood was once a common framing material, but it has steadily lost popularity for number of reasons. The main disadvantage of wood is that it deteriorates over time. If wood is desired, pressure treated lumber should be purchased and then treated with commercially available coatings. Avoid PENTA and creosote since they liberate fumes that are harmful to plants.

4.3.5 Coverings:

Glass allows maximum light transmission in greenhouse production. Despite this, there are several disadvantages to consider. Glass is expensive and, because it is fragile, has to be replaced more often than many other materials in the market today. Also, consider that when using glass, the cost of structural components will be expensive because of the added weight which must be supported. When glass is desired, check with the manufacturer for double and triple strength ratings available. Also, “hammered” or “frosted” panes will distribute incoming light better by dispersing the rays, resulting in fewer shadows. This type of glass is not transparent from the outside, which can be an added security benefit in certain institutions.

A double layer of polyethylene, inflated with air, is another option to consider for covering the greenhouse. One advantage of using this material is that it is relatively inexpensive. Materials have greatly improved and some manufacturers guarantee their materials for up to four years. Look for ultraviolet stabilized products that are slower to yellow and crack. Single and triple layer polyethylene coverings are used less commonly. Replacement of a polyethylene covering as a result of wind, hail, or solar damage will be more frequent than any other covering, but the low investment and the need for less structural components make it a material to consider when a temporary greenhouse is desired. Two additional products, available commercially, to extend the life of a polyethylene house are poly patch and anti-drip material. The anti-drip material reduces condensation that can harm plants growing below. Condensation should also be controlled to prevent lowered light transmission, especially during the winter months when low light levels may limit plant growth.

Fiberglass is another material that has gained popularity over glass. It is very durable, rigid, and available in various light transmission levels. Ultraviolet light will cause fiberglass to deteriorate in a few years from swelling and fraying of the

fibers. This in turn quickly leads to lowered light transmission to the plants. However, there are products now available that will help to reduce the fraying. These coatings should be applied prior to damage to the fiberglass. Although the life span of fiberglass can be as short

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as five years, choosing higher grade products and applying a coating may result in a twenty year life span.

Polycarbonate is one of the newest materials available and is still being evaluated. This material is rigid but also flexible enough to be used in a Quonset style greenhouse. Although the initial cost of polycarbonate is high, a ten to 15 year life span can be expected. Polycarbonate can be purchased in double and triple walled forms which are highly impact resistant.

Acrylic is also new and expensive but it has a minimum ten year warranty from some manufacturers. Although many advantages exist such as high light transmittance, high impact resistance, and great strength, costs have proven prohibitive in most cases.

Remember to check with the covering manufacturer for several factors.

1. Combustibility - Some materials may result in lower insurance premiums if they are fire retardant. Other materials are highly flammable, such as fiberglass reinforced panels (FRP), and that must be considered. Fire retardant FRP panels can be purchased.

2. Durability - Not only will this differ among materials, but also will be determined by whether they are one, two, or three ply.

3. Insulation - Note insulation "R" factor and compare for fuel savings. Heat retention from highest to lowest:

- Acrylic (double layer)
- Polycarbonate (double layer)
- Glass (double layer)
- Polyethylene (double layer)
- Fiberglass

Keep in mind that this is relative to the number and thickness of layers used.

4. Life span.

5. Care - Maintenance may be required to realize life span claims from manufacturer.

6. Guarantee - Read warranties carefully as most will be limited.

4.3.6 Shading Compounds

During the summer months, when solar radiations are too intense for any crops to be grown to acceptable quality. Shading is necessary to make greenhouses usable and to prevent overtaxing the cooling and ventilation systems. Instructions are provided to reach the desired percentage of radiation blockage. Liquid formulas are commonly used for glass and sometimes fiberglass. However, frayed fiberglass may absorb the liquid, making it

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impossible to remove when maximum solar radiation is again needed. Another alternative is to use shade cloth. It can be purchased for the per cent of solar radiation reduction desired, depending on the crops grown.



Module 5.Design criteria and calculations

Lesson 5 Criteria for Design and Construction of Greenhouse

5.1 INTRODUCTION

Depending on the local climate and the bioclimatic requirements of the species to be cultivated, once the proper site has been selected, it will be necessary to choose the cladding material, the type of structure and the architectonic shape of the greenhouse. If the predictable climate generated by the greenhouse is not appropriate complementary facilities and equipment for climate control will have to be considered.

5.2 CRITERIA FOR THE DESIGN OF PLASTIC FILM GREENHOUSES

Greenhouse design is very much influenced, in practice, by the local climate and the latitude of the site, and in many cases is limited by the availability of materials for the construction. No design is perfect, thus it is necessary to prioritize in each case, the criteria to follow, these being:

- i. The maximization of the light
- ii. Minimizing, if possible, the structural elements to avoid shadows
- iii. Ensuring good insulation which decrease the heat losses and
- iv. Affordable costs.

The physical and mechanical properties of the covering materials and their availability limit the options while building a greenhouse, so there is a certain trend among growers to build traditional greenhouses.

Relative to plastic-film greenhouses, the most important aspects to achieve is as below.

Besides the proper structural resistance to the wind, but also to other predictable loads (snow, crops which are trained to hang, auxiliary equipment), the greenhouse must be built in such a way that the plastic film will remain well fastened, airtight, and without wrinkles, to avoid breaks caused by the wind. It must, as well, be easy to change the film. For this, the fastening system must be simple and efficient. The increasing costs of mounting the film and the plastic materials have favoured the use of special films with several years durability. For longer durability, if possible, the structural elements susceptible to heating up by solar radiation which are in contact with the plastic film must be insulated, because excess temperatures contribute to shortening the shelf life of the plastic film.

When arcs or metal frames are used, the separation between them will depend on the predictable loads (wind, snow), normally does not exceed 3 m.

The greenhouse must be airtight, to prevent night cooling in those climates in which low night temperatures are expected, as well as to prevent undesirable leakage of CO. A proper ventilation system is needed, with airtight vents. The entrance of water from rainfall must be avoided.

Its volume must be large enough, not only to obtain a higher thermal inertia, but also to allow for crops that are trained to grow up high supports, and proper movement of the inside air necessary for natural ventilation. The unitary volume of the greenhouse is the quotient between the greenhouse inner volume (m^3) and the area that it covers (m^2), being equivalent to the average height.

Collection of rainfall water by means of gutters, for its later storage and use for irrigation, is not only of interest in areas of low rainfall, but also because the excellent quality of rain water makes it especially valuable for soil less cultivation, a technique for fast growth. The gutter must be 4 cm larger than the diameter of the drainpipe and must have a slope of 1% to avoid overflows (the minimum slope must be higher than 0.2% in any case). The drainpipes must have a cross-section of 7 cm^2 for each 10 m^2 of cover area that is to be drained, which caters for rainfall intensities of up to 75 mm h^{-1} .

To avoid water dripping over the crops from condensation on the inner surface of the cover, it is important to build the greenhouse with roof angles greater than 26° (such angles also allow snow to run off the cover), and have an appropriate collection system, or to use anti-dripping plastic film. In unheated greenhouses, where climate control is quite limited, the slope of the roof becomes relevant to avoiding condensed water dripping from the roof cover; roofs with ogive shape might be of interest (Fig. 5.2.1).

Likewise, as a general rule, the greenhouse must maximize solar radiation transmission, at least in winter (when it is lower), for which proper roof geometry and orientation are fundamental.

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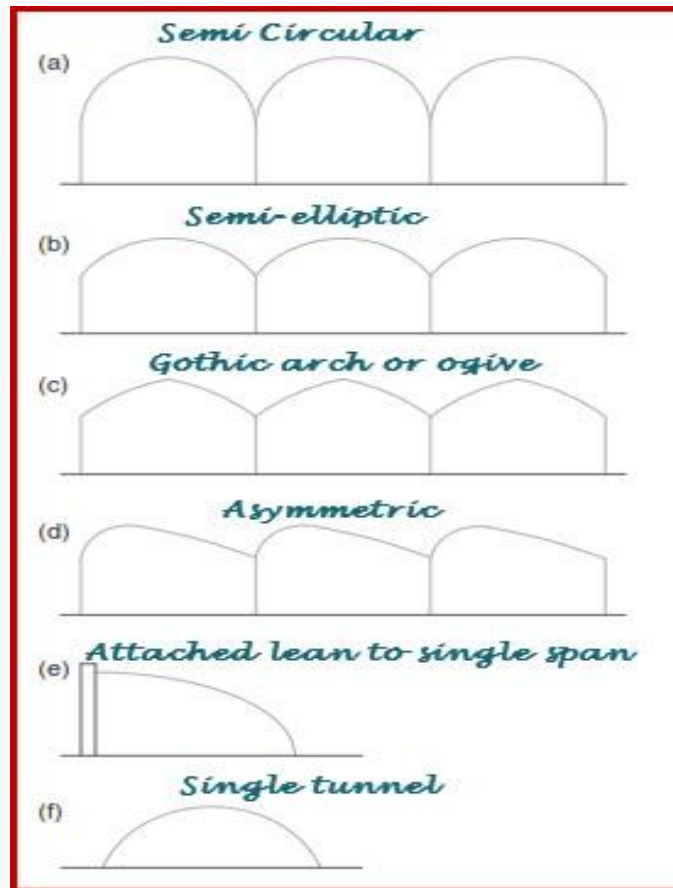


Fig 5.2.1 Some common type of curved roof greenhouses

(Source: Nicolas Castilla, 2013)

5.3 DESIGN CRITERIA IN AREAS WITH A MEDITERRANEAN CLIMATE

The most limiting climate conditions for greenhouse cultivation in Mediterranean climates are:

- i. Low night temperatures in winter;
- ii. High daytime temperatures;
- iii. High ambient humidity at night and low values during the day; and
- iv. CO depletion during the day.

Therefore, it is especially necessary to achieve efficient ventilation, which allows for alleviation of the thermal excesses and extreme humidity, and prevents CO deficiency. Depending on the type of greenhouse and climate conditions it is advisable that the ventilation area is up to 30% of the ground area of the greenhouse. The increasing use of insect-proof screens in the vents, to avoid or limit the entrance of insects, decreases the efficiency of ventilation. Collection of rainfall water must also be a priority. In the low-cost type greenhouses, the general problem of condensed water dripping is aggravated in flat-

roof greenhouses, inducing serious plant protection problems as it facilitates the development of diseases.

Thermal losses must be limited by choosing a suitable cladding material and making it as airtight as possible. Night heating may be necessary for the crop, during the critical winter months but its economic profitability is questionable in many cases.

5.4 DESIGN CRITERIA IN HUMID TROPICAL CLIMATES

The high rainfall during the whole year or during the rainfall season (which induces high RH), the stability of the temperatures (high during both the day and the night) throughout the year, and the solar radiation (which may be excessive in some cases), are the most outstanding characteristics of humid tropical climates.

As a consequence, in these greenhouses protection against the rainfall must prevail (the greenhouse umbrella effect) and there should be efficient permanent ventilation (with vents frequently equipped with screens to prevent the entrance of insects), as well as a good height and sufficient resistance to withstand strong hurricane winds which are usual in such climates. (Figure 5.4.1) shows some of the solutions for humid tropical climates. Achieving a compromise between these requirements, at a low cost, is not easy.

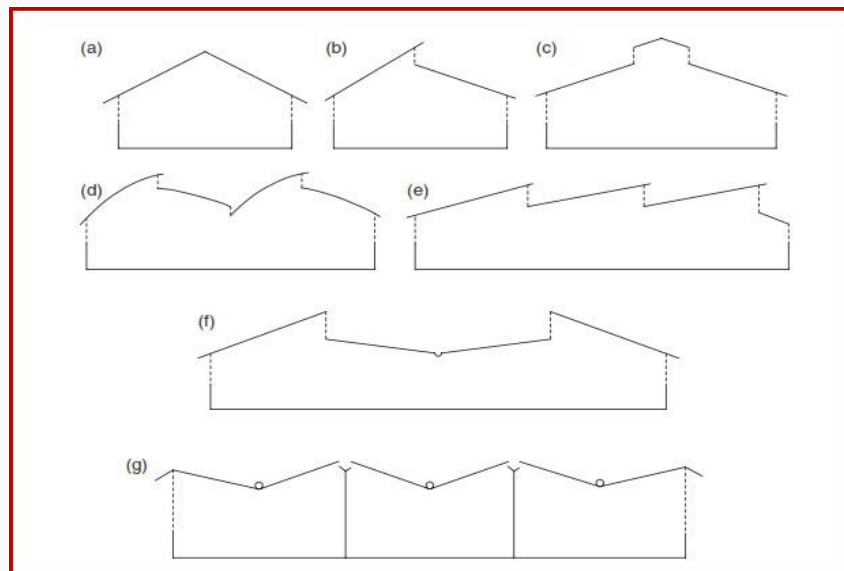


Fig 5.4.1 Greenhouse structures used in tropical regions

(Source: Nicolas Castilla, 2013)

5.5 GREENHOUSES FOR OTHER CLIMATE CONDITIONS

In dry desert climates, the extreme temperature values are more acute than those experienced in Mediterranean climates, and the ambient humidity is notably lower, the winds being frequently loaded with sand and with very low water content.

In these conditions, high ventilation capacity and efficiency is a priority (with the possibility of tightly closing the vents), and there is possibly a need for humidification systems (if the

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evapotranspiration of water is insufficient) to decrease the temperature and increase the RH (oasis effect). Preventing thermal

losses at night is necessary (so choice of a proper cladding material and enough

Sealing are important) to avoid the need for night heating. The structural resistance to the wind is fundamental and the collection of rainfall water for irrigation is normally desirable.

Under cold climate conditions, the greenhouse effect must be enhanced and, normally, the maximum solar energy collection (interception) should be reached with proper roof geometry and cladding material as well as optimized greenhouse orientation. Limiting thermal losses is always desirable (using proper cladding material, thermal screens and being as airtight as possible) .

Frequently, the insulation measures to reduce thermal losses imply a decrease in available solar radiation (the double wall decreases the transmission, the thermal screens generate shadows even when folded) so it is not easy to obtain a compromise solution which must be based on profitability criteria in each specific case. In these cold climates, the obvious choice between multi-span and single-span greenhouses is clearly for the first type. Heating is a must, not just during the winter months, and ventilation is necessary during the season of high radiation.

In some cases, greenhouse cladding with a screen (permeable to air and water) aims at achieving a windbreak effect, a shading effect, or plant protection (limiting the access of pests), when the natural thermal conditions are adequate for crop growth and, therefore, a greenhouse effect is not pursued.

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Lesson 6 Design Load Calculations : Part I

6.1 INTRODUCTION

Load and design requirements for the design of greenhouse structures, their components and enclosure elements (cladding) are as below. The loads specified herein are based on the ASCE 7. The loads are to be used in conjunction with the stress criteria of the International Building Code and referenced standards. Where no standards are referenced in the building code, recognized manufacturer's literature may be used with regard to code compliance.

6.2 LOADS

1. Dead and Live Loads - defined by the building code
2. Environmental Loads - defined by the building code
3. Collateral Loads - weight of support equipment used for the operation or maintenance of plant material, including water.
4. Plant Live Load - weight of supported or suspended plant material

Importance Factors: I_w (wind), I_s (snow), and I (seismic) - a factor that accounts for the degree of hazard to human life and damage to property.

6.3 BASIC REQUIREMENTS

6.3.1 Design

Greenhouse structures and all parts thereof shall be designed and constructed to safely support all loads. These loads include the dead and live, collateral loads, environmental loads and equipment loads specified by the purchaser.

6.3.2 Serviceability

Greenhouse structures and their components shall have adequate stiffness to limit vertical and transverse deflections, vibrations or any other deformation that may adversely affect their serviceability.

Dead and live load deflection shall not exceed the deflection limits specified in the building code. Table 1604.3 of the IBC gives vertical deflection limits as $1/120$. While there are drift limits in the code for seismic design (IBC, Section 1617.3), lateral displacements are not regulated by the code for wind.

However, even when wind loads govern the design of a building, the lateral force resisting systems shall meet seismic detailing requirements and limitations.

Cladding attachment must be designed to accept differential movement under loads.

6.3.3 Analysis

The design of greenhouse structures, the load effect on the individual components and connections shall be determined by rational engineering analysis methods. Rational engineering analysis is a computational analysis, either by hand or computer, that uses accepted load distribution and determination methods. Unusual structural and construction methods shall be based on engineering analysis or physical testing by an approved laboratory. Greenhouse structures shall be analysed for all building code required load conditions. Elements and components shall be designed for load combinations specified in the building code or referenced standards.

6.4 ADMINISTRATIVE ISSUES

6.4.1 Design Requirements

Prior to design the manufacturer should obtain local load information, i.e. wind, snow, etc. Information should include:

- Code of jurisdiction
- Determination of loads:
- Roof Live Load
- Wind speed (3-second gust wind speeds)
- Snow load (ground snow load)
- Earthquake zone or design spectra
- Soil type and allowable pressure

6.4.2 Required Information on Plans

Certain information must be shown on the construction drawings. The following information shown below is required even if it is not a controlling design load. Information to be provided on the plans includes:

- Dead Loads
- Roof Live Loads
- Collateral Loads (irrigation equipment, including water)
- Plant loads
- Snow Loads

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- Ground Snow Load p_g
- Flat-roof snow load, p_f
- Snow exposure factor, C_e
- Snow load importance factor, I_s
- Thermal factor, C_t
- Wind Load
- Basic wind speed (3 second gust), miles per hour
- Wind importance factor, I_w and building category
- Wind exposure category
- Applicable internal pressure coefficient and prevailing wind direction
- Design Wind Pressure on Components and cladding.
- Exterior components and cladding materials are not specifically designed by the design professional.
- Earthquake design data
- Seismic use group
- Spectral response coefficients (S_{DS} and S_{D1})
- Site class
- Basis seismic-force resisting system
- Design base shear
- Analysis procedure
- Flood load –

If a building is located in a flood hazard area, established by a jurisdiction having authority, the following shall be shown for areas not subject to high-velocity wave action:

- Elevation of the lowest floor
- Elevation to which any non-residential building will be dry flood proofed
- Foundation Design

Reactions of structural elements when the foundation or other systems are to be designed by others. If the structure is designed for future additions, the foundation information should include the probable design load information.

6.4.3 Additions and alterations

Additions to existing greenhouses may be made. The new structure shall not make the existing structure unsafe. For structural purposes it is related to the per cent of overstress in structural members. When a greenhouse is added to an existing building, the capability of the building to withstand any loads superimposed by the greenhouse shall be verified including lateral loads due to attachment and snow drift loads due to proximity. Alterations may be made to any greenhouse if any loads imposed on the existing structure do not create an unsafe condition.

6.4.4 Load Testing

Load testing is typically not desirable for any product that is within the scope of computational analysis. Typically, specialty products such as cladding components are candidates for testing rather than calculations. Any load testing must be carried out by an independent approved testing agency.

6.5 DESIGN METHODOLOGY

6.5.1 Allowable stress design vs strength design requirements - Design of typical greenhouse structures may be made by using the allowable stress design (ASD) or the strength (LRFD) design methods. The load combination equations used will depend on the design method. The ASD is the most common approach used by most engineers for greenhouse structures.

6.5.2 Safety factors for greenhouse components - Safety factors for the structural members are included in the code referenced standards.

6.5.3 Greenhouse classification (Code occupancy group under IBC 2000) - Greenhouse structures may be considered an occupancy classification "U" when used as a Production Greenhouse. Research facilities may be considered the same. Commercial greenhouse structures used for retail use are considered as a "B" or "M" occupancy classification. This is based on the fact that the building is normally occupied.

6.5.4 Deflection and Drift - There is no criteria limiting drift. The engineer should consider the serviceability requirements of the building, previously discussed in Section 6.3.2.

6.6 LOADS

6.6.1 General

Buildings and other structures shall be designed to resist the load combinations. Applicable loads shall be considered, including both earthquake and wind, in accordance with the

specified load combinations. Effects from one or more transient loads not acting shall be investigated.

6.6.2 Dead loads

- Structure weight
- Cladding weight

6.6.3 Live loads

6.6.3.1 Roof

- 10 psf minimum in the IBC (ASCE -7 permits the Authority having jurisdiction to accept 10 psf.)

6.6.4 Collateral Loads

Collateral loads shall not be included in Wind Uplift resistance analysis. These loads shall be considered a live load for wind design.

- Mechanical Equipment - Irrigation, transfer systems, etc.
- Permanently mounted service equipment (heaters, fans, water lines, etc.)

Such permanently mounted equipment shall be considered as a dead load when considering load combinations.

6.6.5 Plant Loads

Hanging plants, 2 psf minimum, applied as a concentrated load at the truss panel points. Greenhouse purchasers may have additional or other criteria for hanging plant loads or mechanical watering systems.

6.7 SNOW

6.7.1 General

Provisions for the determination of design snow loads on greenhouse structures are as per the ASCE 7 98(Section 7.0). They apply to the calculation of snow loads for both continuously heated greenhouses and for intermittently heated or unheated greenhouses.

6.7.2 Definitions

The following definitions apply only to this section.

- **Continuously heated greenhouse.** Any greenhouse, production or commercial, with a constantly maintained interior temperature of 50°F or more during winter months.

Such a greenhouse must also have a maintenance attendant on duty at all times or a temperature alarm system to provide warning in the event of a heating system failure. In addition, the greenhouse roof material must have a thermal resistance (R -value) less than $2.0 \text{ ft}^2 \cdot \text{hr} \cdot ^\circ\text{f}/\text{Btu}$.

- **Intermittently heated or unheated greenhouse.** Any greenhouse that does not meet the definition of a continuously heated greenhouse.

6.7.3 Design Procedure

The elements outlined herein are the general process for snow design. Design snow loads for greenhouses shall consider following factors;

- The ground snow load p_g - based on map in code or local requirements
- The flat -roof snow load p_f calculated taking into consideration the roof exposure, the roof thermal condition, and the occupancy of the structure.
- The sloped-roof snow load p_s for greenhouses with gabled, hipped, arched, and gutter connected roofs shall be determined as referenced in 6.7.4
- Partial loading conditions to account for wind scour, melting, or snow -removal operations shall be considered as referenced in 6.7.4.
- Unbalanced snow loads due to the effects of winds on sloped roofs shall be considered as referenced in 6.7.4.
- Local snow load surcharges due to snow drifts on lower roofs and from roof projections as referenced in 6.7.4.
- Local snow load surcharges from snow sliding off of adjacent higher sloped roofs shall be considered as referenced in 6.7.4.

6.7.4 Calculation of Snow Loads

6.7.4.1 Ground Snow Loads: As per ASCE 7 Section 7.0, or local code requirements.

6.7.4.2 Flat-Roof Snow Loads: (ASCE 7, Equation 7-1) Although greenhouses rarely, if ever, have flat roofs, the calculation of flat -roof snow loads, p_f , is necessary for the calculation of sloped-roof snow loads, p_s .

A flat roof is a roof with a slope less than or equal to 5 degrees. For low -sloped roofs refer to ASCE 7, Section 7.3.4 for further information and load limitations.

First the flat roof snow load p_f is calculated. If the building has a low-slope roof (generally between 5 and 15 degrees), the flat roof snow load will have a minimum value determined by the Code. The governing flat roof snow load, either calculated or Code-determined minimum, is then used to determine the sloped roof snow load, p_s by multiplying with a slope factor C_s .

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If the building has a sloped roof (greater than 15 degrees), the calculated value for p_f is used, with a slope factor C_s , to determine the sloped roof snow load p_s . For greenhouses, where the ground snow load, p_g , is in the 15 psf to 20 psf range, the snow load will generally govern over the roof live load.

For gutter-connected greenhouses resulting in a multiple folded plate, saw-tooth or barrel vault roof, the value of C_s is 1.0.

The flat roof snow load p_f shall be calculated using the following equation, with exposure factor C_e , thermal factor C_t and snow importance factor I_s found in ASCE 7.

$$p_f = 0.7 * C_e * C_t * I_s * p_g$$

The flat roof snow load p_f , for low-sloped roofs only, shall not be less than the following:

$$p_f = I_s P_g, \text{ when } p_g \text{ is less than or equal to 20 psf or}$$

$$p_f = I_s 20 \text{ psf when } p_g \text{ is greater than 20 psf}$$

Where,

P_g = Ground snow load, as per ASCE 7, Figure 7-1

C_e = Exposure factor, as per ASCE 7, Table 7 -2

C_t = Thermal factor, as per ASCE 7, Table 7 -3

I_s = Importance factor for snow loading, as per ASCE 7, Table 7 -4

Exposure Factor: is a function of the greenhouse site terrain category and roof exposure category. Most greenhouse roofs are likely to be fully or partially exposed and located in Exposures B or C. Thus, the snow exposure factor is most likely to be 0.9 or 1.0.

Thermal Factor: is a function of the thermal resistance of the greenhouse roof glazing and the temperature conditions within the greenhouse, and shall be determined from the following Table:

Table 6.1 Thermal Factor, C_t

Thermal condition	C_t
Continuously heated greenhouse (see 6.7.2)	0.85
Intermittently heated greenhouse kept just above freezing	1.1
Unheated greenhouse	1.2
All greenhouses except those above	1.0

Note:

The thermal condition should be representative of the anticipated conditions during winters or the life of the greenhouse.

Snow Load Importance Factor: The value of the snow load importance factor, I_s , used in the calculation of p_f is a function of the type of greenhouse and its use, and shall be determined in accordance with the following Table:

Table 6.2- Classification of Greenhouses for Snow Load Importance Factors

Category ASCE7 IBC	Nature of occupancy and location of Greenhouse	Factor I_s
II I	All commercial greenhouses that are not in ASCE 7 Category I (IBC Category IV)	1.0
I IV	Production greenhouses that are occupied for growing plants on production or research basis, without public access	0.8

6.7.4.3 Sloped-Roof Snow Loads: (ASCE 7 Section 7.4) The sloped -roof snow load, p_s , shall be obtained by multiplying the flat -roof snow load, p_f , by the roof slope factor, C_s .

Warm-Roof ($C_t \leq 1.0$) Slope Factor, C_s : For all greenhouses, except unheated and intermittently heated greenhouses kept just above freezing with unobstructed slippery roof surface that will allow snow to slide off the eaves (such as light transmitting coverings including plastics, glass and similar materials), the roof slope factor shall be determined by using the following formula, as depicted in ASCE 7, Fig. 7-2a:

$$C_s = 1 - [(\theta - 5)/65] \quad (\text{when } \theta > 5^\circ)$$

Where, θ is the angle of slope from the horizontal in degrees.

Warm-roof slope factors for common roof slopes are given in the following Table:

Table 6.3 - Common Warm-roof Slope Factors

Roof slope	C_s
3/12	0.85
4/12	0.80
6/12	0.65
8/12	0.55
12/12	0.40
Gutter connected	1.0

Greenhouses Kept Just Above Freezing ($C_t = 1.1$) Roof Slope Factor, C_s : For all intermittently heated greenhouses kept just above freezing with unobstructed slippery roof surface that will allow snow to slide off the eaves (such as light transmitting coverings including plastics, glass and similar materials) the roof slope factor shall be determined from the average of the values obtained for warm-roof slope factors and cold -roof slope factors. For common roof slopes these values are given in the following Table:

Table 6.4 - Common Roof Slope Factors C_s for Just Above Freezing Greenhouse

Roof slope	C_s
3/12	0.95
4/12	0.90
6/12	0.80
8/12	0.60
12/12	0.45

Unheated Greenhouse ($C_t = 1.2$) Roof Slope Factor, C : For all unheated greenhouses with unobstructed slippery roof surface that will allow snow to slide off the eaves (such as light transmitting coverings including plastics, glass and similar materials), the roof slope factor shall be determined by using the following formula, as depicted in ASCE 7, Fig. 7 -2b:

$$C_s = 1 - [(\theta - 15)/55]$$

Where, θ is the angle of slope from the horizontal in degrees.

Unheated greenhouse roof slope factors for common roof slopes are given in the following Table:

Table 6.5 - Common Unheated Roof Slope Factors

Roof slope	C_s
3/12	1.00
4/12	0.95
6/12	0.75
8/12	0.65
12/12	0.45
Gutter connected	1.00

Curved Roof Slope Factor, C_s : (ASCE 7, Section 7.4.3) Portions of arched greenhouse roofs having a slope exceeding 70 degrees shall be considered free of snow load (i.e. $C_s = 0$). The point at which the slope exceeds 70 degrees shall be considered the “eave” for such roofs. For arched roofs the roof slope factor shall be determined from the appropriate formula in Sections 6.7.4.3, by basing the angle of slope on the slope line from the “eave” to the crown.

Multiple Roofs Slope Factor, C , (Gutter-Connected): (ASCE 7, Section 7.4.4) Gutter connected (multiple) gable, saw tooth and barrel vault greenhouse roofs shall have a $C_s = 1$, with no reduction in snow load because of slope (i.e., $p_s = p_f$). Greenhouse design should consider future additions when the gutter is on an exterior wall or on a single building to allow for future additions.

Ice Dams and Icicles along Eaves: (ASCE 7, Section 7.4.5) Two types of warm roofs that drain water over their eaves shall be capable of sustaining a uniformly distributed load of $2p_f$ on all overhanging portions. These roof types include the unventilated roof with an R -value less than 30 ft².h.°F/ BTU, and the ventilated roof with an R -value less than 20 ft².h.° F/ BTU. No other loads except dead loads shall be present on the roof when this uniformly distributed load is applied.

6.7.4.4 Partial Loading: (ASCE 7, Section 7.5) Roofs with continuous beam systems need to be designed for the partial loading of selected spans with the balanced snow load, while the remaining spans are loaded with half the balanced snow load.

6.7.4.5 Unbalanced Snow Loads: (ASCE 7, Section 7.6) The combination of snow and wind from all directions contributes to unbalanced snow load conditions. The amount of the unbalanced snow load is often dependent upon the width of the building, as well as the slope of the roof. The gable roof drift parameter b , based on the relative shape of the building, and

the snow density g , derived from the ground snow load, are used to determine the slope of the roof that limits the amount of unbalanced snow loads for the varying roof shapes.

6.7.4.6 Drifts on Lower Roofs (Aerodynamic Shade): (ASCE 7, Section 7.7) Greenhouse roofs shall be designed to sustain localized loads from snow drifts that form in the wind shadow of higher portions of the same structure and adjacent structures and terrain features.

Lower Roof of a Greenhouse: (ASCE 7, Section 7.7.1) Drift loads shall be superimposed on the balanced snow load. As the difference in adjacent building heights approaches zero, drift loads are not required to be applied. Refer to ASCE 7 for surcharge loads from leeward drifts, formed by snow coming from a higher upwind roof, and windward drifts, formed next to a taller downwind building.

Note that the clear height difference between the upper roof height and the top of the balanced snow load on the lower roof, h_c , is determined based on the assumption that the upper roof is blown clear of snow in the vicinity of the drift. This is a reasonable assumption when the upper roof is nearly flat. However, sloped roofs often accumulate snow at eaves. For such roofs, it is appropriate to assume that snow at the upper roof edge effectively increases the height difference between adjacent roofs, and using half the depth of the unbalanced snow load in the calculation of h_c produces more realistic estimates of drift loads.

Adjacent Structures and Terrain Features: (ASCE 7, Section 7.7.2) The effect of higher structures or terrain features within 20 feet of a lower roof shall be considered in the design of that lower-roofed building.

6.7.4.7 Roof Projections: (ASCE 7, Section 7.8) Gives a method that shall be used to calculate drift loads on all sides of roof projections and at parapet walls. If the side of a roof projection is less than 15 ft. long, a drift load is not required to be applied to that side.

6.7.4.8 Sliding Snow: The extra load caused by snow sliding off a sloped roof of a greenhouse or other structure onto a lower greenhouse roof shall be superimposed on the balanced snow load. It shall be determined assuming that all the snow that accumulates on the upper roof under the balanced loading condition (p times the roof area) slides onto the lower roof. Even if the upper roof is a greenhouse roof that is an unobstructed slippery surface, it shall be considered as not being slippery for purposes of calculating the extra sliding snow load. The final resting place of snow that slides off a higher roof onto a lower roof will depend on the size, position and orientation of each roof. Distribution of the sliding snow might vary from a uniform load 5 feet wide if a significant vertical offset exists between the two roofs, to a 20 foot wide uniform load where a low slope upper roof slides its load onto a roof that is only a few feet lower or when snow drifts on the lower roof create a sloped surface that promotes lateral movement of the sliding snow.

6.7.4.9 Rain-on-Snow Surcharge Load: Rain-on-snow surcharge loads need not be considered on greenhouse roofs when they have slopes that exceed $\frac{1}{2}$ inch per foot. However, all gutters in gutter-connected greenhouses shall be provided with adequate slope and drains to allow for run off of rain and snow melting and to prevent ponding.

6.7.4.10 Ponding Instability: Roofs shall be designed to preclude ponding instability. For roofs with a slope less than $\frac{1}{4}$ in./ ft., roof deflections caused by full snow loads shall be investigated for ponding instability from rain-on-snow or from snow meltwater.

6.7.4.11 Existing Roofs: Existing roofs shall be evaluated for increased snow loads caused by additions, alterations, and new structures located nearby, and strengthened as necessary.



Lesson 7 Design Load Calculations: Part II

7.1 WIND

7.1.1 General

Provisions for the determination of wind loads and other wind design criteria on greenhouse structures are contained in the IBC, which in turn references ASCE 7. Whether wind loads are derived from the IBC simplified method, or from the ASCE 7 simplified or analytical methods as referenced in the IBC, the choice is up to the designer and will undoubtedly depend upon the physical characteristics of the structure and the site. The provisions found in either source apply to the calculation of wind loading on the main wind force -resisting system and the components and cladding (including glazing) of the structure.

7.1.2 Definitions

- **Windward** -toward the wind; toward the point from which the wind blows
- **Leeward** -the side or point to which the wind blows
- **Simple Diaphragm Building** -While traditional greenhouse coverings are not considered diaphragm materials, a horizontal truss system at the roof level will transfer lateral loads to vertical lateral force-resisting systems and can be considered a diaphragm.

7.1.3 Design Procedure

Design wind loads for greenhouses shall consider:

- The basic wind speed, V
- The velocity pressure q_z , where z is the height, which is calculated taking into consideration the exposure category, the surrounding terrain, the wind directionality, and the occupancy of the structure.
- The design wind pressure p , which is calculated taking into consideration the direction of the wind, the exposure category, the height of the building or element, and the openness of the structure.

7.1.4 Calculation of Wind Loads

7.1.4.1 General: The design wind loads, pressures and forces are determined by the appropriate equations given in ASCE 7, Section 6.5.12 or 6.5.13; or in the case of the simplified procedure, found in Figures 6-3 and 6-4 of ASCE 7. Gust effect factors and pressure coefficients are found in figures and tables in ASCE 7.

7.1.4.2 Basic Wind Speed: The basic wind speed, V , in miles per hour, for the determination of the wind loads shall be found in a figure in the referenced code or standard being used.

7.1.4.3 Importance Factor: Greenhouses shall be assigned a wind load importance factor, I_w , in accordance with the following Table:

Table 7.1 - Classification of Greenhouses for Wind Load Importance Factors

Category ASCE 7 IBC	Nature of Occupancy and Location of Greenhouse	Wind Factor I_w
II I	All commercial greenhouses that are not in ASCE 7 Category I (IBC Category IV)	1.00
I IV	Production greenhouses in non-hurricane prone regions and in hurricane prone regions with $V = 80$ -100 mph and Alaska	0.87
I IV	Production greenhouses in hurricane prone regions with $V > 100$ mph	0.77

7.1.4.4 Wind Speed-up Over Hills and Escarpments, K_{zt}

Wind speed-up over isolated hills and escarpments that constitute abrupt changes in the general topography shall be considered for buildings and other structures sited on the upper half of hills and ridges or near the edges of escarpments. The effect of wind speed -up shall not be required to be considered when hill height to distance upwind of crest of hill ration $H/L_h < 0.2$, or when height of hill $H < 15'$ for Exposure D, or $H < 30'$ for Exposure C, or $H < 60'$ for all other exposures. Factor K_{zt} shall not be less than 1.0. Refer to Sec. 6.5.7 of ASCE 7 for further information.

7.1.4.5 Wind Directionality Factor: A wind directionality factor, K_d , shall be used in the analytical method of determining the wind velocity pressure, q_z , per Sec. 6.5.10 and 6.5.4.4 of ASCE 7.

Care should be taken in applying the wind directionality factor, which is a number less than 1.0. By ASCE 7 definition, the factor is to be used with ASCE load combinations, and is contrary to use of the IBC load combinations.

7.1.4.6 Exposure Categories: For each wind direction considered, an exposure category that adequately reflects the characteristics of ground surface irregularities shall be determined for the site at which the greenhouse is to be constructed. For a site located in the transition zone between categories, the category resulting in the largest wind forces shall apply. Account shall be taken of variations in ground surface roughness that arise from natural topography and vegetation as well as from constructed features. For any given wind direction, the exposure in which a specific greenhouse is sited shall be assessed as being one of the exposure categories A, B, C, or D.

7.1.4.7 Enclosure Classifications: All buildings are classified as enclosed, partially enclosed, or open. Whether the IBC or ASCE 7 is used to determine wind loads, the enclosure classifications are essentially identical. In wind -borne debris regions, special consideration is given to glazing with respect to the determination of openness. ASCE 7 continues beyond the basic definitions to provide for clarification of buildings that fall under multiple classifications, by stating if a greenhouse by definition complies with both the “open” and “partially enclosed” definitions, it shall be classified as an “open” building. A greenhouse that does not comply with either the “open” or “partially enclosed” definitions shall be classified as an “enclosed” building.

7.1.4.8 Velocity pressure q_z : When using the analytical method in calculating the wind loads, the velocity pressure at height z is calculated by factoring the given basic wind speed with the velocity pressure exposure coefficient K_z , the wind speed -up factor K_{zt} , the wind directionality factor, K_d , and the importance factor I . Refer to Sec. 6.5.10 of ASCE 7.

7.1.4.9 Internal & External Pressure Coefficients and Gust Effect Factors, G_{cpi} : Internal and external pressure coefficients, and gust effect factors are needed when using the analytical method of determining wind pressures. The factors are found in Sec. 6.5.11 of ASCE -7, based on physical characteristics of the structure and the site.

7.1.4.10 Design Loads and Wind Pressures: No matter which method is used in determining wind loads on a structure, the goal is to determine the worst case loading on the main wind force resisting system and on the components and cladding.

Using the IBC simplified method of Sec. 1609.6.2, design wind pressures are given in Tables 1609.6.2.1 and are multiplied by the appropriate factors for height, exposure, and importance.

When using the simplified method of Sec. 6.4.2 in ASCE 7, design wind pressures are found in Tables 6-2 and 6-3, and are adjusted by importance, exposure or area reduction factors.

When using the analytical method of Sec. 6.5.12 in ASCE 7, design wind pressures are calculated by factoring the wind velocity pressure with internal and external pressure coefficients and gust effect factors. Sec. 6.5.13 in ASCE 7 gives the equation that is used in determining the design wind force for open buildings.

7.1.5 Wind and Seismic Detailing

The IBC requires that lateral force-resisting systems shall meet seismic detailing requirements and limitations prescribed in the code, even when wind code prescribed load effects are greater than seismic load effects, per Sec. 1609.1.5. Seismic requirements in the IBC (Sections 1616.4 & 1620.1) state that all parts of the structure shall be interconnected. These connections are designed to resist the seismic force, F_p , induced by the parts being connected. Any smaller portion of the structure shall be tied to the remainder of the structure with a connection that shall be capable of transmitting the greater of 0.133 times the design, 5% damped, spectral response acceleration for short periods (S_{DS}) times the weight of the smaller portion, or 5% of the weight of the smaller portion to a larger portion of the structure. Each beam, girder, or truss member shall be provided with a positive connection to its support for resisting horizontal forces acting on the member. This support connection shall

have sufficient strength to resist 5% of the dead and live load vertical reaction applied horizontally. Similar seismic detailing requirements are found in ASCE 7, Section 9.5.2.6.

7.2 SEISMIC LOADS

7.2.1 Seismic Design -Background

Seismic design no longer uses the concept of seismic zones. Instead it uses maps, soil type and occupancy. The seismic maps in the building code and ASCE 7 are based on recent work by the US Geological Service. Some areas of the country have had their seismicity reduced. A number of areas are now in seismic zones that never were considered as areas having seismic potential. Seismic design requires determination of the Seismic Design Category (SDC). The SDC is a classification assigned to a structure based on its occupancy (Seismic Use Group) and the level of expected soil modified seismic ground motion. The SDC is determined by:

- the anticipated earthquake ground accelerations at the site,
- the type of soil at the specific site and
- the Seismic Use Group (SUG)

Because earthquake design seldom governs for greenhouses, designers may find that the use of default values may reduce the amount of calculations. All greenhouse structures would be Seismic Use Group I. The default soil type, Site Class D, simplifies the determination of the SDC. Designers will have to determine the site ground shaking (S_s and S_1) by use of the applicable seismic map. These seismic maps are contained in the building code and ASCE 7.

Using S_s and S_1 and the Site Class (soil type), coefficients S_{DS} and S_{D1} are computed. Then based on these computed values and the Seismic Use Group, the Seismic Design Category can be determined from the tables in the code or ASCE 7. The SDC directs users to specific code requirements. SDC A has minimum requirements, whereas an SDC E structure would have numerous analysis and detailing requirements.

Exceptions in the seismic design requirements (IBC 1614.1, Exception 3) include exemptions for agricultural storage buildings intended only for incidental human occupancy, areas with low S_s and S_1 values and for computed S_{DS} and S_{D1} with low values. Most production greenhouses should qualify for the agricultural exemption. However individual state and local regulations may still require design of all agricultural structures.

Once the seismic design category is determined, an R-value (a measure of the ductility of the structure) is determined from the building code (IBC Table 1617.6 or ASCE 7 Table 9.5.2.2). Greenhouse structures appear to qualify as ordinary steel concentrically braced frames, which have an R-value equal to 5. If a greenhouse is mounted on the roof of another structure, the R value for the greenhouse is independent of that underlying structure. The connection reactions for the greenhouse shall be applied to the underlying structure's roof, just as roof-mounted equipment would be, and the supporting structure's roof shall be designed for those loads, considering all applicable load combinations.

Designers will have to determine whether such earthquake design loads, and the installed equipment, are critical compared to wind loads. For a greenhouse, this will depend on the location and mass of the structure and its equipment compared to the exposed areas that the building presents.

7.3 Other Loads

7.3.1 Flood and hydrostatic

7.3.1.1 Soil and hydrostatic pressure and flood loads - Local regulations will identify flood design zones. Whether such criteria are critical for a greenhouse will depend on FEMA and local requirements.

7.3.2 Other Loads

Other design factors the engineer should consider in individual structures include:

- Thermal expansion and the need for joints
- Rainwater



Module 6. Construction materials and methods of construction

Lesson 8 Construction Material

8.1 INTRODUCTION

In greenhouses, the choice of structural materials is linked to: (i) their availability and cost; (ii) their technical characteristics depending on the greenhouse to be built (use of wood, steel); (iii) the performance required by the greenhouse depending on the crops to be grown; (iv) the local climate; and (v) the local conditions in terms of experience and creativity. The materials commonly used to build frames for greenhouse are Wood, Bamboo, Steel, Galvanized iron pipe, Aluminum and Reinforced concrete (RCC). The selection of above materials is based on their specific physical properties, requirements of design strength, life expectancy and cost of construction materials.

8.2 WOOD

Wood and bamboo are generally used for low cost poly-houses with straight roof structure (fig 8.1) due to difficulty and high cost associated with its use on curved sections. In low cost poly-houses, 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 poly-houses, 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.



Fig 8.1 Wooden framed greenhouse

(Source: Nicolas Castilla, 2013)

8.3 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. For multi-tunnel greenhouses, metallic structures prevail (a predominance of galvanized steel, due to the high cost of aluminium;) or a mixture of materials (wood-wire, steel-wire, steel-wood, steel-concrete) are used over wooden structures.

Steel structures (Fig 8.2), which are normally more expensive than wooden structures, allow for a reduction in the number of interior pillars (relative to wood), easing the interior manoeuvrability (passage of machinery, implementation of thermal screens) and creating fewer shadows than wood, increasing the available light. In addition, steel structures are easier to assemble than wood, have more accessible roof ventilation mechanisms and are more airtight, although the higher heat conduction of metal weakens these advantages.

Reinforced concrete structures are not common. RCC is generally limited to foundations and low walls. In permanent bigger greenhouses, floors and benches for growing the crops are made of concrete.



Fig 8.2 Greenhouse with steel structure

(Source: www.poly-tex.com)

8.4 GLASS

Glass has been traditional glazing material all over the world (Fig 8.3). Widely used glasses 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.



Fig. 8.3 Glass greenhouse

(Source: www.gothicarchgreenhouses.com)

8.5 POLYETHYLENE FILM

Polyethylene is principally used today for two reasons- (i) Plastic film greenhouses with permanent metal frames (Fig 8.4) 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 up to a max. of 91.5 m. Condensation on polyethylene film is a big problem. Condensation causes disease development, development of water logged condition and oxygen deficiency 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 photo synthetically active radiation (PAR) into the greenhouse. IR absorbing polyethylene, reduces radiant heat loss, transmits about 82% of photo synthetically 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.



Fig 8.4 Polyethylene Greenhouse

(Source: www.poly-ag.com)

8.6 Polyvinyl chloride film (PVC films)

PVC films (fig 8.5) 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 up to 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.



Fig 8.5 PolyVinyl Chloride films

8.6 Tefzel T² film

The most recent addition of greenhouse film plastic covering is Tefzel T² 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% (0.95×0.95). Tefzel T² 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.



Fig 8.6 ETFE greenhouse (Eden project, Cornwall, England, 2001)

8.7 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.

8.8 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 this light intensity is rather uniform throughout the greenhouse in comparison with a glass covering. Disadvantages 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, whereas 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 roof 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.



Fig 8.7 Acrylic and polycarbonate rigid panel greenhouses

Lesson 9 Methods of construction

9.1 INTRODUCTION

At one time, greenhouses were constructed exclusively of cypress wood frames and single glass lites. Recent years have seen substantial changes in construction techniques and materials. In general, construction may be considered to fall into one of the following four categories:

1. Glass
2. Plastic film
3. Fiberglass or similar rigid plastics
4. Combination of two and three.

All of the above are generally constructed of steel or aluminum frames.

Glass greenhouses are the most expensive to construct because of both the cost of the glazing material and the requirement for a stronger framework to support the glass. In many cases, fiberglass panels are employed on the side and end walls of the structure. The building profile is generally of peaked design, with 36 and 42 ft widths, and lengths in 20 ft increments most common. This type of greenhouse is preferred by growers whose plants require superior light transmission qualities. In addition to offering the highest light quality, the glass greenhouse also has the poorest energy efficiency. Heating costs are high because of the poor insulating quality of single glazing and the high infiltration of cold air through the many "cracks" in the construction. This issue of high transmission loss has been addressed in recent years through the introduction of new, double glazing panels for glass houses. However, because of the expense of these panels and their effect upon light transmission, most glass greenhouses remain single layer.

Plastic film greenhouses are the newest variation in greenhouse construction techniques. This type of structure is almost always of the arched roof or "quonset hut" design. The roof can come all the way down to the ground or can be fitted with side walls. The side walls, if employed, and end walls are generally of fiberglass construction. Maintenance requirements for the plastic film are high in that it generally requires replacement on 3-year intervals or less, depending on the quality of the material. Most plastic film houses employ a double layer of film separated by air space. The air space is maintained by a small blower that pressurizes the volume between the layers. This double poly design is a very energy efficient approach to greenhouse design. Double poly not only reduces transmission losses (losses through the walls and roof) by 30 to 40%, but also substantially reduces infiltration (in leakage of cold air). Although the plastic film tends to lose more heat than glass through radiation, the net effect is a reduction in heating requirements compared to glass construction. Infiltration is reduced because the "cracks" present in other types of

construction are eliminated through the use of the continuous plastic film. As a result, there is less opportunity for the cold outside air to penetrate the structure. The superior energy efficiency of the film construction comes at the price of reduced light transmission, however. As a result, highly light sensitive crops cannot be grown in the double-poly greenhouse as successfully as in other constructions. These greenhouses are generally constructed in 30 ft width, and 100 and 150 ft lengths.

Fiberglass greenhouses are similar in construction to the glass houses described above. They are generally of peaked roof design, but require less structural support as a result of the lower weight of the fiber glass. Heat loss of the fiberglass house is about the same as the glass house. Although the fiberglass material has a lower conductivity than glass, when considered in the overall building heat loss, this has little effect.

9.2 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.

9.2.1 Material requirement

The structural members of greenhouse are

- (a) Hoops
- (b) Foundation
- (c) Lateral supports
- (d) Poly grip 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 Nos.)
- 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 m³)
- vii. UV- stabilized LDPE film (single layer 800 gauge, 5.4 m²/kg, 154 m²)

- viii. Poly grip (channel 2000× 3.5× 4 cm, 2 Nos.; Angle 2000 ×2 ×2 cm, 2 Nos; 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 m³)
- x. Nuts and bolts 96 mm diameter, 35 mm long, 70 sets)
- xi. Miscellaneous items like nails, hinges and latches as per requirement

1. Mark a $4\text{m} \times 20\text{m}$ rectangular area 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 bay; 17 points). The same procedure is repeated on the other side of the rectangle.
4. Dig 10 cm diameter holes up to 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. Poly grip sections formed according to the drawing into two 20m length.

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6. Fix the prefabricated poly grip channels to the foundation pipes at 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 a way that straight portion of hoop is inserted into the foundation and rests on the bolt used for fixing of poly grip 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 centre to centre. 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 poly grip 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 poly grip. 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.

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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.



Module 7. Covering material and characteristics

Lesson-10 Greenhouse Covering

10.1 INTRODUCTION

One of the most important parts of a greenhouse facility is the covering. Since sunlight is generally the limiting factor in wintertime greenhouse production, a covering that transmits maximum sunlight in the plant growth spectrum is essential. Physical durability and optical stability are other critical factors. Several types of covering materials are presently available. Which one is best, or most economical over the long term, is not easy to state. Glass has been the long-time standard and is still the most stable but other film and rigid plastic materials are offering lower cost coverings but with varying levels of dependability and life.

10.2 FACTORS TO BE CONSIDERED WHILE SELECTING GREENHOUSE COVERINGS

10.2.1 Performance

Plants respond best to diffused light. If you're looking for the greenhouse covering that will give you the best, most dynamic plant growth, you should consider greenhouse covering that provides optimal light diffusion. Greenhouse coverings which provide less light diffusion increases chances for burning and can cause the greenhouse to overheat.

10.2.2 Climate

If you live in a cool climate, greenhouse insulation is very important. In order to provide good insulation, the greenhouse plastic must be twin-walled. Because of this, twin-walled Solexx and polycarbonate greenhouse covering make good materials for people concerned with both cold weather and substantial snow loads. However, if you live in a warmer climate, it is important to ensure that your greenhouse covering will not let your plants burn from intensely concentrated light. Light diffusion is crucial to preventing plant sun burn. If you are hoping to grow during the summer months, avoid single-walled or twin-walled polycarbonate, which easily overheat.

10.2.3 Appearance

For many people, the desire to see in and out of the greenhouse is important. In this case, polycarbonate greenhouse covering is the best option because it is the most transparent. It is important to note that polycarbonate does wear over time, so if you want your greenhouse to remain looking like new it needs to be washed with a soft cloth periodically and kept clear of anything that may cause scratches.

10.2.4 Longevity and Cost

Replacing a greenhouse covering can be a hassle, so it is important to choose something long-lasting. Polycarbonate, typically the most expensive greenhouse covering, has a warranty

period of about ten years, depending on the manufacturer. Although it is quite long-lasting, it can be difficult to replace because polycarbonate sheets come in limited sizes and are not easily cut. Therefore, you may be unable to find polycarbonate replacement sheets suitable for your particular greenhouse. Polyfilm plastic is a common greenhouse covering for people covering large greenhouses that are only being used seasonally. Although it is relatively inexpensive, it needs replaced yearly to every few seasons and is tears easily in wind and hail.

The covering material used on a greenhouse influences the productivity and performance of a structure. It impacts on the level and quality of light available to the crop. Diffused light is better than direct light. Fluorescent and pigmented films can increase the proportion of good red light. Dust, attracted to plastic films, will reduce the transmission of radiation. Water droplets on the inside of coverings have been shown to reduce light transmission by 8% and will also block thermal radiation.

Greenhouse coverings all reduce light to some extent. As coverings become dirty and as they get older, less light enters the greenhouse. Condensation (water drops) on the covering material also reduce light. Light coloured materials in the greenhouse, such as white weed matting, increase the light available to the crop.

Key characteristics that should be considered in selecting a covering material are the cost, its durability (how long it lasts), its weight and ease of repair or replacement, how much light is transmitted through the material and how much energy moves through the material.

Diffusing materials are designed to scatter incoming light and result in better light conditions for crops e.g. a cloudy white plastic film diffuses light better than a clear plastic film.

10.3 TYPES OF GREENHOUSE COVERINGS

10.3.1 Glass

Glass has long been the traditional covering. Its favorable properties include:

- High transmission in the photo synthetically active radiation (PAR) bandwidth
- Good heat retention at night
- Low transmission of UV light
- Durability
- Low maintenance costs

The biggest draw-back of glass is the initial cost, though it has been demonstrated that over a period of time (10+ years) the cost of glass compares favourably with other materials.

10.3.2 Plastic Sheeting

Essentially there are three materials in this category - polycarbonate, acrylic (polymethyl methacrylate) and fibre glass. Sheeting products are more durable than plastic films and have

fairly good heat retention, good initial transmission in the PAR range and low UV light transmission.

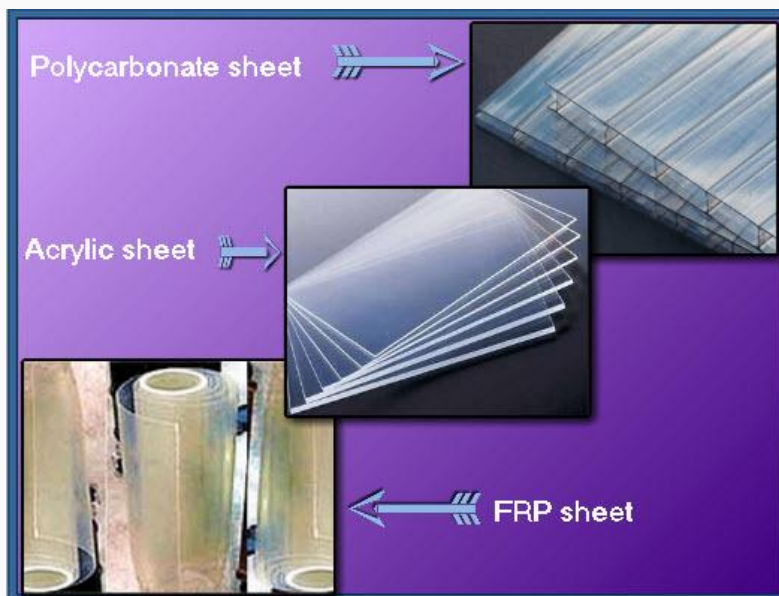


Fig 10.3.1 Plastic sheets used for greenhouse covering

(Source: www.e-tplastics.com, www.ebay.co.uk, www.gothicarchgreenhouses.com)

10.3.3 Plastic films

Films are the most common and lowest cost type of covering material. The types of film available are polythene (polyethylene), EVA (ethyl vinyl acetate) and PVC (poly vinyl chloride). With the constant improvements in plastics, these covering materials offer a lot of flexibility and performance options. Coverings can have a variety of additives which are used to give plastic films useful properties. For example, films may be used to exclude ultra violet (UV) light for chemical free pest control or reflect long wave infra- red (IR) radiation to improve heat retention at night. As a result, some plastic covering materials are coloured or tinted.

Additives to the plastic determine its;

- Durability
- Capacity to reduce heat loss
- Capacity to reduce droplet formation
- Transmission of particular wavelengths of light
- Capacity to reduce the amount of dust sticking to the film.

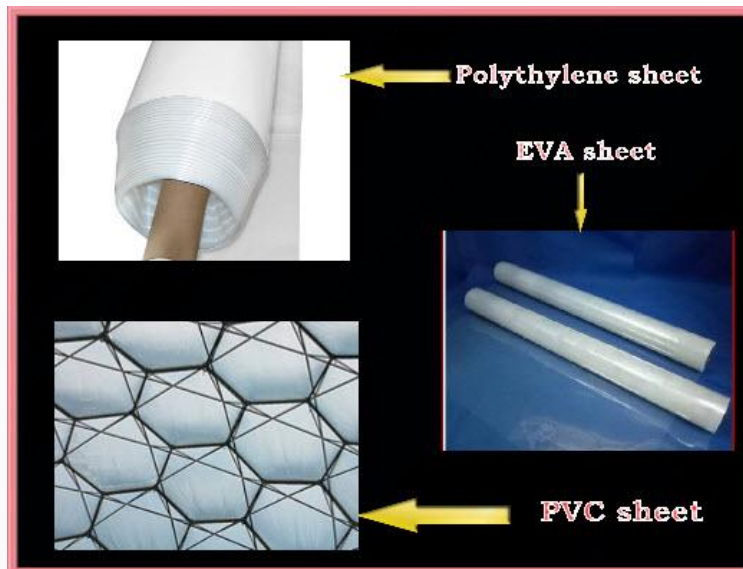


Fig 10.3.2 Plastic films

(Source: www.greenhousemegahouse.com, www.tarimasal.com, www.evafilm.org)

Types of Additives

1. UV (290-400 nm) absorbers and stabilizers increase durability, reduce the potential damage to biological systems in the greenhouse and may control some plant pathogens.
2. Infrared (700-2500 nm) absorbers reduce long wave radiation and minimize heat loss.
3. Long wave radiation (2500-40000 nm) absorbers reduce the loss of heat radiated from materials and objects (including plants) inside the greenhouse.
4. Light diffusers scatter light entering the greenhouse, reducing the risk of plants getting burnt and improving the amount of light available to the lower parts of the plant.
5. Surfactants reduce the surface tension of water, dispersing condensation.
6. Antistatic agents reduce the tendency of dust to accumulate on plastic films.

In addition,

1. Colour pigments may improve plant growth by altering the proportion of selected wavelength ranges.
2. Fluorescence may be used to increase the emission of red light.
3. Glossy surfaces may repel insects.

The process of making multilayer films enables thin layers of materials with different properties to be joined to make superior composite films.

Properties such as durability, creep (deformation over time) and long wave radiation absorption can be improved.

10.3.4 PROTECTIVE SCREEN FABRICS

There are a number of different materials in this category.

10.3.4.1 Shade cloth:

- Reduces the amount of solar energy entering the greenhouse, which lowers plant stress
- Reduces light intensity
- Will protect structures from hail damage.

If shading is required, pale coloured materials should be used as these uniformly reflect solar radiation. A range of products exist that offer shading from 30% up to almost total blackout. Whitewash paints are another option that can be applied to reduce the amount of radiation entering the greenhouse.



Fig 10.3.4 Shade cloth

(Source: www.rrpolynet.com)

10.3.4.2 Solar and thermal screens:

- Reduce the amount of solar radiation incident on the crop or
- Prevent the escape of long wave radiation from the greenhouse and trap warm air.

The first use allows some radiation to penetrate and reflects the rest. This is used for temperature control during the day. The second type retains energy within the greenhouse and is used at night. Thermal screens are typically drawn over the crop or structure when needed.



Fig 10.3.4 Thermal screens

(Source: www.growsave.co.uk)

10.3.4.3 Insect-proof screens:

- Exclude insect pests, reducing the need for chemicals.

Restricted airflow is the main disadvantage. The type of screen used will depend on the insects to be excluded, for example, thrips require the finest sized screen. Plastic screens eventually suffer from the same UV deterioration as plastic films.

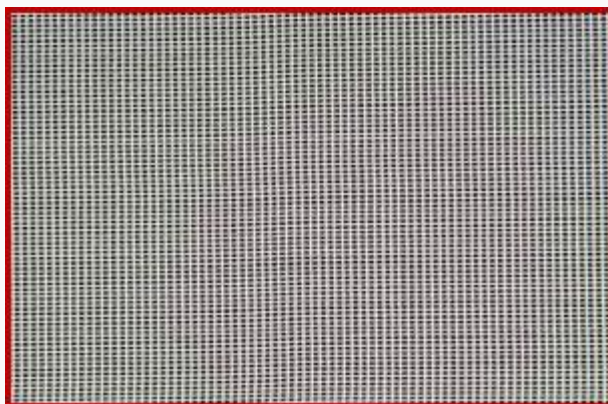


Fig 10.3.5 Insect proof screens

(Source: www.greenhousemegastore.com)

10.4 MAINTENANCE OF GREENHOUSE COVERINGS

A poorly maintained covering material can lose a lot of energy and significantly increase production costs. Glass coverings should be kept clean and broken panels should be replaced. Plastic coverings need to be replaced routinely. The performance of plastic coverings declines over time. Old coverings reduce light transmission which can restrict

yield. The useful life of plastic films depends on the specifications of the plastic purchased. All plastic covering materials need to be replaced before they visibly start to break down; discoloration, for instance, is an early indication of wearing.

10.5 PROPERTIES OF THE IDEAL GREENHOUSE COVERING MATERIAL

- 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 111 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. It should be of minimum cost.
- v. It should have usable life of 10 to 20 years.



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Module 8. Solar heat transfer

Lecture 11 Solar Radiation

11.1 INTRODUCTION

The sun is a sphere of intensely hot gaseous matter, continuously generating heat by thermo-nuclear fusion reactions, which convert hydrogen atoms to helium atoms. This energy is radiated from the sun in all directions and a very small fraction of it reaches the earth.

11.2 THE EARTH AND THE SUN

Earth receives radiant energy from sun which is vast and hot mass of hydrogen and helium gases in the proportion of 3:1. In the sun, energy is generated in its central core which may be considered as a giant nuclear reactor.

The sun rotates about its axis but not as a rigid body. The period of rotation varies from about 25 earth days at its equator to about 27 days at 40° latitude. The structure of the sun (Fig 11.1) is generally divided into three regions-solar interior, the photosphere and the solar atmosphere.

The upper layer of convective zone is called the photosphere and it is our source of light and heat. Above the photosphere there is transparent layer of rarefied gas 10000km thick. It is known as the chromosphere because of its red colour resulting from the strong H_a line of hydrogen in the spectrum of the layer, a continuous band of low intensity mainly caused by the scattering of solar radiation. Finally, there is the corona, a whitish glowing layer that may be observed in all in beauty only during total solar eclipses.

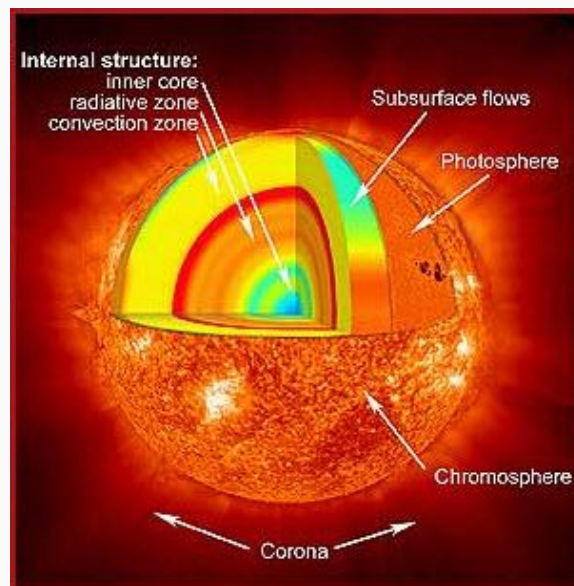


Fig 11.1 Structure of sun

(Source: www.solarviews.com)

The characteristics of the sun and its spatial relationship to the earth result in a nearly fixed intensity of solar radiation outside the earth's atmosphere. (Fig 11.2) shows schematically the geometry of the sun-earth relationship. The distance between the earth and the sun varies by $\pm 3\%$ and the radiation incident varies inversely with the square of the earth-sun distance, the earth receives about 7% more radiation when it is nearest to the sun. The sun subtends an angle $32'$

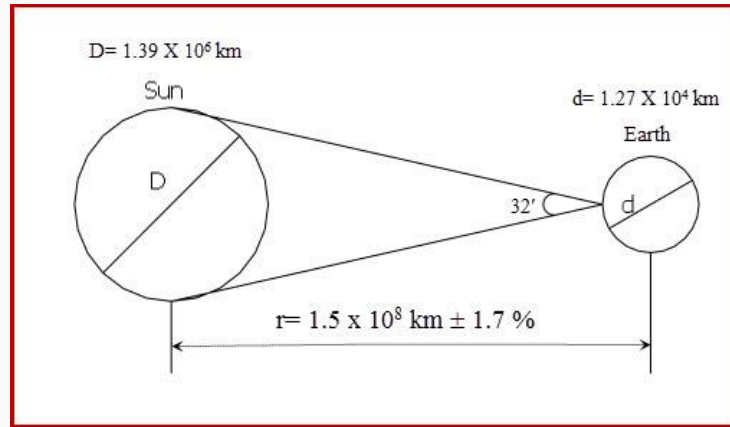


Fig 11.2 Schematic of sun earth relationship

The Solar Constant (I_{sc}): The total energy received from the sun, per unit time, on a surface of unit area kept perpendicular to the radiation, in space, just outside the earth's atmosphere when the earth is at its mean distance from the sun. The value of the solar constant has been measured by various investigators to range from 1350 to 1382 W/m^2 . Arbitrarily value of the solar constant is taken as 1353 W/m^2 .

11.3 SOLAR RADIATION AT THE EARTH'S ATMOSPHERE

For utilization of solar energy we are more interested in the energy received at the earth's surface than in the extra-terrestrial energy. In order to study solar radiation received at the earth's surface following terms need to be studied.

- **Beam solar radiation:** The portion of the incident solar radiation which comes directly from the apparent solar disc, without reflection from other objects, is called direct or beam radiation. These radiations are received from the sun without change in direction.
- **Diffuse radiation:** The solar radiation which is received from the sun after its direction has been changed by reflection and scattering by the atmosphere. It is defined as the solar radiation scattered by aerosols and dust molecules. It does not have a unique direction.
- **The total solar radiation or global solar radiation:** All solar radiation incident on a surface including scattered, reflected, and direct. Total solar radiation does not include radiation that has been absorbed by matter and then re-emitted because most of this radiation is at longer wavelengths 3 mm.

- **Sun at Zenith:** Position of the sun directly overhead
- **Air mass (m):** It is the path length of radiation through the atmosphere considering the vertical path at sea level as unity.
- **Attenuation of beam radiation:** The variation in solar radiation reaching the earth than received at the outside of the atmosphere is due to absorption and scattering in atmosphere.
- **Absorption:** As solar radiation passes through the atmosphere the short wave ultraviolet rays are absorbed by the ozone in the atmosphere and the long wave infrared waves are absorbed by the carbon dioxide and moisture in the atmosphere and long wave infrared waves are absorbed by the carbon dioxide and moisture in the atmosphere. This results in the narrowing of the band width.
- **Scattering:** As solar radiation passes through the earth's atmosphere, the components of the atmosphere, such as water vapour and dust, scatter a portion of the radiation. A portion of this scattered radiation always reaches the earth's surface as diffuse radiation. Thus the radiation finally received at the earth's surface consists partly of beam radiation and partly of diffuse radiation.

11.4 BASIC EARTH SUN ANGLES

- **Celestial sphere:** Considering the sky in the clear night, it appears that the stars, planets, moon etc. are all located at the same distance away from the observer. The sky may conveniently be assumed to be a large sphere. This imaginary sphere is called the celestial sphere.

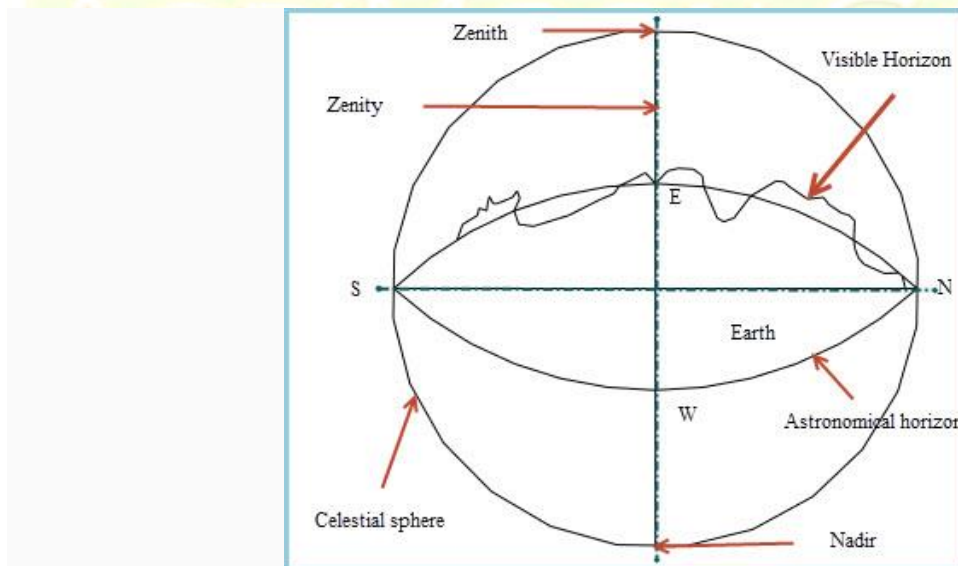


Fig 11.3 Basic Earth Sun angles

- **Zenith:** Zenith is a point on the celestial sphere directly over the observer's head. The zenith would change with respect to the location.

- **Nadir:** The point of the celestial sphere diametrically opposite to the zenith. Nadir would also change with respect to the location. Unlike zenith nadir is not visible.
- **Visible Horizon:** It appears to be an observer that the celestial sphere meets the ground, the location of this apparent meeting is called the visible horizon.
- **Astronomical Horizon:** Because visible horizon is uneven, so we cannot define a location in the sky with reference to it. It is therefore necessary to define a horizon, the same distance away from the zenith. It is an even circle which may be either below or above the horizon. This is shown as astronomical horizon and can be obtained by manage in all directions from the zenith, an angular distance of 90° .
- **Poles of the earth:** The ends of the axis of rotation of the earth mark two important points on the earth's surface. They are called the poles of the earth, one as North, while the other as South.
- **Earth's equator:** It is an imaginary great circle normal to the earth's axis dividing the distance between the earth's poles among its surface into two equal parts. The equator divides the earth into two hemisphere called Northern and Southern hemispheres.
- **Meridian:** It is necessary to select some reference location on the earth for locating a particular position. The location of the Royal Laboratory Greenwich, outside of London has been universally accepted as a reference point. An imaginary great circle passing through this point and the two poles, intersecting the equator at right angles, is called the prime (Greenwich) meridian.
- **Longitude:** It is the angular distance of the location, measured east or west from the prime meridian.

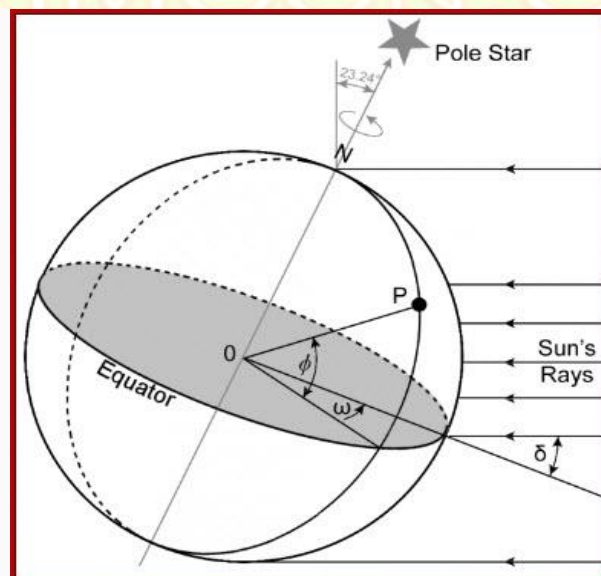


Fig 11.4 Latitude, hour angle and sun's declination

(Source: www.itacanet.org)

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The fundamental angles are shown in fig 11.4. The position of point P on the earth's surface with respect to the sun's rays is known at any instant if the latitude (ϕ) and hour angle (ω) for the point, and the sun's declination (δ) are known.

The latitude (ϕ) of a point on the surface of the earth is, its angular distance north or south of the equator measured from the centre of the earth.

The hour angle (ω) is the angle through which the earth must turn to bring the meridian of a point directly in line with the sun's rays.

The sun's declination (δ) is the angular distance of the sun's rays north (or south) of the equator. It is the angle between a line extending from the centre of the sun to the centre of the earth, and the projection of this line upon the earth's equatorial plane.

The declination, in degrees, for any given day may be calculated from the approximate equation of Cooper (1969)

$$\delta = 23.45 \sin \left[360 \times \frac{284 + n}{365} \right]$$

Where, n is the day of the year.

11.5 DETERMINATION OF SOLAR TIME

Time as measured by apparent diurnal motion of the sun is called apparent solar time or solar time. It is that would be shown by solar dial whereas a civil day is precisely 24 hours, a solar day is slightly different due to irregularities of the earth's rotation, obliquity of the earth orbit and other factors, in other words due to elliptical shape of the earth's orbit and to its increase in velocity at the perihelicon, the length of the apparent solar day i.e. the interval between two successive passages of the sun through the meridian, is not constant. Local civil time may deviate from true solar time by as much as 4.5° because even if the length of any apparent solar day and its corresponding mean solar day differ little, the effect is cumulative.

The difference between local solar time and local civil time is called the equation of time. Thus,

$$\text{LST} = \text{LCT} + \text{Eq. of time}$$

Local civil time can be derived from the Indian standard time with the help of the following equation:

$$\text{LCT} = \text{Standard time} \pm (L_{\text{st}} - L_{\text{local}}) \times 4$$

And solar time

$$LST = \text{standard time} + E \pm (L_{st} - L_{local}) \times 4$$

(+sign for west and – sign for east)

Where,

E= the equation of time in minutes

L_{st} = the standard meridian for the local time zone

L_{local} = the longitude of the location in question in degrees east or west.

Positive sign is for western and negative sign for eastern hemisphere. Hence for India, negative sign is taken and hence equation becomes

$$LST = \text{Indian standard time} + E - (L_{st} - L_{local}) \times 4$$

11.6 DERIVED SOLAR ANGLES

1. Altitude angle (α) : It is a vertical angle between the projection of the sun's rays on the horizontal plane and the direction of sun's rays (passing through the point)

2. Zenith angle (q_z) = It is complementary angle of sun's altitude angle. It is the vertical angle between the sun's rays and line perpendicular to the horizontal plane through the point i.e. the angle between the beam from the sun's rays and a line perpendicular to the horizontal plane through the point, i.e. the angle between the beam from the sun and the vertical.

3. Solar azimuth angle (g_z): It is solar angle in degrees along the horizon east or west of north or it is a horizontal angle measured from north to the horizontal projection of the sun's rays this angle is positive when measured westwise.

4. Surface azimuth angle (g): It is the angle of deviation of the normal to the surface from the local meridian, the zero point being south, east positive and west negative

5. Incident angle (q): It is the angle being measured between the beam of rays and normal to the plane.

6. Slope (s): The angle between the horizontal and the plane

11.7 SUNRISE, SUNSET AND DAY LENGTH

At the time of sunrise (or sunset), the zenith angle, $q_z = 90^\circ$.

Sunrise hour angle,

$$\omega_s = \cos^{-1}(-\tan \phi \tan \delta), \text{ hours}$$

The day length is

$$T_d = \frac{2}{15} \cos^{-1}(-\tan\phi \tan\delta), \text{hours}$$

11.8 SOLAR ENERGY MEASURING EQUIPMENT

1. Pyrheliometer: A pyrheliometer is an instrument for measuring the intensity of direct solar radiation at normal incidence; it can either be a primary standard instrument or secondary instrument scaled by reference to a primary instrument. It is a small telescope like device mounted on a drive mechanism that causes it to follow the sun throughout the day.



Fig 11.5 Eppley Pyrheliometer

(Source: www.lampes-et-tubes.info)

2. Pyranometer: A pyranometer is an instrument for the measurement of the solar radiation received from the whole hemisphere. It is suitable for the measurement of the global or sky radiation usually on a horizontal surface.



Fig 11.6 Pyranometer (Make Kipp & Zonen)

(Source: www.kippzonen-blog.nl)

3. Pyrgeometer: A pyrgeometer is an instrument for measurement of terrestrial radiation only.



Fig 11.7 Pyrgeometer

(Source: <http://en.wikipedia.org>)

4. Pyradiometer: A pyradiometer is an instrument for the measurement of both solar and terrestrial radiation, i.e. for net atmospheric radiation on a horizontal upward facing black surface at the ambient air temperature



Fig 11.8 Pyradiometer

(Source: www.eko-eu.com)

5. Sunshine Recorder: Sunshine recorder is used to measure the duration in hours of bright sunshine during the course of the day. It essentially consists of a glass sphere mounted in a section of spherical brass bowl with grooves for holding the recorder cards. The sphere burns a trace on the card when exposed to the sun, the length of trace being a direct measure of duration of bright sunshine. There are set of grooves for taking three sets of cards, long curved for summer, short curved for winter and straight cards at equinoxes.



Fig 11.9 Campbell-stokes Sunshine recorder

(Source: <http://en.wikipedia.org>)

Lecture 12 Heat Transfer for Solar Energy Utilization

12.1 INTRODUCTION

To estimate the size, the efficiency and cost of equipment necessary to transfer a specified amount of heat in a given time, a heat transfer analysis must be made. The dimension of solar collector depends not so much on the amount of heat to be transmitted but rather on the rate at which heat is to be transferred under given external conditions. From engineering point of view, the determination of rate of heat transfer at a specified temperature difference is the key problem in sizing a solar collector.

Heat transfer occurs mainly by three mechanisms viz. conduction ,convection and radiation (Fig.12.1) The heat transfer may be accompanied by other physical phenomena such as heat generation within the medium, vapour condensation, liquid evaporation etc.

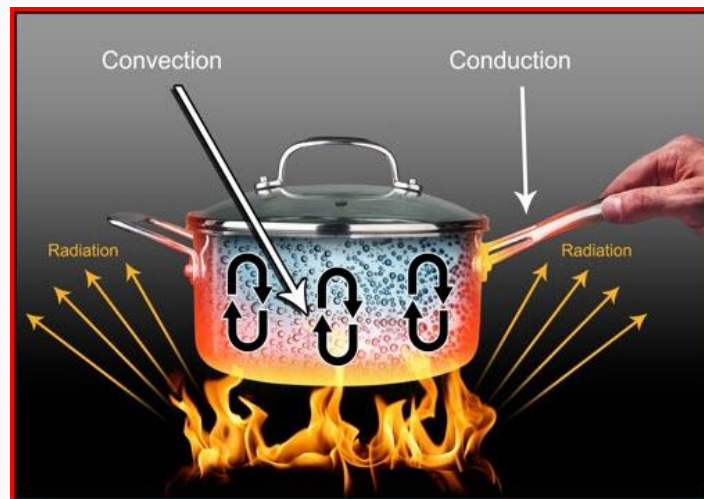


Fig 12.1 Mechanism of heat transfer

(Source: www.spectrose.com)

12.2 CONDUCTION

The heat transfer takes place between the objects that are in direct contact with each other. For example, when you place a pot on the stove, the hot coils come in contact with the metal pan, making it hot.

The basic heat conduction equation is:

$$q = -K_x A \frac{\delta T}{\delta x}$$

..... (12.2.1)

Where,

q is the rate of heat transfer

K_x is the thermal conductivity of the material in the direction x

A is the area normal to the direction of heat flow and

$\delta T / \delta x$ is the temperature gradient in the direction of flow

12.3 RADIATION

Radiation is a process by which heat flows from a body at higher temperature to a body at lower temperature when the bodies are separated in space or even a vacuum exists between them. The term radiation is generally applied to all kinds of electromagnetic wave phenomena, but in heat transfer only those phenomena that are the result of temperature and can transport energy through a medium such as air or space are of interest. The energy transmitted in this way is called radiant heat. Radiation is the mode of heat transfer by which the sun transfers energy to the earth. The quantity of energy leaving a surface as radiant heat depends on the absolute temperature and the nature of the surface. A perfect radiator, so called black body emits radiant energy from its surface at a rate q given by

$$q = A\sigma T^4 \quad \text{.....(12.3.1)}$$

Where,

A is area of the body

T is the absolute temperature $^{\circ}\text{K}$

σ is a constant known as Stefan Boltzmann Constant

$$= 487.6 \times 10^{-10} \text{ kcal/m}^2.\text{hr.K}^4$$

$$= 56.7 \times 10^{-9} \text{ W/m}^2.\text{K}^4$$

Real bodies do not meet the specifications, of an ideal radiator and emit radiation at lower rate than do black bodies. The ratio of the radiation emission of a real body to the radiation emission of a black body at the same temperature is called the emittance. Thus a real body emits radiation at a rate

$$q = \epsilon A\sigma T^4 \quad \text{.....(12.3.2)}$$

where ϵ is the average emittance of the surface.

If radiation exchange takes place between two grey bodies e.g. two large, parallel plates with areas A_1 and A_2 the rate of heat transfer between them is given by,

$$q_{r \text{ net}} = A_1 F_o (T_1^4 - T_2^4) \quad \text{.....(12.3.3)}$$

where F is the geometrical factor of the surface with respect to the other.

Equation for radiant heat transfer can be written as

$$q_{r \text{ net}} = \frac{T_1 - T_2}{R_r} \dots\dots\dots(12.3.4)$$

where the resistance to radiation heat transfer is

$$R_r = \frac{1}{A_{12} F \sigma (T_1^2 + T_2^2)(T_1 + T_2)} \dots\dots\dots(12.3.5)$$

For example, for infra- red radiation between two parallel, large, flat plates of the same area with emittance e_1 and e_2

$$F_{12} = \frac{1}{\left[\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2}\right] - 1} \dots\dots\dots(12.3.6)$$

For simplification of linear equation radiant heat transfer coefficient h_r is given by,

$$q = h_r (T_1 - T_2) \dots\dots(12.3.7)$$

then it is clear that,

$$h_r = \frac{\sigma(T_1^2 + T_2^2)(T_1 - T_2)}{\left[\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2}\right] - 1} \dots\dots(12.3.8)$$

Reception of radiant energy: Radiation impinging on the surface of a body may be partly absorbed, partly transmitted and partly reflected as shown in fig 12.2

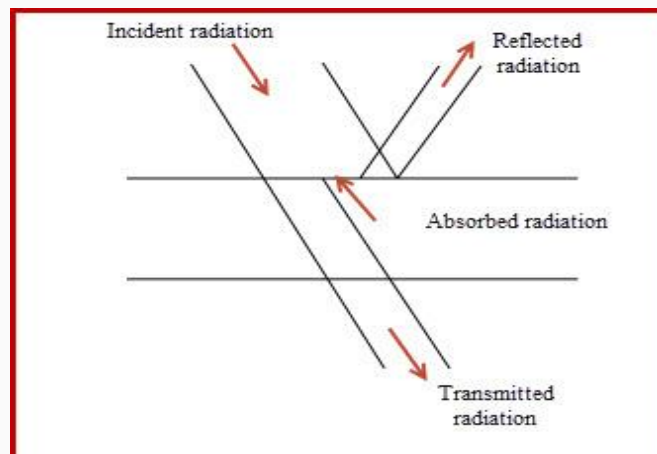


Fig 12.2 Total radiation utilized in different ways

The fraction of the incident radiation absorbed is called the absorptivity a . Similarly, the fraction of the incident radiation reflected is called as the reflectivity, r and the fraction transmitted is called as transmissivity, t .

If I denotes the total incident radiation per unit time per unit area of surface, and I_a , I_r and I_t , represent respectively the amount of radiation absorbed, reflected and transmitted then,

$$\alpha = \frac{I_a}{I} \quad \dots\dots(12.3.9)$$

$$\rho = \frac{I_r}{I} \quad \dots\dots(12.3.10)$$

$$\tau = \frac{I_t}{I} \quad \dots\dots(12.3.11)$$

Also, $I_a + I_r + I_t = I$

Hence $a + r + t = 1 \quad \dots\dots(12.3.12)$

The relationship given in equation (12.3.12), hold for surfaces or for layers of finite thickness. The following points are to be noted:

- i. The values of a , r and t are always positive and lie between the limits 0 and 1 i.e. $0 \leq r, t, a \leq 1$
- ii. $r=0$ (i.e. $t+a=1$) represents a non-reflecting surface, $r=1$ (i.e. $t= a=0$) represents perfect reflector.
- iii. $t=0$ (i.e. $r+a =1$) represents an opaque surface, $t=1$ (i.e. $r = a=0$) represents a perfectly transparent surface.
- iv. $a=0$ (i.e. $r+t =1$) represents non absorbing surface, $a=1$ (i.e. $r=t=0$) represents perfectly absorbing surface.

12.4 REFLECTIVITY

Reflectivity of opaque surface depends not only on the temperature and the properties of the surfaces but also on the wavelength and directions of the incident and reflected radiation. Based on the nature of the reflected radiation, reflecting surfaces may be classified as diffuse or specular.

Diffuse reflector: A surface is called diffuse reflector if intensity of the reflected radiation is constant, for all angles of reflection and is independent of the direction of the incident radiation.

Specular reflector: If the incident and reflected rays lie symmetrically with respect to the normal to the surface at the point of incidence and the reflected beam is contained in a solid angle equal to the solid angle of the incident beam.

Rough surface behaves like a diffuse reflector where as polished metallic surface behave like a specular reflector. No real surface is either perfectly diffuse to perfectly specular.

White surface: A diffuse surface which reflects all incident energy (i.e. $r=1$), is termed as a white surface.

Non Reflecting surface: if $r=0$ it is non- reflecting surface.

Opaque surface: If $r=0$, $t=0$ and $a=1$ then it is opaque surface.

Black surface: Surface which absorbs all incident energy is called as a black surface. Black surface is extensively used in radiation heat transfer work as an idealized body with which the radiation characteristics of real bodies can be conveniently compared.

12.4.1 Reflectivity of translucent materials: Since in most applications there will be a slab of materials involving two faces, reflection at both faces shall have to be considered.

12.4.1.1 Reflection at interfaces: Fresnel has given the relationship for the reflection of non-polarized radiation on passing from one medium to another. (Fig. 12.4.1).

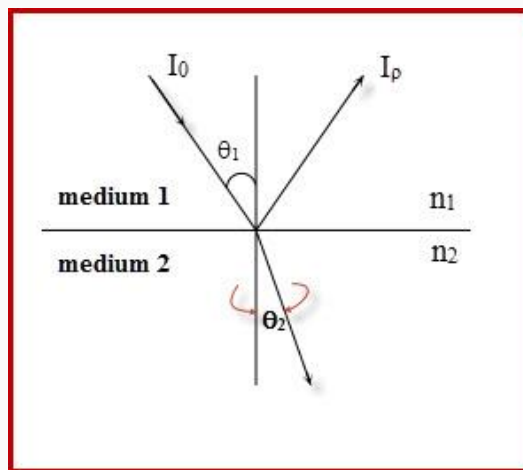


Fig 12.4.1 Angle of incidence and reflection in two media.

$$\frac{I_p}{I_0} = \rho = \frac{1}{2} \left[\frac{\sin^2(\theta_2 - \theta_1)}{\sin^2(\theta_2 + \theta_1)} + \frac{\tan^2(\theta_2 - \theta_1)}{\tan^2(\theta_2 + \theta_1)} \right] \quad \dots\dots\dots(12.4.1)$$

Where,

θ_1 is the angle of incidence

θ_2 is the angle of refraction

In the expression the two terms in the square brackets represent the reflection for each of the two components of polarization. The angles θ_1 and θ_2 are related to the indices of refraction.

$$\frac{n_1}{n_2} = \frac{\sin \theta_2}{\sin \theta_1} \dots\dots\dots(12.4.2)$$

Thus if the angle of incidence and refraction indices are known from equation (12.4.2) one can calculate the reflectance of the single interface.

For radiation at normal incidence,

$$\theta_1 = \theta_2 = 0,$$

Combining equation 12.4.1 and 12.4.2 gives

$$\rho = \frac{I_p}{I_0} = \left[\frac{(n_1 - n_2)}{(n_1 + n_2)} \right]^2 \dots\dots\dots(12.4.3)$$

12.5 TRANSMISSIVITY

Transmissivity like reflectivity and absorptivity, is a function of the wavelength and the angles of incidence of the incoming radiation. Other variables which effect the transmissivity are the refractive index n and tile extinction coefficient k of the medium but strictly speaking, both n and K are also functions of the wavelength λ .

For $t=1$, the medium is perfectly transparent however, most real materials are only partially transparent with $0 < t < 1$.

Transmissivity in partially transparent (i.e. translucent) materials is dependent both upon the reflection and absorption of radiation. The problem is usually tackled in two stages:

- i. The transmissivity ' t_r ' is first calculated considering reflection alone.
- ii. The transmissivity ' t_a ' is then calculated considering absorption alone.

The transmissivity τ , allowing for both reflection and absorption is then given by,

$$\tau = \tau_p, \tau_a \dots\dots\dots(12.5.1)$$

It is found that the equation (12.5.1) is a satisfactory relationship for use in the design of solar collectors.

12.5.1 Calculation of t_p

Cover materials used in solar applications require the transmission of radiation through a slab or film of material and there are thus two interfaces per cover to cause reflection loss. In this situation, the depletion of the beam at the second

surface is the same as that at the transmission through one cover. First, for each component of polarization, assuming cover interfaces are with air on both sides. Neglecting absorption in the slab as shown in Fig.12.5.1. and considering unit incident beam, $(1 - r)$ of the incident beam reaches the second interface. Of this, $(1 - r)^2$ passes through the interface and $r(1 - r)$ is reflected back to the first, and so on. Summing up the resulting terms, the transmittance for a single cover neglecting absorption is,

$$\tau_{\rho,1} = \frac{1 - \rho}{1 + \rho} \quad \dots\dots(12.5.2)$$

For system of n covers, all of same material

$$\tau_{\rho,n} = \frac{1 - \rho}{1 + (2n - 1)\rho} \quad \dots\dots(12.5.3)$$

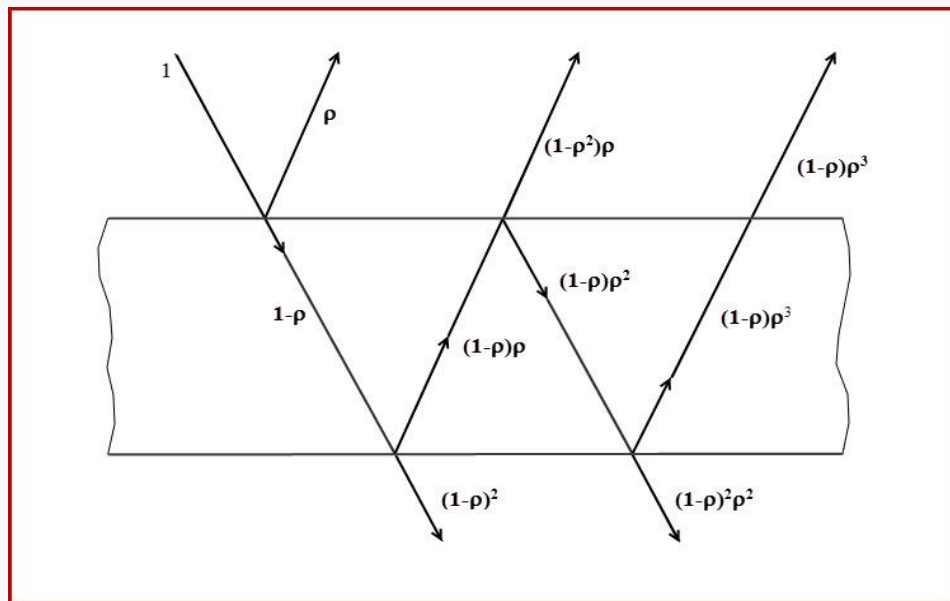


Fig 12.5.1 Transmission through one cover

12.5.2 Calculation of t_a

The absorption of radiation in partially transparent (i.e. translucent) materials is described by the Bouger's law,

$$dI = I k \, dx \quad \dots\dots(12.5.4)$$

where dI is the diminution in the radiation intensity, I is the local value of intensity, k is the extinction coefficient and x is the distance travelled by the radiation. Assuming k to be constant in the range of l of the solar spectrum. Equation (12.5.4) can be integrated to give,

$$\tau_{\alpha} = \frac{I_L}{I} = e^{-kL} \quad \dots\dots\dots(12.5.5)$$

.Note that 't_a'. is the transmittance considering only absorption and L is the actual path of the radiation through the medium. For n covers,

$$\tau_{\alpha} = e^{-nkL} \quad \dots\dots\dots(12.5.6)$$

when angle of refraction q₂ is given,

$$\tau_{\alpha} = \frac{e^{-nkL}}{\cos \theta_2} \quad \dots\dots\dots(12.5.6)$$

The value of k for glass varies from about 0.01/cm for absolutely clear "whiter-white" glass to 0.321cm for poor quality glass with a greenish cast of the edges. Note that t_a is the transmittance considering only absorption and L is the actual path of the radiation through the medium. Now the transmittance allowing for both reflection and absorption can be obtained by the equation (12.5.1).

12.6 Transmittance-Absorptance Product

For solar collector analysis, it is necessary to evaluate the transmittance-absorption product (t.a). Of the radiation passing through the cover system and striking the plate, some is reflected back to the cover system. However, all this radiation is not lost since some is reflected back to the plate. This is illustrated in Fig.12.6.1, where 't' is the transmittance of the cover system as can be known from equation (12.5.1) and a is the angular absorptance of the absorber plate. 't.a' is absorbed by the absorber plate and (1 - a)t, is reflected back to the cover systems. The reflection from the absorber plate is probably more diffuse than specular so that the fraction (1 - a)t that strikes the cover plate is diffuse radiation and (1 - a)t. r_d is reflected back to the absorber plate. The quantity r_d refers to reflection of the cover plate for incident diffuse radiation that may be partially polarized due to reflections as it is passed through the cover system. Hence summation yields,

$$\begin{aligned} < \tau \alpha > = \tau \alpha + \tau \alpha (1 - \alpha) \rho_d + \tau \alpha (1 - \alpha)^2 \rho_d^2 + \tau \alpha (1 - \alpha)^3 \rho_d^3 + \dots \\ < \tau \alpha > = \frac{\tau \cdot \alpha}{1 - (1 - \alpha) \rho_d} \end{aligned} \quad \dots\dots\dots(12.6.1)$$

Due to reflection <ta> will be greater than ta.

For incidence angle of 60°, r_d is approximately 0.16, 0.24, 0.29 and 0.32, for one, two, three and four glasses respectively.

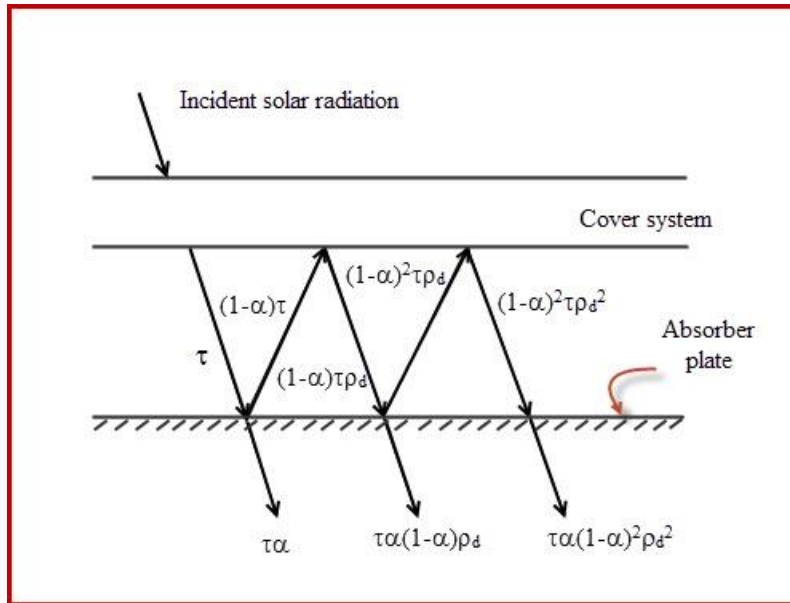


Fig 12.6.1 Absorption of solar radiation by absorber plate

The radiation absorbed in the glass cover system is not completely lost to the system. Slightly raising the temperature for the cover plates serves to reduce the rate of upward heat loss from the collector plate. This reduction in collector losses due to absorption in the cover can be conveniently thought of as an artificial increase in the transmittance. This gives rise to the term "effective transmittance", or more exactly the 'effective' transmissivity-absorptivity product $(\tau\alpha)_e$. The effective transmissivity absorptivity product, $(\tau\alpha)_e$ is calculated from the following formula;

$$(\tau\alpha)_e = \tau\alpha + a_1 (1 - e^{-K_1 L_1}) + a_2 T_1 (1 - e^{-K_2 L_2}) + a_3 T_2 (1 - e^{-K_3 L_3})$$

.....(12.6.2)

where α 's are constants and the subscripts 1, 2, 3 etc. refer to the first (outer), second, third etc. layers of transparent cover system.

12.7 CONVECTION

Convection is a process that transfers heat from one region to another by motion of a fluid. The rate of heat transfer by convection q_c , between a surface and a fluid can be calculated from the relation

$$q_c = h_c A(T_s - T_f) \quad \text{.....(12.7.1)}$$

where,

q_c = rate of heat transfer by convection kcal/hr

A = base area of heat transfer by convection m^2

T_s = surface temperature $^{\circ}C$

Design and Maintenance of Green House

T_f = fluid temperature °C

h_c = convection heat transfer coefficient kcal/hr.m².°C

Thermal resistance to convective heat transfer, R_c is given by,

$$R_c = \frac{1}{h_c A} \quad \dots\dots\dots(12.7.2)$$

The surface of the solar energy collector losses heat by mechanism of convection and radiation to the surrounding. The total rate of heat transfer q is given by equation

$$q = q_r + q_c = \frac{T_{coll} - T_{out}}{R_{cr}} \quad \dots\dots\dots(12.7.3)$$

Where,

R_{cr} = combined resistance for the two mechanisms,

T_{coll} = average temperature of collector surface

T_{out} = outside air temperature

12.7.1 Dimensionless numbers used for convection studies :

1. Nusselt Number: non dimensional heat transfer coefficient

$$N_u = \frac{hL}{k}$$

2. Reynold's Number: ratio of inertia to viscous forces, used in the description of forced convection, where the fluid has an initial velocity with respect to the heated surface.

$$Re = \frac{V.L.\rho}{\mu}$$

3. Prandtl number: ratio of molecular diffusivities of momentum with respect to heat.

$$P_r = \frac{\mu C_p}{k}$$

4. Grashof number: ratio of buoyant to viscous forces: replace Re in case of natural convection

$$G_r = \frac{g\beta\Delta TL^2}{\gamma^2}$$

5. Rayleigh number: ratio of thermal buoyance to viscous inertia

$$Ra = Gr \cdot Pr$$

Where,

L = Plate spacing

k = Thermal conductivity

β = Volumetric coefficient of expansion of air

ΔT = temperature difference between plates

V = fluid velocity

μ = dynamic viscosity

C_p = specific heat

ρ = fluid density

ν = kinematic viscosity



Module 9. Solar fraction for greenhouse

Lesson 13 Solar Radiation in Greenhouses

13.1 INTRODUCTION

Greenhouse is the structure in which sunlight passes through its cover to heat the plants and ground inside. Objects heated by sunlight emit infrared radiation. These objects then emit infrared radiation that is absorbed or reflected by the greenhouse cover, thus trapping the thermal energy in the greenhouse instead of letting it escape (Fig 13.1). This helps keep the greenhouse building warm.

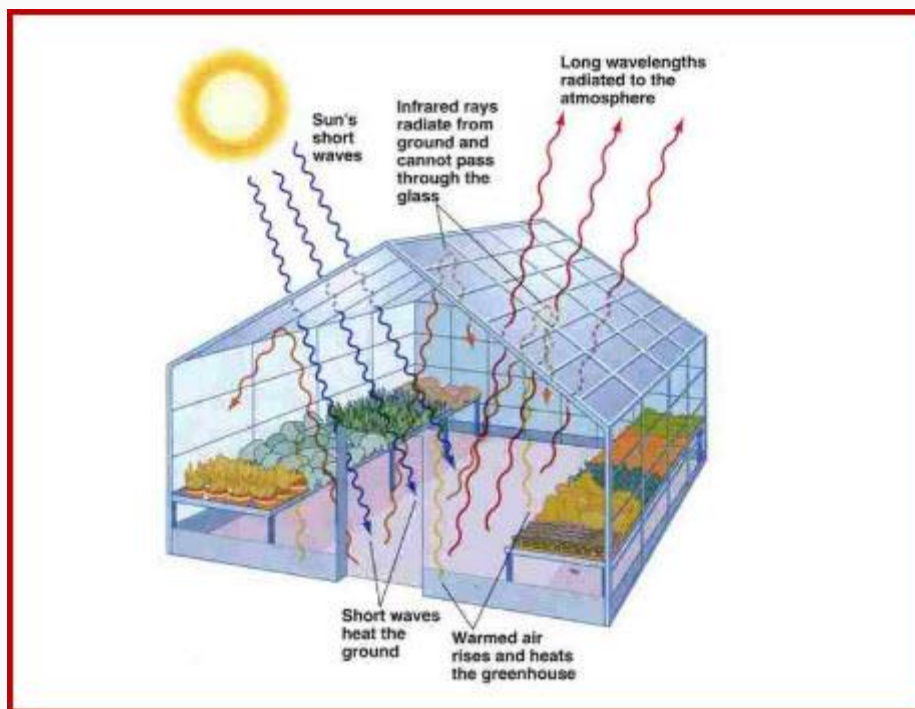


Fig 13.1 Heating of greenhouse by solar radiation

(Source: <http://www.hydroponics-simplified.com>)

The light received by plants in a greenhouse has three qualities that growers are concerned with—intensity (brightness), quality (color whiteness) and the ability for light (amount of light received) to reach the plants. Plants respond to all three qualities. Light transmission into the greenhouse is the most important factor affecting plant growth and crop production. Solar radiation is required for plants to photosynthesize and produce flowers, fruits and vegetables. Without adequate light, plants grow slowly and are generally unable to produce the quantity and quality that will generate desired profits. There are many factors that affect both the amount of light (intensity) and the quality (color) of light transmission into a greenhouse. These are considered to be structural or environmental factors.

The first alteration which the greenhouse causes on the microclimate parameters is a decrease in available solar radiation (Fig. 13.2). On single-span greenhouses and on the greenhouse

sidewalls of multi-span greenhouses, an important part of the penetrating light is lost through the sidewalls. Therefore, the use of reflecting surfaces on the north sides of greenhouses (in the northern hemisphere) contributes to an increase in the available light. Equally, the use of reflecting surfaces over the soil, to reflect the light not intercepted by the crop, allows for an increase in the light available for the crop.

13.2 TRANSMISSIVITY TO RADIATION

The fraction of global solar radiation transmitted inside the greenhouse is called as 'greenhouse global transmissivity'. Maximizing the radiation inside the greenhouse is in fact a desirable objective in all latitudes, especially during the autumn and winter seasons.

At latitudes higher than 30°, from the equator, the natural decrease of solar radiation is the most important uncontrolled limiting factor for crop growth inside greenhouses, and thus it becomes imperative under such conditions to strive for the maximum possible intensity, duration and uniformity of radiation.

Factors affecting transmissivity inside the greenhouse:

1. The climate conditions (cloudiness, mainly, which determines the proportions of direct and diffuse radiation);
2. The position of the Sun in the sky (which will depend on the date and time of day and the latitude);
3. The geometry of the greenhouse cover;
4. Its orientation (east-west, north-south);
5. The covering material (radiometric characteristics, cleanliness, water condensation on its inner surface); and
6. The structural elements and equipment inside the greenhouse which limit, due to shadowing, the available radiation inside.

13.2.1 Effect of climatic conditions on light transmission

On clear days, when direct radiation predominates, the average global transmissivity (fraction of global exterior radiation that penetrates inside the greenhouse) must be integrated as an average value for the whole greenhouse. This is because of the variability of radiation at different points throughout the greenhouse caused by differential shadowing of the structural elements of the greenhouse and of various pieces of installed equipment.

On completely cloudy days, when all the solar radiation is diffuse (i.e. when there are no defined shadows) the distribution of radiation is more homogeneous inside a greenhouse. The average instantaneous transmissivity of a certain greenhouse varies throughout the day, according to the position of the Sun in the sky and the characteristics of the radiation; normally, on a sunny day, it slightly increases from dawn until noon, and decreases later until dusk. When talking about global greenhouse transmissivity, it is normally understood

as the daily average transmissivity (proportion of daily accumulated radiation which penetrates inside the greenhouse with respect to the outside), to distinguish it from the instantaneous values.

It is important to highlight the notorious differences that exist, from the point of view of radiation transmissivity, between single-span and multi-span greenhouses (even when spans have the same roof geometry) because of the shadows between spans (Fig. 13.3); consequently, transmissivity estimates obtained in single-span greenhouses cannot be extrapolated to multi-span types.

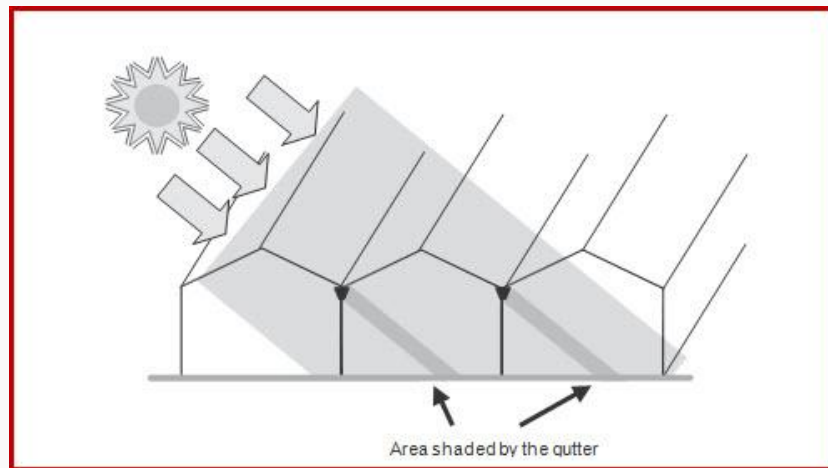


Fig 13.3 Shadow effect in multi-span greenhouses

(Source: Nicolas Castilla (2013))

13.3 EFFECT OF GREENHOUSE ORIENTATION ON LIGHT TRANSMISSION

The greenhouse orientation influences the transmissivity, in autumn and in winter, under clear sky conditions (when direct radiation predominates). A greenhouse oriented with the ridgeline running North-South will receive the most PAR radiation throughout the year. In North-South oriented greenhouse, there will be two receiving areas of sunlight, the East roof section (in the morning), and the West roof section (in the afternoon). It is also true that the majority of the radiation enters the greenhouse through these two roof sections when the sun is high in the sky from April to October. The difficulty is that during this time of the year, at latitude 40° N, one needs to reduce radiation because of the resulting high temperatures in the greenhouse. The most PAR transmission into the greenhouse is needed from October to March when there is less light available because of the normally low sun angle in this latitude. To achieve this goal, a free-standing greenhouse will receive more light with an East-West orientation during this critical period. Therefore, the designer should not aim to maximize total yearly radiation but the radiation during the darker periods of the year.

The uniformity of radiation in east-west oriented greenhouses (symmetrical with a roof pitch of around 30°) is less (on clear days) than in north-south oriented greenhouses, but their transmissivity in autumn-winter is higher, with differences of more than 10% of the outdoors daily global radiation around the winter solstice. However, these differences in uniformity between multi-span greenhouses oriented east-west and north-south are attenuated by:

- the greater the height of the greenhouse (3.5–4.0 m at the gutters);
- the lower the span width; and
- the radiation diffusion characteristics of plastic films used nowadays.

Another important aspect to consider when orienting the greenhouse is the direction of the predominant winds, which may become a primary consideration in choosing one or other orientation. The wind has a strong influence on the structure as a result of its mechanical effects, and because it has an indirect influence on the greenhouse indoor microclimate and energy balance. The wind increases the heat losses and the air infiltration leakage. Therefore, orientating the ridge parallel to the direction of the prevailing winds can, in certain cases, be advisable, but a reduction of ventilation must be expected.

The characteristics of the building plot (shape, slope, obstacles that generate shadows) may also limit the greenhouse orientation options.

13.4 INFLUENCE OF STRUCTURAL DESIGN

Roof slope is an important parameter affecting light transmission in greenhouse. The maximum amount of light energy transmittance occurs when the glazing surface is perpendicular to the sun. Essentially this happens only for a short time of the day. The design of the greenhouse should be such that it will maximize the light energy entering through the roof of a greenhouse during the time of year when light is at a premium (i.e period from October to March). Glazing materials of different strength require supporting members at various spacings. For wider spacing the individual structural support members will be heavier but produce less overall shadow than closely spaced supports. Some glazings have less unit weight but the design of the greenhouse structural members should be essentially the same because the primary loads are live loads of wind and snow and the dead load of the glazing is small in comparison to the total loads experienced by the greenhouse.

13.5 INFLUENCE OF INTERIOR GREENHOUSE COMPONENTS AND SYSTEMS

With the advent of thermal screens, supplemental lighting and other greenhouse handling systems along with traditional overhead heating systems concern has been expressed for obstruction of PAR lighting which is caused by these overhead mounted components of the growing system. Under bench heating and in-floor heating systems have reduced the number of overhead heating pipes necessary to meet the demand load. Thermal screens which are installed and move gutter to gutter can reduce shading because the thermal screen shares the shadow pattern with the shadow caused by the structural gutter and does not add an additional shadow which is caused by the system which moves from truss to truss. The grower must be concerned with the adoption of new practices which add significant overhead components.

13.6 INFLUENCE OF WEATHERING ON GLAZINGS

The design of sophisticated greenhouse glazing films nearly eliminate this problem. It is also true that not all waveband are attenuated the same over time of exposure of greenhouse

glazings. There are distinct differences between the new and weathered film, particularly in the lower PAR region.

13.7 INFLUENCE OF CONDENSATION ON THE GLAZING

Condensation is found on most glazings and is useful at night for reducing energy loss for direct radiation to the sky from polyethylene glazed greenhouses which are not glazed with IR film. During the day, however, excess condensation can cause reduced PAR transmission and create localized disease potential if dripping occurs on the crop. Condensation between the two layers of polyethylene film can be reduced or eliminated by using outside air to supply the fan used to inflate and separate the two layers of film. Air which is introduced into the space within the film envelope will always be warmed if it is taken from outside. Warm moist air taken from within the greenhouse will be cooled when it enters the air envelope. The moisture will be condensed on the cooler surfaces causing build-up of moisture between the two layers. Although helpful from an energy standpoint it can be detrimental from a light transmission viewpoint. Installing the inflation fans properly can completely overcome this problem. The use of IR films also is helpful in controlling condensation because the plastic film itself is usually at a higher temperature than conventional grade polyethylene greenhouse glazing.

13.8 OPTIMIZATION OF THE TRANSMISSIVITY

Daily transmissivity values above 70% in simple cover greenhouses are very infrequent, because normally they range between 55% (winter) and 70% (summer), whereas in double cover greenhouses they range between 50 and 60%. The average reflectivity of a greenhouse ranges between 20 and 25%, and the absorptivity for both the cover and the structure ranges from 15% with a simple cover to 25% with a double cover.

At canopy level, the 'radiation saturation level' has been defined as the value above which the radiation increments do not involve parallel increases of photosynthesis. This situation (widely studied in laboratory growth chambers) may occur in greenhouses during the high radiation months at midday, but only on the leaves located on the upper strata of the crop, exposed to higher radiation, whereas the leaves of the lower strata (shadowed by the upper leaves) receive much less radiation, and are far from the saturation level. Therefore, considering the plant as a whole, it is not usual to achieve radiation saturation in species of edible vegetables, even under mediterranean conditions, and normally it does not seem justified to decrease the radiation in the greenhouse for this reason. It might be necessary, however, to limit radiation for other reasons (e.g. to limit temperature in insufficiently ventilated greenhouses, for fruit quality considerations, to improve the colour of the product, or to reduce water stress).

The anti-dripping effect of the inner side of a multilayer plastic film (once located over the greenhouse) prevents the formation of thick drops (when water vapour condenses on the film), reducing transmissivity and later contributing to water dripping on the crop, with negative effects on plant health.

Washing the plastic film covers and restricting greenhouse white washing as much as possible, together with a good selection of the plastic film, allow for a better availability of

Design and Maintenance of Green House

radiation inside the greenhouse. Other measures, such as limiting the shadows of the superstructure and of the installed equipment (thermal screens, ventilator's screens) and the outside windbreaks, are quite advisable.

The quality of radiation is affected by the soil particles deposited on the greenhouse cover, limiting the PAR even more than the IR radiation.

We must also consider those crop management techniques which optimize the use of radiation (intercepting it) inside the greenhouse:

- north-south orientation of the crop rows;
- plant density;
- plant training;
- pruning; and
- use of mulching.

It is interesting to experiment with novel growing techniques, prior to their general adoption. In this respect, it is important to highlight the potentially negative influence in productivity of the use of white mulching in autumn-winter to increase the radiation intercepted by the crop, in unheated greenhouses under certain conditions, because of concomitant significant reductions in root temperature, both in crops grown in the soil or in artificial substrates.

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Lesson 14 Effect of Different Spectrum of solar Radiation on Plant Growth

14.1 INTRODUCTION

The light received by plants in a greenhouse has three qualities that growers are concerned with intensity (brightness), quality (colour whiteness) and the ability for light (amount of light received) to reach the plants. Plants respond to all three qualities. Light transmission into the greenhouse is the most important factor affecting plant growth and crop production [2].

The importance of light in the growth of plants is a well-established phenomenon. A common observation is that plants grown in the dark are yellow (chlorotic), taller (etiolated), have thinner stems, and in general, are not so healthy looking.

Greenhouse plant producers also know the importance of light for proper plant production. They often grow plants with artificial lights, if sunshine is inadequate; or in a shaded area, if sunshine appears to be too plentiful (and hot) or if the plant producers are trying to slow the growth of the plants.

In this lesson the discussion will focus on (1) basic principles of light and plant development, (2) principles on light regulation of plant development in the emerging field of photomorphogenesis, and (3) alternative methods of regulating plant development that modifies the wavelengths of light that surrounds the plant.

14.2 Light – Radiant Energy

All light is made up of energy. Light available to plants includes the different wavelengths of the electromagnetic spectrum viz. the wavelengths that humans can see (visible light) and the wavelengths that humans can't see (such as microwaves and infrared light). Light for the plant is used for producing food through the process of photosynthesis. The characteristics of direction and spectral composition of light in the plant's environment is transferred to the plant through the interception and activation of pigment systems (coloured cells of the plant). This information affects the morphological development (size/proportion of root and shoots) of the plant.

14.3 Colour - The Wavelength Distribution of Radiant Energy

According to the *Random House Webster's College Dictionary* (1992 edition), colour is "the quality of an object or object with respect to light reflected by it, usually determined visually by measurement of hue, saturation, and brightness of the reflected light". Note that this definition is based on human vision. For our purposes, a more appropriate *definition of colour would be the distribution of wavelengths coming from a radiation source, or reflected from a reflective object.*

14.4 Plant Uses of Radiant Energy and Plant “Vision”

Plants utilize specialized pigments to intercept and capture radiant energy. For example, plants capture the energy in light during the process of photosynthesis. Photosynthetic wavelengths (400-700 nm) activate the chlorophyll pigments, which transform light energy into chemical energy for production of carbon molecules (sugars) that are then used to construct more complex compounds, and ultimately plant cells and organs (root, leaf, stem, flower, fruit).

Plants also monitor radiant energy within their environment for the purpose of adjusting their growth appearance. This monitoring of the light environment (“plant vision”) and subsequent response is termed photo-morphogenesis. Photo-morphogenesis is more properly defined as the ability of light to regulate plant growth and development, independent of photosynthesis. Plant processes that appear to be photomorphogenic include internode elongation (distance between leaves on stem), chlorophyll development, flowering, abscission (deleafing), lateral bud outgrowth, and root and shoot growth.

If photosynthesis is the “engine” providing the energy for plant growth, photomorphogenesis is the “steering wheel” to influence the direction and final plant appearance.

Photomorphogenesis involves the activation of several photoreceptor (pigment) systems (Senger and Schmidt, 1994). These systems include phytochrome, which absorbs red (R) light (wavelengths 660-680 nm) and far-red (FR) light (730-740 nm), “cryptochrome”, which absorbs ultra-violet (UV-A) (320-380 nm) and blue light (400-500 nm), and a UV-B receptor (290 nm). These receptors detect the light environment and subsequently influence plant growth and development.

Plants monitor the environment by sensing changes in the quality (wavelength(s)), quantity (intensity), duration (length of exposure), and direction of light. Light perception in plants is a sequential process. Light must first be absorbed by the photoreceptor, and then the photoreceptor is transformed to either its Red (Pr) or Far Red (Pfr) form. Depending on the distribution of the wavelengths of the light, a specific proportion (ratio) of the two forms of the photoreceptor (Pr and Pfr) is established within the plant. This ratio becomes a “message” to the plant, and causes the production of plant growth regulators to stimulate a plant growth response.

14.5 Light Energy Capture by Plants - Photosynthesis

One of the main roles of light in the life of plants is to serve as an energy source through the process of photosynthesis. Using water and carbon dioxide, plants produce the “foodstuffs” necessary for growth and survival. Carbohydrates (starches and sugar) for plant components and stored chemical energy are produced during this biochemical process in plants.

Plants capture the energy in light using a green photoreceptor pigment called chlorophyll. In the research laboratory, chlorophyll can easily be extracted from plant tissue using chemical solvents. Chlorophyll can also be extracted by abrasion, as anyone who has ever pruned tomato plants by hand, or has gotten grass stains on their clothes, can attest.

14.6 Photosynthetic Radiation

Photosynthetically active radiation is well established as the primary measurement for quantifying radiation of the plant light environment. The following guidelines put forth by LI-COR (1979) and generally accepted by most plant science journals should be followed in the reporting of photosynthetically active radiation (PAR):

14.6.1 Units

The mole is the unit for a very large number of photons. It equals 6.02×10^{23} photons and it is also designated as an Avogadro's number of photons.

14.6.2 Terminology

Photosynthetically Active Radiation (PAR) is defined as the photons of radiation in the 400 to 700 nm waveband. PAR is a general term that can describe either the photosynthetic photon flux density (PPF), or the photosynthetic irradiance (PI).

Photosynthetic Photon Flux Density (PPF, or sometimes written as PPFD) is defined as the photon flux density of PAR. This is the number of photons in the 400 to 700 nm (PAR) waveband contacting a unit surface area over a given time period. The appropriate unit is (micro-mol per square meter per second), or abbreviated as $\mu\text{mol m}^{-2} \text{s}^{-1}$.

Photosynthetic Irradiance (PI) is defined as the radiant energy flux density of PAR. This is the energy of the radiation in the 400-700 nm waveband, which is contacting a unit surface area over a given period of time. The appropriate unit is Watts per square meter, or abbreviated as Wm^{-2} .

14.7 Light Regulated Plant Development - Photomorphogenesis

Photomorphogenesis is defined as the ability of light to regulate plant growth and development, independent of photosynthesis. Plant processes that appear to be photomorphogenic include internode elongation, chlorophyll development, lowering, abscission, lateral bud outgrowth, and root and shoot growth.

Photomorphogenesis differs from photosynthesis in several major ways. The plant pigment responsible for light-regulated growth responses is phytochrome, not chlorophyll. Phytochrome is a colourless pigment that is in plants in very small amounts. Only the red (600 to 660 nm) and far red (700 to 740 nm) wavelengths of the electromagnetic spectrum appear to be important to influence the phytochrome pigments. The wavelengths, which affect photosynthesis, are broader (400 to 700 nm) and less specific.

Photomorphogenesis requires very little light energy (light intensity) to get a growth-regulating response. Plants generally require a greater amount of energy for photosynthesis to occur.

14.8 PHOTOMORPHOGENIC RADIATION

14.8.1 Phytochrome Wavelengths (Red and Far-red Light Responses)

The second most discussed effect of radiation, after photosynthesis and its subsequent effect on plant growth rates, is photomorphogenesis and its specific effects on plant development. The wavelengths specific for phytochrome responses are Red and Far-red light. The plant light environment must be characterized according to the absorption spectra or action spectra of phytochrome, since phytochrome is the pigment involved in the regulation of plant development. The action or response spectrum is indicated by the wavelengths that will cause a plant response.

Phytochrome is found in both active (Pfr) and inactive (Pr) forms. The relative proportion of each form is beneficial to know, since it is this proportion, which determines the type of plant response. Unfortunately it is not easy to measure the proportion of active and inactive forms of phytochrome directly. However, separately measuring photon flux densities at 660 nm and 730 nm offers an indication of the proportion of Pfr to P_{total} in the plant (Smith, 1994), and provides (Pfr/Ptot) which is the proportion of Far-red “active” form to the total phytochrome in green leaves.

Reporting specific wavelength ratios for the quantification of the wavelengths of light important to phytochrome is consistent with McCree's (1979) recommendations on spectral measuring and reporting. He suggested that certain parts of the radiation spectrum were identified with specific physiological plant responses, and that simplified measures of the quantity of radiation available to plants in those spectral regions should be reported.

It is unrealistic to expect complete spectroradiometric data (the intensity of light at each wavelength) for all experiments, and specifically for those, which are not photo biological in nature. Even if such data were available, the data would be hard to use to interpret the plant response results of an experiment, because the action spectra for various plant responses are not universally known.

14.8.2 “Cryptochrome” Wavelengths (Blue Light Responses)

There are a series of well-documented plant responses that have been attributed to radiation in the blue portion (400 to 500 nm) of the electromagnetic spectrum. Unfortunately, our knowledge on the action or even the location of this hypothesized plant pigment (“cryptochrome”) is not known. In addition some of the plant's responsiveness to blue light may be attributed to perception and activation of phytochrome in these wavelengths (Mohr et al., 1984).

14.9 CURRENT METHODS TO REGULATE THE GROWTH OF PLANTS

14.9.1 Using Light to Regulate Plant Growth in the Greenhouse

- Exposing the Plants to Red and Far-red Light
- Supplementing the Greenhouse Light Environment with Fluorescent Light
- Filtering out FR Light Using the Greenhouse Covering



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Module 10. Steady state analysis of greenhouse

Lesson15 State Analysis of A Ridge Ventilated Greenhouse

Greenhouse is developed to provide favorable growing environment to plants. Greenhouse environment is set of various parameters which depend on each other. To better understand relation of these parameters on each other i.e. inside condition of greenhouse to those of existing outside environment, various mathematical models have been developed. These models predict the growing conditions as a function of the external climatological variables. Application of these models include the computation of heating and ventilation requirements, the analysis of unconventional designs, the evaluation of different control devices and the testing of new control algorithms

Most of the existing models are based on energy balance method consist of dividing the greenhouse in different elements, modeling the heat and mass fluxes among these elements and generating a heat balance equation for each element. The solution of resulting system of algebraic equations yields the temperature and humidity inside the greenhouse. Assumption used in all these models is that the heat storage capacity of the system is negligible relative to the daily energy input and therefore greenhouse is considered to adjust immediately to the changes in the external environment so that steady state equation may be used.

15.2 REVIEW OF WORK DONE AT VARIOUS PLACES

A lot of research work has been carried out on greenhouse technology for the last few decades but very few of them are relevant to Indian climatic condition with fan pad evaporative cooling. Ganguly and Ghosh [2] have presented a thermal model of a fan-pad ventilated floriculture greenhouse to predict the inside greenhouse temperature.

They have also shown the effects of shading and ventilation rate on greenhouse temperature. Shukla et al. [3] have carried out an experimental study to see the effect of an inner thermal curtain in an evaporative cooling system of a cascade greenhouse. A thermal model has also been developed to predict the air temperature. Kittas et al. [4] have shown that the evaporative cooling system is able to keep the greenhouse air temperature at rather low levels. Impron et al. [5] demonstrated that air temperature was affected more by variations of ventilation and leaf area index than by the applied cover properties. The leaf area index had the highest impact on greenhouse air temperature, implying that a large proportion of the cooling is achieved by the crop itself. Sethi and Sharma [6] developed a thermal model for heating and cooling of an agricultural greenhouse integrated with an Aquifer Coupled Cavity Flow Heat Exchanger System (ACCFHES). Kittas et al. [7] reported experimental investigation of the climatic variables of greenhouse such as air temperature, solar radiation, outside wind speed and direction and their interactions affecting the air temperature in a fan-ventilated multi-span greenhouse with rose crop.

Ghosal et al. [9] presented a mathematical model considering heat transfer through flowing water film on shade cloth, stretched over the roofs and south wall of an even span greenhouse to study the effectiveness of cooling in greenhouse.

In the conventional fan-pad evaporative cooling and ventilation system greenhouse fans and the cooling pads are installed on the opposite walls of the house. When outside air is drawn by the induced draught fan in the greenhouse through the wet pad, it gets cooled as latent heat of evaporation of water is taken from the air. This cold air picks up heat while flowing from the pad end to the fan end, causing a temperature gradient along the length of the greenhouse. This puts a restriction on the construction of longer greenhouse.

15.3 CASE STUDY

In this case study, a thermal model of a greenhouse with distributed evaporative cooling is presented. An uneven-span ridge type greenhouse is considered, the fans being aligned along the ridge of the greenhouse and the cooling pads being aligned along the side wall segments (Fig.15.1).

During the operation, air is drawn by the fans through the wet pads and ventilated out of the greenhouse through the roof. This avoids temperature gradient along the length but a small temperature gradient is set up along the width and height of the greenhouse. Therefore, temperature gradient does not put any restriction on the length of the greenhouse. The study is based on the climate data for the city of Kolkata (22.83°N , 88.82°E), which bears the mixed climatic conditions of the plains and coastal areas of India.

In the present model an east-west oriented, un-even span, single ridge greenhouse has been considered, with a floor area of 180-m². Fig.15.1 represents the general arrangement of the proposed system. Central and side wall heights of greenhouse are 4 m and 2 m, respectively. The greenhouse is covered with Fiber Reinforced Plastic (FRP). The cooling pads are on the north and south walls, one on each side of each of the six bays or segments. A door is on the west wall and fans are aligned along the ridge of the greenhouse as shown in Fig.15.1. Shade nets are provided along both of the canopy in inclined manner.

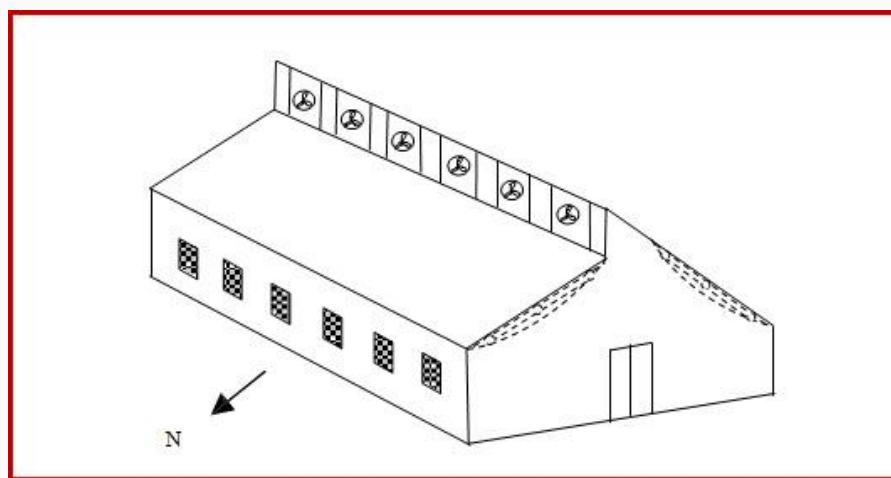


Fig 15.1 General arrangement of Greenhouse

(Source: D.Mishra and S.Ghosh [1])

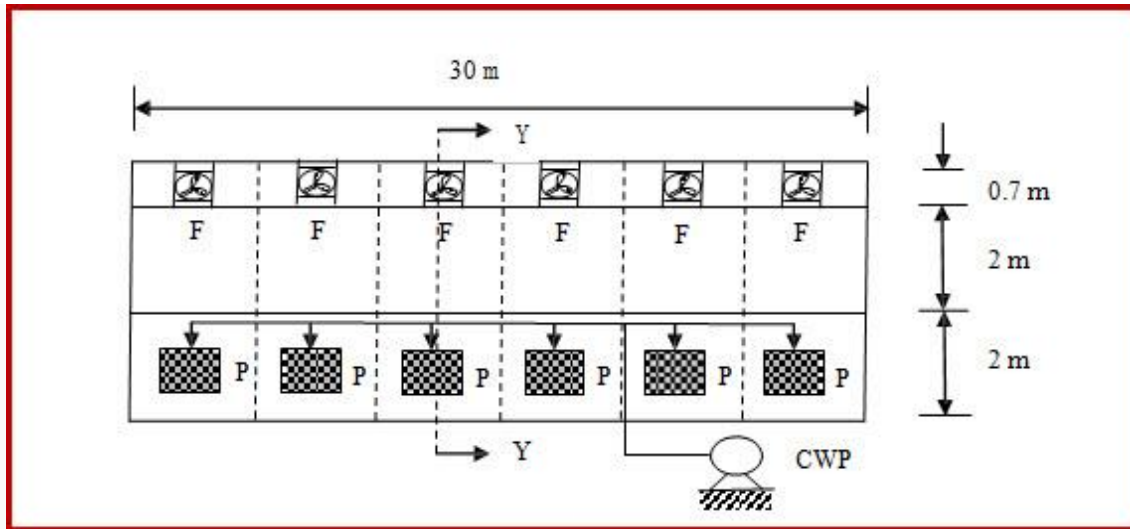


Fig 15.1a. Side Elevation of the System

(Source: D.Mishra and S.Ghosh[1])

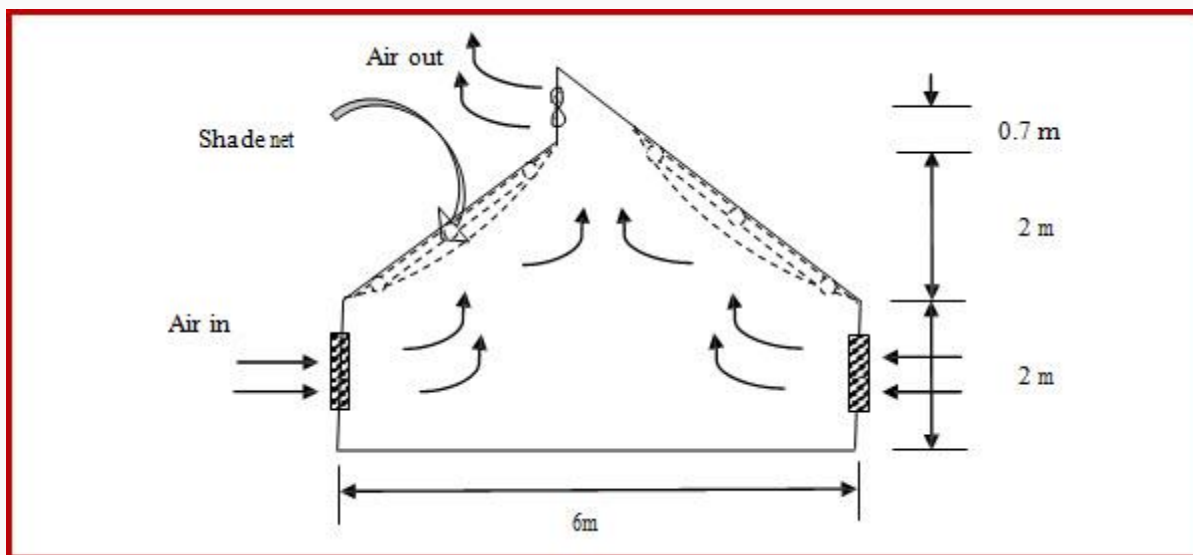


Fig 15.1 b. Sectional elevation of Y-Y

(Source: D.Mishra and S.Ghosh[1])

15.4 THERMAL MODELING

15.4.1 Assumptions

- Analysis is considering **steady-state condition**.
- Heat flow is considered to be one dimensional.
- No energy is absorbed by the structural elements.
- Radiative heat exchange between canopy and side walls has been neglected.

15.4.2 Input Parameters

1. Transmissivity of the covering material for normal beam radiation [2]: 0.8
2. Transmissivity for diffused and reflected radiation [2]: 0.76.
3. Saturation efficiency of cooling pad [2]: 0.88
4. Heat absorptivity of Ground [6]: 0.30.

15.4.3 Total incident solar energy on greenhouse cover

The total intensity of solar radiation falling on different inclined and vertical surfaces of greenhouse is calculated using solar radiation geometry for the relevant surfaces and solar radiation. The total incident heat load of greenhouse is given by:

$$S_t = \sum (1 - SF) A_i I_{ti} \quad \dots\dots\dots (1)$$

Where A_i is the area of the surface 'I' and I_{ti} is the intensity of transmitted solar radiation into the greenhouse through that surface. The intensity of transmitted solar radiation (I_t) into the greenhouse can be written as:

$$I_t = \sum I_b R_b \tau_b + I_d R_d \tau_d (I_b + I_d) R_r \tau_r \quad \dots\dots\dots (2)$$

Where I_b and I_d are intensity of beam and diffuse radiation respectively. R_b , R_d , and R_r are tilt factors for beam, diffuse and reflected radiation respectively.

τ_b is the transmissivity of the beam radiation which varies with hour angle and the maximum value is assumed as 0.8 for the material fibre reinforced plastic (FRP). τ_r and τ_d are the transmissivity of the global and diffuse radiation which are assumed to be constant and value chosen is 0.76 respectively.

To calculate the total heat load into the greenhouse it is considered that the vertical surfaces receive only diffused radiation because during the peak radiation hours the contribution of beam radiation on the vertical walls is insignificant compared to the total radiation [2].

15.4.4 Energy balance equations

It is considered that the transmitted solar radiation into the greenhouse is fully absorbed by the plants, inside-air and floor of the greenhouse. The temperature inside the greenhouse air can be calculated by applying the law of conservation of energy for the different elements (plant, floor, inside air) of the greenhouse. In the following section energy balance equations for each of the greenhouse components has been presented.

15.4.4.1 Greenhouse plants

$$\alpha_p S_t = M_p C_p \frac{dT_p}{dt} + h_{pr} A_p (T_p - T_G)$$

.....(3)

[Rate of energy absorbed by the vegetation]= [Rate of energy used to increase plant temperature]+[Rate of energy convected and evaporated to the surrounding through leaves.]

Where α_p is absorptivity of plant suggested Sameshima [10] is given by,

$$\alpha_p = (1 - r_f)(1 - \tau)$$

.....(4)

In equation (4) ' r_f ' is the reflectivity of leaves which depends on the variety of plants; ' τ ' is transmissivity of leaves; ' h_{pr} ' is convective-evaporative heat transfer coefficient and ' P_T ' is saturation pressure, suggested by Tewari [8].

15.4.4.2 Greenhouse floor

$$\alpha_g (1 - \alpha_p) S_t = -K A_g \frac{dT}{dx}|_{x=0} + h A_g (T_{x=0} - T_G)$$

.....(5)

[Rate of energy absorbed by the floor] = [Rate of energy conducted through the floor] + [Rate of energy convected into the greenhouse air]

The rate of thermal energy conducted in the ground is expressed in a steady state condition as

$$-K A_g \frac{dT}{dx}|_{x=0} = h_b A_g (T_{x=0} - T_0)$$

.....(6)

Where, $T_{x=0}$ is the surface temperature of the ground, °C. Temperature in the ground after a certain depth (T_α) becomes constant and is considered equal to the underground annual temperature, which is assumed to be constant (T_0) beneath the greenhouse floor as discussed by Tiwari and Goyal [12]. Thus, eqn. (5) can be written as

$$\alpha_g (1 - \alpha_p) S_t = h_b A_g (T_{x=0} - T_0) + h_a A_g (T_{x=0} - T_G)$$

.....(7)

[Rate of energy absorbed by the floor] = [Rate of energy convected from floor to underground] + [Rate of energy convected into the greenhouse air]

15.4.4.3 Greenhouse Air

The total heat accumulation in the greenhouse air is the summation of transmitted heat after absorption by the plant and floor, convected-evaporated heat from the plants and convected heat from the floor. It is also considered that the heat exchange occurs across the greenhouse covering due to temperature difference between inside and the ambient. If ambient temperature is more than the inside temperature then heat transfer takes place from outside to inside. This total heat increases the inside air temperature and is required to be ventilated out of the greenhouse by ID fans. Thus energy balance equation for the air becomes

$$\begin{aligned} (1 - \alpha_g)(1 - \alpha_p) S_t + h_{pr} A_p (T_p - T_g) + h_a A_g (T_{x=0} - T_0) \\ = h A_{gc} (T_G - T_a) + \rho V C_a (T_{fan} - T_{pad}) \end{aligned}$$

.....(8)

[Rate of energy gained by the greenhouse air after absorption by plants and floor] + [Rate of energy convected and evaporated in the greenhouse air through plant leaves] + [Rate of energy convected from the floor to the greenhouse air] = [Rate of heat transfer between the greenhouse air and the ambient] + [Rate of sensible heat gain of greenhouse air which is to be ventilated out under steady state condition]

Where V is the volume of air handled by ID fan and expressed as

$$V = ACM \times (L \times B \times H) / 60$$

.....(9)

Where, H is the effective height considering the entire shape of the greenhouse as a parallelepiped. Thus the total volume of air inside the greenhouse is equivalent to the volume of the parallelepiped. Temperature of pads can be expressed as

$$T_{pad} = T_a - \varepsilon(T_a - T_{wb})$$

.....(10)

Where, ε is the saturation efficiency of cooling pads. In equation (8) 'h's the overall heat transfer coefficient, given by Sethi [6].

From Eq. (7) the surface temperature of the floor of the greenhouse ($T_{x=0}$) can be written as

$$T_{x=0} = \frac{\alpha_g(1 - \alpha_p)S_t + h_b A_g T_0 + h_a A_g T_{0g}}{h_b A_g + h_a T_g}$$

.....(11)

The average greenhouse air temperature (T_G) can be considered to be the arithmetic average of temperature at pad and fan end and Thus

$$T_G = \frac{T_{fan} + T_{pad}}{2}$$

.....(12)

Combining equations (8), (11) and (12) greenhouse air temperature (T_G) can be obtained.

$$T_G = \frac{PS_t + RT_p + H_G(MS_t + N) + hA_{gc}T_a + QT_{pad}}{hA_{gc} + Q + R + H_G + h_b + A_G}$$

.....(13)

Considering

$$H_G = \frac{h_a}{h_a + h_b}$$

$$N = h_b A_g T_0$$

$$Q = 2\rho_a V C_a$$

$$M = \alpha_g (1 - \alpha_p)$$

$$P = (1 - \alpha_g)(1 - \alpha_p)$$

$$R = h_{pr} A_p$$

In simplified form TG can be written as

$$T_G = A + B T_p$$

.....(14)

Where

$$A = \frac{PS_t + H_G (MS_t + N) + h A_{gc} T_a + Q T_{pad}}{h A_{gc} + Q + R + H_G h_b A_g}$$

$$B = \frac{R}{h A_{gc} + Q + R + H_G h_b A_g}$$

Combining equation (14) and equation (3) and after simplification it can found as

$$\frac{dT_p}{dt} + A_1 T_p = B_1$$

.....(15)

$$A_1 = \frac{R(1 - B)}{M_p C_p}$$

$$B_1 = \frac{\alpha_p S_t + AR}{M_p C_p}$$

Where

Solving Eqn. (15) temperature of the plant (T_p) can be obtained as

$$T_p = \frac{B_1}{A_1} - \left(\frac{B_1}{A_1} - T_{po} \right) e^{-A_1 t}$$

.....(16)

Where T_{po} = initial plant temperature of the greenhouse and 't' is the time in seconds.

By the value of plant temperature (T), greenhouse air average temperature (T_G) can be obtained from Eqn. (14) and fan (T_{fan}) temperature can be found out from the eqn.(12). Accordingly, temperature gradient along the flow path

$$d_{Lc} = \frac{T_{fan} - T_{pad}}{L_c}$$

.....(17)

Considering L_c (length L_c that can be geometrically evaluated by the Fig.15.2) is the linear distance from the centre of pad to fan which can be calculated greenhouse geometry. It has been seen that the average temperature of greenhouse air (calculated by eqn. 14) located above gutter level of shed net (point D in Fig.15.2). Though greenhouse vegetation below the gutter level therefore it may be considered average air temperature of the effective plantation zone occurs in between the gutter level and pad (shown at point B in Fig.15.2). From the geometry average greenhouse temperature around plantation zone

$$T_{GP} = T_{pad} + (dT_{LC} \times L_c/6)$$

.....(18)

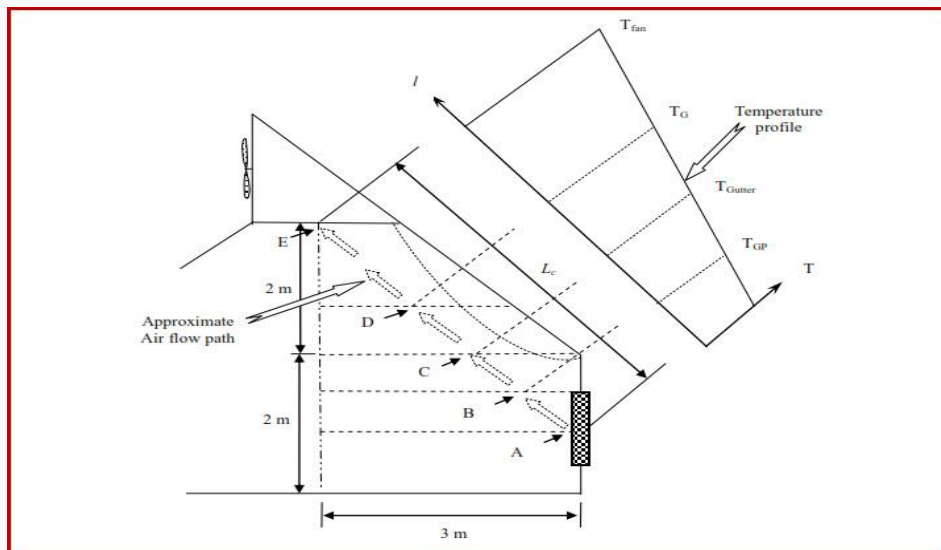


Fig 15.2 Air flow path and temperature profile

(Source: D.Mishra and S.Ghosh[1])

15.5 PERFORMANCE OF THE MODEL

The model performance has been carried out using radiation and temperature data published for Kolkata [11], assuming a relative humidity.

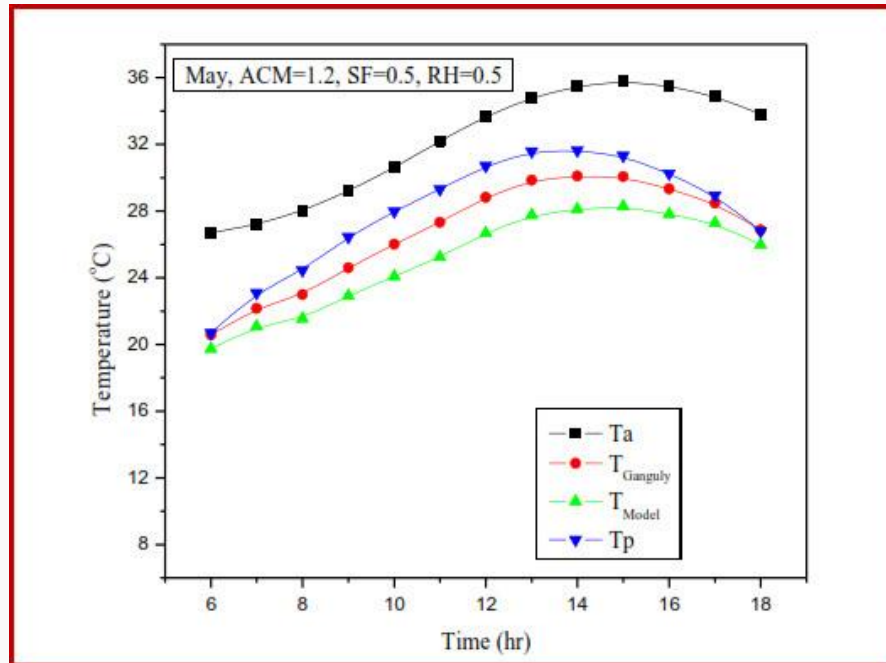


Fig 15.3 Variation of greenhouse plant and air temperature for a representative hot and dry summer day of 15th May.

(Source: D.Mishra and S.Ghosh[1])

Fig. 15.3 shows the hourly variation of greenhouse air temperature for a given value of ventilation rate, shading and LAI on 15th May (a representative hot and dry day in summer). At 15 hours of the day when ambient temperature is at the maximum it is seen that using 50% shading, 1.2 ACM ventilation rate and assuming 50% relative humidity a temperature difference of about 7.52°C between ambient and greenhouse air is obtained by using longitudinally pads and fan ventilated distributed evaporative cooling system when LAI is one. Maximum greenhouse air temperature is limited by 28.28°C when the ambient temperature is 35.8°C.

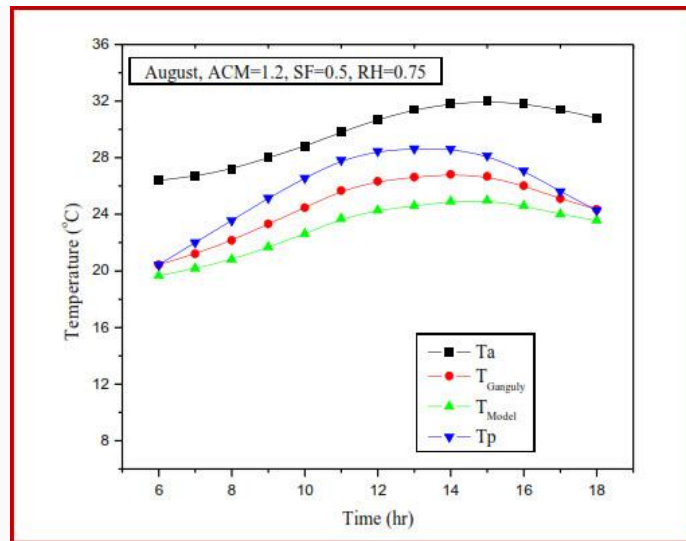


Fig 15.4 Variation of greenhouse plant and air temperature for a representative hot and humid day of 16th August.

(Source: D.Mishra & S.Ghosh [1])

Fig. 15.4 shows the variation of greenhouse air temperature on 16th August (a representative hot and humid day in the monsoon). The model considers the average hourly radiation intensities for clear sky as the input values. The relative humidity is assumed 75% in this month. It is seen that during hot and humid condition greenhouse inside temperature is well manageable though high relative humidity restricts the temperature reduction by evaporative cooling occurring in the cooling pad. The result arises when greenhouse provides 50% shading, 1.2 ACM ventilation and one LAI.

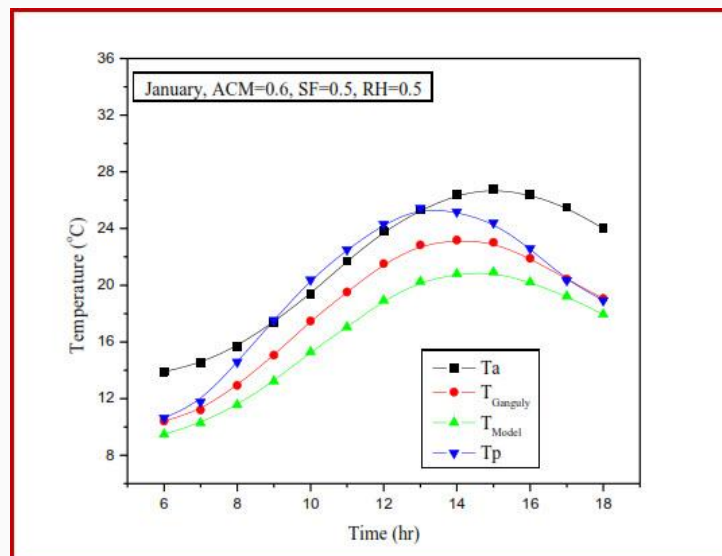


Fig 15.5 Variation of greenhouse plant and air temperature for a representative winter day of 17th January.

(Source: D.Mishra and S.Ghosh[1])

Fig. 15.5 shows the variation of greenhouse air temperature on 17th January (a representative day in winter). As the thermal load in the month of January is low, ventilation rate of 0.6 ACM is used instead of 1ACM with 50% shading and assuming 50% relative humidity. It is seen that the model predicts the greenhouse inside air temperature below 16°C during the off peak radiation hours in the morning up to 10 a.m.

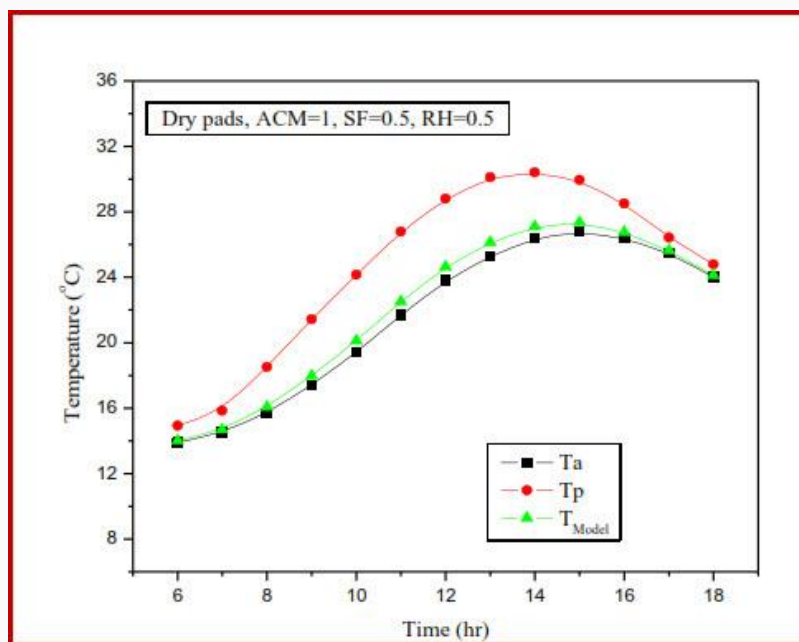


Fig 15.6 Variation of greenhouse plant and air temperature for a representative winter day of 17th January.

(Source: D.Mishra and S. Ghosh [1])

Fig.15. 6 shows the variation of greenhouse air temperature on 17th January with dry pads. It is seen that greenhouse temperature becomes more than the ambient temperature using the dry run during the winter season. The greenhouse temperature can be maintained between 14.01-24.12°C, a favourable temperature for the plant growth, using 1 ACM ventilation rate with dry pad and 50% shading when LAI is one. Relative humidity assumed to be 50% throughout the day.

It can be concluded that the length of the greenhouse cannot put any restriction for moderating room air temperature. From the analysis it has been shown that

the greenhouse and plant temperature can be maintained satisfactorily throughout the season in a place like Kolkata. In the month of summer the model it is most effective. In winter the model shows very low temperature during the non-peak radiation hours. Thus during those hours in winter natural ventilation with dry pads can be employed.

Lesson 16.Greenhouse Steady State Energy Balance and Mass Balance Models

The energy balance for the greenhouse was obtained by applying energy conservation to the greenhouse system as a control volume and identifying the energy terms.

16.2 ENERGY BALANCE MODEL

In this study, the energy storage term in the greenhouse was ignored since the heat capacity of internal air and plants was small compared to the existing fluxes (Walker, 1965 and Kindelan, 1980). The air in each defined zone in the greenhouse was assumed to be well mixed resulting in no spatial variation in temperature. The greenhouse surface and the surrounding were assumed gray bodies and the sky was at sky temperature. Also, it was assumed that the greenhouse ground was completely covered with plants. During the periods of high solar radiation when ventilation was required, the heat loss to ground, the heat of respiration and heat utilized in photosynthesis were assumed to be very small compared to other fluxes and were neglected (Walker, 1965). The cover was assumed to be double layer polyethylene. Neglecting the rate of change of energy stored in the greenhouse and other small fluxes, the energy balance equation for the greenhouse was written as:

$$0 = Q_{sr} - Q_e - Q_{cd} - Q_v - Q_t$$

.....(1)

Where, Q_{sr} was the amount of direct and diffuse short wave solar radiation in the greenhouse (W), Q_e was the latent heat energy flux due to plant transpiration (W), Q_{cd} was the conduction heat transfer through the greenhouse covering material (W), Q_v the energy removed by ventilation air (W), and Q_t was the net thermal radiation through the greenhouse covers to the atmosphere (W). Each term was defined by a relationship.

The variable Q_{sr} was expressed as:

$$Q_{sr} = \tau_c S_1 I_{sr} A_f$$

.....(2)

where τ_c was the transmissivity of the greenhouse covering materials for solar radiation, S_1 was the shading level, I_{sr} was the amount of solar radiation energy received per unit area and per unit time on a horizontal surface outside the greenhouse (W/m²), and A_f was the floor area of the greenhouse (m²).

The variable Q_e in equation (1) was expressed as:

$$Q_e = ETL_v A_f$$

.....(3)

Where ET was rate of transpiration (KgH₂O/sec.m²) and L_v was latent heat of vaporization of water (J/Kg H₂O).

The variable Q_{cd} in equation (1) was defined by the following relationship:

$$Q_{cd} = UA_c(T_i - T_o)$$

.....(4)

where U was the heat transfer coefficient (W/m² °C), A_c was area of the greenhouse covers (m²), T_i was the inside air temperature (°C), and T_o was the outside air temperature (°C).

Since the transmitted thermal radiation loss was considered separately and not included as a part of the U value for conduction heat loss, U was given the value of 2.73 W/m² °C (ASHRAE guide and data book fundamentals, 1981)

The variable Q_v in equation (1) was expressed as:

$$Q_v = V_{va}(1/v)C_p(T_i - T_o)$$

.....(5)

where V_{va} was the volumetric ventilation rate (m³/s), v was the specific volume of air (m³/kg), and C_p was the specific heat of air (J/Kg °C). When the evaporative cooling system was used, T_o in equation (5) was the temperature of the air leaving the cooling system. It was expressed as:

$$T_e = T_o - \eta(T_o - T_{wb})$$

.....(6)

The variable Q_t was the difference between the thermal radiation emitted from the surface and the thermal radiation gained from the atmosphere such that:

$$Q_t = \sigma A_f \tau_{tc} \tau_{os} (\varepsilon_i T_i^4 - \varepsilon_i T_{sky}^4)$$

.....(7)

where σ was the Stefan-Boltzmann's constant ($5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$), τ_{tc} and τ_{os} were the transmissivities of the thermal radiation for the double layer polyethylene and the shading material, respectively, ε_i was the average emissivity of the interior surface, and ε_{sky} was the apparent emissivity of the sky. The emissivity of the sky was evaluated by the following equation (Idso, 1981):

$$\varepsilon_{sky} = 0.70 + 5.95 \times 10^{-7} e_o \exp(1500/T_o) \quad \dots\dots\dots(8)$$

where $e_o(T_o)$ and T_o were ambient vapor pressure and temperature at a standard height in Pa and K, respectively.

The sky temperature was approximated by the Swanbank model (1963) as a function of outside air temperature (T_o in unit of Kelvin):

$$T_{sky} = 0.0552 \times (T_o)^{1.5} \quad \dots\dots\dots(9)$$

Substituting equations (2-5) into equation (1), and expressing each term per unit floor area yielded:

$$I_{sri} = ETL_v + a(T_i - T_o) + V_{va}b(T_i - T_e) + \frac{Q_t}{A_f} \quad \dots\dots\dots(10)$$

where V_{va} was the volumetric ventilation rate ($\text{m}^3/\text{s.m}^2$ of floor area), $a = A_c/A_f$, $b = (1/v)C_p$, $T_e = T_o$ when the natural or fan ventilation was used without evaporative cooling, and $I_{sri} = \tau_c S_l I_{sr}$.

Then, an expression for the interior temperature was derived as

$$T_i = [I_{sri} - Q_t/A_f + (aT_o + bV_{va}T_e) - ET L_v] / (a + bV_{va}) \quad \dots\dots\dots(11)$$

It is clear from equation (11) that the variables affecting inside greenhouse temperature (T_i) were the inside solar radiation (I_{sri}), outside temperature (T_o), transpiration rate (ET), and ventilation rate (V_{va}).

16.3 MASS BALANCE MODEL

To evaluate the inside relative humidity for a given ventilation rate and a rate of moisture production, a mass balance calculation was performed. In this study, it was assumed that moisture loss from the air by condensation on the surfaces was small and was neglected. Also, the plant transpiration was assumed to be the only source of moisture production in

naturally and fan ventilated greenhouses. When the evaporative cooling system was used, additional moisture was added to the greenhouse environment by the cooling system. The overall mass balance was:

$$M_v = M_{et} \quad \dots\dots\dots(12)$$

Where, M_v was the amount of moisture transferred from the inside air to the outside air via ventilation ($\text{Kg H}_2\text{O} / \text{s}$), which was expressed as:

$$M_v = (1/v) V_a (w_i - w_o) \quad \dots\dots\dots(13)$$

Where w_i and w_o were the humidity ratios of the inside and outside air, respectively, in $\text{KgH}_2\text{O} / \text{Kg dry air}$.

The variable M_{et} in equation (13) was the amount of moisture added by transpiration ($\text{Kg H}_2\text{O} / \text{s}$).

The relationship for relative humidity (RH) expressed as a percent was given by the equation:

$$\text{RH} = [e(T) / e^*(T)] * 100 \quad \dots\dots\dots(14)$$

Where, $e(T)$ was the partial pressure of the water vapor in moist air (P_a) and $e^*(T)$ was the saturation vapour pressure (P_a). The partial pressure of water vapour was defined by:

$$E(T) = (w + P_{atm}) / (w + 0.622) \quad \dots\dots\dots(15)$$

Where, P_{atm} was the atmospheric pressure (P_a).

The saturation vapor pressure for a given temperature was computed with the equation given by ASHRAE Handbook of Fundamentals, (1993):

$$e^*(T) = \exp [-5800.2206/T + 1.3914993 - 0.04860239T + 0.41764768E-4T^2 - 0.14452093E-7T^3 + 6.5459673\ln(T)] \quad \dots\dots\dots(16)$$

Where, T was in K and $e(T)$ was in P_a .

Water use during the mass transfer process between the air and water for the evaporative cooler was evaluated by the steady flow mass balance equation:

$$M_a w_o + m_w = m_a w_e \quad \dots\dots\dots(17)$$

Where m_w was the evaporative cooling system water intake (Kg H₂O/s), m_a was the mass flow rate of the outside air through the cooling system (Kg dry air/s), and w_e was the humidity ratio of the leaving air passed through the cooling system (Kg H₂O/Kg dry air).

Therefore,

$$M_w = m_a (w_e - w_o) \quad \dots\dots\dots(18)$$

Or

$$M_w = (1/v) V_{av} (w_e - w_o) \quad \dots\dots\dots(19)$$

Equation (19) can be used to evaluate the water evaporation rate in the evaporative cooling system for a given air flow rate through the greenhouse. However, a general formula for water intake for the cooling system as a function of outside conditions needed to be evaluated. Cooling load of the evaporative cooling system of a greenhouse was expressed as:

$$Q_v = Q_{sr} - Q_e - Q_{cd} - Q_t \quad \dots\dots\dots(20)$$

The volumetric ventilation rate with an average inside design temperature was defined as:

$$V_{va} = \left[I_{sri} - \frac{Q_t}{A_f} - a(T_i - T_o) - ETL_v \right] / b(T_i - T_e) \quad \dots\dots\dots(21)$$

Where ,a and b were described in equation (10)

Since the evaporative cooling process is an adiabatic exchange of heat, the amount of sensible heat removed from the air equals the amount of heat absorbed by the water evaporated as latent heat of vaporization. Therefore, the difference ($w_e - w_o$) was expressed as:

$$w_e - w_o = \frac{C_p}{L_v} (T_o - T_e) \quad \dots\dots\dots(22)$$

Substituting equations (22) and (21) in equation (19) yielded

$$m_w = \left\{ \frac{[I_{sri} - Q_t - a(T_i - T_o) - ETL_v]}{T_i - T_e} \right\} d(T_o - T_e) \dots\dots\dots(23)$$

Where, $d=1/L_v$.

In Equation (23), water intake by the evaporative cooling system was a function of solar radiation, ambient and inside temperatures.



Module No. 11 Greenhouse Heating, Cooling, Shedding and Ventilation System

Lesson 17 Heating Systems

17.1 INTRODUCTION

A Greenhouse is developed with a motto of getting optimum crop production or maximum profit. This includes an environment for work efficiency as well as for crop growth. There are many methods and equipment which are used for controlling or maintaining desired temperature and other environmental conditions

inside a greenhouse. While selecting a heating system one needs to consider types of plants produced, level of quality of production strived for, types of greenhouses used and management procedures followed.

17.2 HEATING OF GREENHOUSE

A good heating system is one of the most important steps to successful plant production. Any heating system that provides uniform temperature control without releasing material harmful to the plants is acceptable. Suitable energy sources include natural gas, LP gas, fuel oil, wood and electricity. The cost and availability of these sources will vary somewhat from one area to another. Convenience, investment and operating costs are all further considerations. Savings in labour could justify a more expensive heating system with automatic controls. Greenhouse heater requirements depend upon the amount of heat loss from the structure. Heat loss from a greenhouse usually occurs by all three modes of heat transfer: conduction, convection and radiation. Usually many types of heat exchange occur simultaneously. The heat demand for a greenhouse is normally calculated by combining all three losses as a coefficient in a heat loss equation.

17.2.1 Factors affecting heat loss

Heat loss by air infiltration depends on the age, condition and type of greenhouse. Older greenhouses or those in poor condition generally have cracks around doors or holes in covering material through which large amounts of cold air may enter. Greenhouses covered with large sheets of glazing materials, large sheets of fibre glass, or a single or double layer of rigid or flexible plastic have less infiltration (Figure17.2.1).

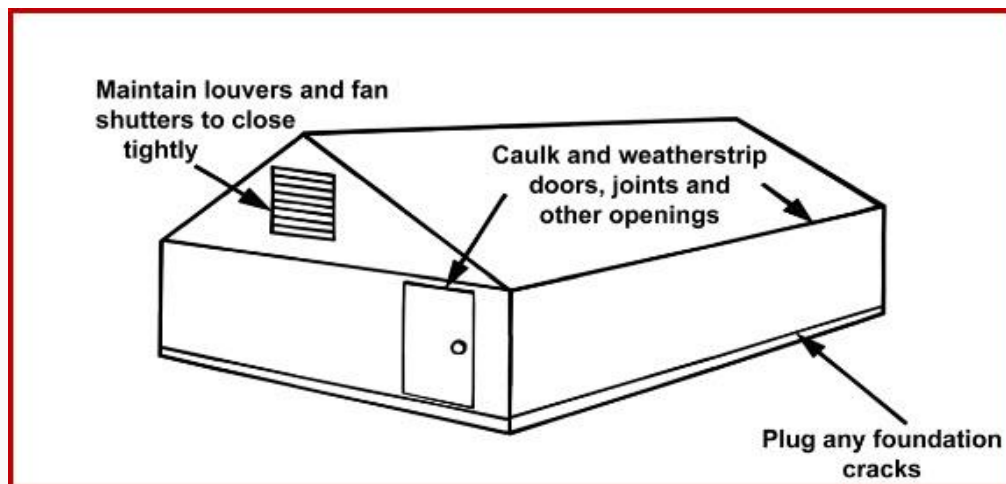


Fig 17.2.1 Energy loss due to infiltration

(Source: John Worley *et al.* 2011)

The greenhouse ventilation system also has a large effect on infiltration. Inlet and outlet fan shutters often allow a large air exchange if they do not close tightly due to poor design, dirt, damage or lack of lubrication. Window vents seal better than inlet shutters, but even they require maintenance to ensure a tight seal when closed. Solar radiation enters a greenhouse and is absorbed by plants, soil and greenhouse fixtures. The warm objects then re-radiate this energy outward. The amount of radiant heat loss depends on the type of glazing, ambient temperature and amount of cloud cover. Rigid plastic and glass materials exhibit the “greenhouse effect” because they allow less than 4 percent of the thermal radiation to pass back through to the outside.

17.2.2 Heat loss calculation

Heat loss by conduction may be estimated with the following equation:

$$Q = A (T_i - T_o) / R$$

Where,

Q = Heat loss, BTU/hr

A = Area of greenhouse surface, sq ft

R = Resistance to heat flow (a characteristic of the material)

($T_i - T_o$) = Air temperature differences between inside and outside

Table 17.2.1 lists different materials commonly used in greenhouse construction and their associated R values. Table 17.2.1 also lists overall R values for various construction assemblies. Note that high R values indicate less heat flow. Building materials that absorb moisture will conduct heat once they are wet. Use vapour barriers to protect materials that are permeable to water vapour. Heat is also lost to the ground underneath and beside a

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greenhouse. The perimeter heat loss may be added to other losses using Table 17.2.1 and the equation:

$$Q = PL (T_i - T_o)$$

P = Perimeter heat loss coefficient, BTU/ft °F hr

L = Distance around perimeter

Add infiltration heat losses to the conduction heat losses. The equation for infiltration heat transfer follows:

$$Q = 0.02 V C (T_i - T_o)$$

V = Greenhouse volume, cu ft

C = Number of air exchanges per hour

Table 17.2.2 lists estimates of air exchanges through types of greenhouses. The number of air exchanges per hour will vary depending on the type and condition of the greenhouse and the amount of wind.

Table 17.2.1 Heat flow through various construction materials and assemblies.

Materials	R value
Glass fiber board, 1"	4.0
Expanded polystyrene, 1", cut surfaces	4.0
Expanded polystyrene, 1", smooth skin surface	5.0
Expanded polystyrene, moulded beads, 1"	3.6
Expanded polyurethane, 1"	6.2
Vermiculite, 1"	2.2
Glass fibre blanket, 3-3.5"	11.0
Glass fibre blanket, 5.0-6.5"	19.0
Wall material	
Concrete block, 8"	2.0*
Plywood, ½"	1.43*
Concrete, poured, 6"	1.25*
Concrete block or plywood, plus 1" foamed urethane	7.69*

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or plus 1" polystyrene	5.0*
Greenhouse with thin thermal curtains	1.42-3.33*
Construction assemblies material	
Roof and wall coverings	
Glass, single layer	0.91*
Glass, double layer, ¼" space	2.00*
Polyethylene or other film, single layer	0.83*
Polyethylene or other film, double layer separated	1.43*
Polyethylene film, double layer, separated, over glass	2.00*
Fiberglass reinforced pane	0.83*
Double acrylic or polycarbonate	2.00*
Perimeter	BTU/linear ft.°F hr
Uninsulated	0.8
Insulated	0.4

* Includes effects of surface coefficients

Table 17.2.2 Natural Air Exchanges for Greenhouses

Construction System	Air Exchanges per Hour ¹
New Construction, glass or fiberglass	0.75 to 1
New Construction, double layer plastic film	0.5 to 1.0
Old Construction glass, good maintenance	1 to 2
Old Construction glass, poor condition	2 to 4

1 Low wind or protection from wind reduces the air exchange rate.

Minimum Design Temperatures

A good outside temperature to use in heater design calculations (to select heater size) can be found by subtracting 15°F from the average daily minimum January temperature. Another requirement the heater must meet is to provide enough heat to prevent plants from freezing during periods of extremely low temperatures.

17.2.3 Other heating system design considerations

Plastic greenhouses often have a humidity build-up within the enclosure since almost no cracks or openings exist as in a glass house. High humidity can lead to increased occurrence of leaf and flower diseases. A forced air heating system helps mix the air within the house and helps prevent temperature variation within the house. In fact, it is desirable to have fans along the walls to circulate and mix the warm air with the cooler air near the surface. They can be operated continuously during cold periods even if the heater is not on.

Duct systems to evenly distribute the heated air from the forced warm air furnace are desirable. Two or more small heating units are preferable to one larger unit, since two units offer more protection if one unit malfunctions. A warning device is good insurance should the heating system malfunction or if a power failure occurs. Some greenhouse operators prefer to have a battery powered alarm system to warn them if the temperature gets out of the acceptable range.

17.3 HEATING SYSTEM

17.3.1 Unit Space Heater

Unit space heaters, either floor mounted or supported, are normally fuelled with natural or bottled gas or fuel oil and use fans for heat distribution. This system requires a relatively moderate capital investment, is easy to install, and provides for easy expansion of facilities. If unit air heaters are used they should be spaced and directed to blanket the entire area with heated air.

There are two main types of unit heaters that are used for space heating in greenhouses: vented and unvented. The traditional vented gas fired unit heater transfers heat from combustion gases outside the greenhouse through a flue pipe. An unvented unit heater burns the gas and exhausts all combustion gases directly into the greenhouse, so virtually all the heat from the fuel is used to heat the air.

There are four types of vented unit heaters; gravity vented, power vented, separated combustion and high efficiency condensing heaters.

17.3.1.1 Gravity vented unit heaters

Gravity vented unit heaters rely on thermal buoyancy and draw from wind blowing past the vent pipe to exhaust the flue gases. These heaters use inside air for combustion which accounts for 2% of the efficiency loss and some heaters use continuous pilot lights, which consume a small amount of additional energy. Thermal efficiency of gravity vented unit heater is 80%.



Fig 17.3.1 Gravity vented unit heaters

(Source: Scott Sanford, 2011)

17.3.1.2 Power vented unit heaters

A power vented unit heater has small blower that meters the correct amount of air for combustion and exhaust the flue gases. The blower operates only when the heater is firing. This type of unit heater uses a smaller exhaust pipe that can be run horizontally through the wall of the greenhouse reducing installation costs and acting like a vent damper to minimize thermal buoyancy losses. Gas fired power vented heaters often use an intermittent or electronic pilot, which reduces flameouts and pilot gas use. The seasonal efficiency of a power vented unit heater is typically about 78% with thermal efficiency of 80%.



Fig 17.3.2 Power vented unit heaters

(Source: www.modinehvac.com)

17.3.1.3 Separated combustion unit heaters

Separated combustion heater is designed for heating areas that have negative pressure or high humidity, dusty or corrosive environments. These heaters use a power vented exhaust and have a separate air intake duct for combustion air. Modern plastic greenhouses are tightly constructed with fewer seams than glass greenhouses and thus have low infiltration rates, it is possible during times of peak heating for many types of unit heaters to use enough oxygen in the greenhouse to cause poor combustion or to cause flue gases to be drawn into the greenhouse through the flue pipe. Back drafts of flue gases can be a problem if greenhouse is located in windy area or if exhaust fans and heaters are inadvertently used at the same time. Thermal efficiency of these heaters is 80%.

17.3.1.4 High efficiency condensing heater

These heaters condense some of the moisture out of flue gas to squeeze out more energy. This technology has been around for many years and is used in most residential furnaces sold today. High efficiency condensing heaters use a power vented exhaust and a separate air intake, so heated greenhouse air is not used for combustion and they require a drain or other way to dispose of the acidic condensate. Both the thermal and seasonal efficiencies are typically about 93%. High efficiency condensing heaters are more expensive than other types but they provide more heated air per unit of fuel.

17.3.1.5 Portable unit heaters

Portable unit heaters are often used for temporary or emergency heating and operate on kerosene heating oil or LP gas. These unvented units are not suited for use in enclosed structures because they do not have air intake venting. If using portable units for emergency or temporary greenhouse heating, use only LP gas fired units and open a vent or prop open a door to replace the oxygen burned by the heater.



Fig 17.3.3 Portable unit heaters

(Source: Scott Sanford, 2011)

17.3.2 Hot water system

Hot water systems utilizing piping that can be perimeter, under benches, or overhead fan forced unit heaters can be used. These require a boiler, valves, and other necessary controls. However, a hot water system is simpler to install and normally requires less maintenance than a steam system. There are slower heating and cooling of pipes, but temperatures are normally more uniform. Hot water systems are mainly used in smaller ranges.



Fig 17.3.4 Hot water system

(Source: <http://blog.maripositas.org>)

17.3.3 Steam heating system

A steam heating system needs a boiler, valves, traps and other controls depending upon the size and type of boiler used. Steam provides rapid heating and cooling of the steam lines and usually pipe length needed is less. Lines may be smooth or finned, and about 1/3 of the heat should be overhead and about 2/3 along the side walls. Lines can also be arranged under benches or with overhead fan-forced unit heaters. A steam system also allows the use of steam for soil pasteurization. A steam system requires a high initial investment; however, it has a long life expectancy. Steam heating systems are most often used in large ranges as steam can be transported long distances efficiently.



Fig 17.3.5 steam heater

(Source: <http://blog.maripositas.org>)

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The boiler has to distribute the steam or hot water into the greenhouse there are various ways of doing this as shown below:

- Pipe rail heating distribution



(Source: <http://blog.maripositas.org>)

- Hoist Heating distribution



(Source: <http://blog.maripositas.org>)

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- Under Bench Heat Distribution



(Source: <http://blog.maripositas.org>)

- In Floor Heat Distribution



(Source: <http://blog.maripositas.org>)

- Overhead Heat Distribution



(Source: <http://blog.maripositas.org>)

- Perimeter Heat Distribution



(Source: <http://blog.maripositas.org>)

17.3.4 Unit radiant heaters

Radiant heater, as opposed to warm air systems (such as a forced air unit heaters), delivers the source of heat to the floor level, not the ceiling. Radiant energy is the oldest form of heating used to provide comfort and is the basis for all heating systems. Radiant energy is totally pure radiation and is absorbed by an object without physical contact with the heat source or by heating the surrounding air, as is the case with convective, forced air systems. Radiant heaters are the most efficient and effective method in which to deliver "heat" under the diverse conditions present in warehouses, garages, storerooms as well as the largest facilities imaginable. Hot gases are moved through the radiant tube either by vacuum (negative) or power (positive) pressure. The radiant energy produced is then directed downward by the reflectors positioned above the radiant tubes. The floor is typically the largest mass within any building. Thus the floor becomes the primary source of heat. A gas fired radiant heating system emulates the sun's radiant output. Like the sun, the radiant tube emits Radiant energy in all directions. Convection losses from a radiant tube which is not covered by a reflector are great. Reflectors positioned above the radiant tube direct the radiant energy towards the floor area. The radiant energy is converted into heat when absorbed by objects in its path. The radiant energy is absorbed by the building's heat sinks, i.e. concrete floors, machinery, fixtures, etc. This heat sink is what in turn re-radiates energy for the "warmth" that is felt in the surrounding air. Because stratification of air (difference between floor temperature and ceiling temperature) is significantly lower than conventional hot, forced air systems, the structure heat loss is greatly reduced resulting in large savings in heating dollars.

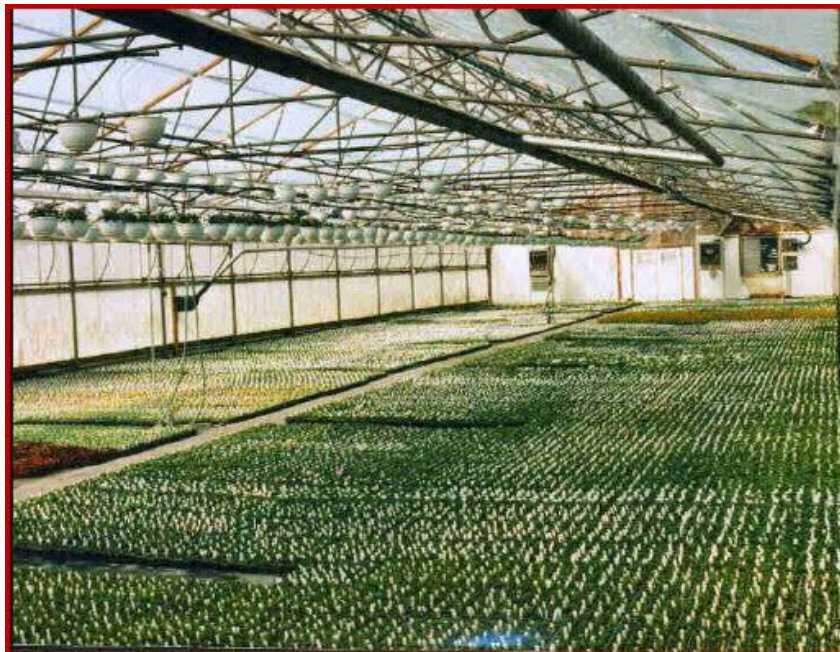


Fig 17.3.6 Radiant heaters

(Source: www.radiantheater.net)

17.3.5 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. 17.3.7) 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 collector 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.

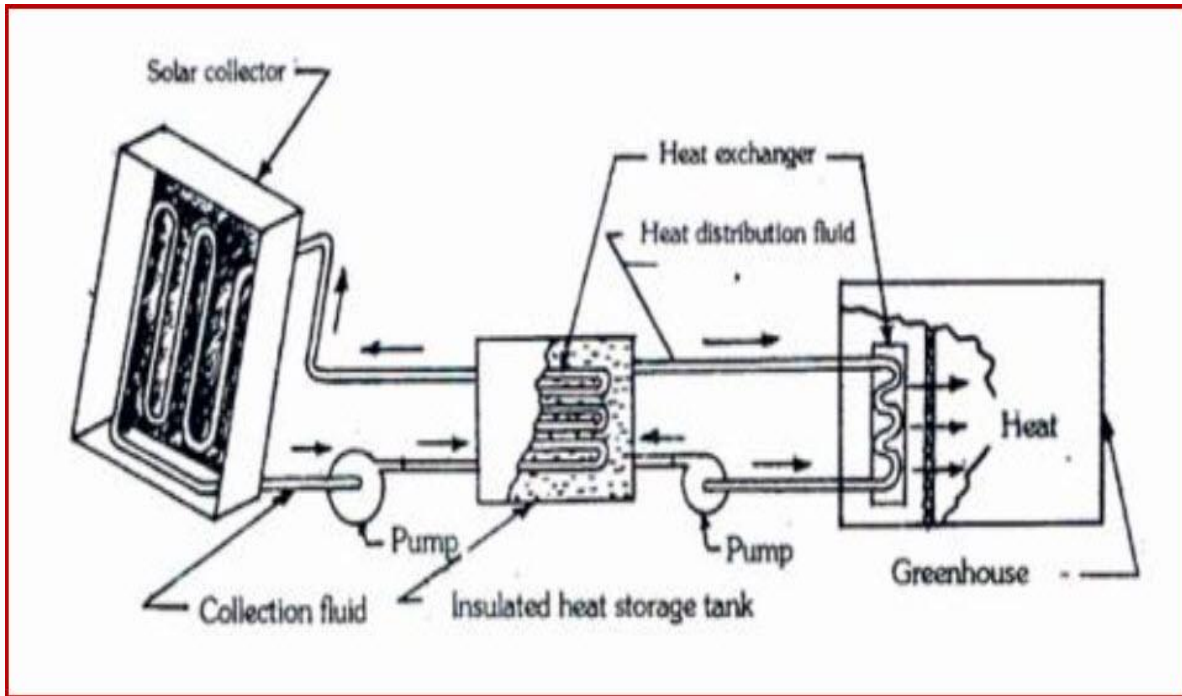


Fig 17.3.7 Solar heating system used for greenhouse heating

(Source: www.tnau.ac.in)

17.4 FACTORS TO CONSIDER WHILE SELECTING GREENHOUSE HEATING SYSTEM

1. Before determining the type of a system to use, it is necessary to calculate the amount of heat that will be required. Remember this should be based on the most adverse conditions that you reasonably expect to encounter.
2. The minimum inside temperature depends on the type of plants to be grown. Decide whether you just want to save the plants from the severe injury or if you want normal or near normal growth to continue. Then determine the temperature needed to achieve your objective, subtracts expected minimum adverse temperature for your location and obtain the differential in °F or which you need to be prepared.
3. An easy and fairly accurate method for estimating the amount of heat required can be obtained by multiplying the surface area of the greenhouse by the maximum temperature difference to be maintained, and this product times a heat transmission factor that depends on the covering of the greenhouse and is also influenced by quality of construction. A factor of 1.0 to 1.2 is used if the house is covered by a single layer of polyethylene film (PE) or rigid plastic. 1.0 would assume a well built, tight greenhouse, while 1.2 would assume a little less quality construction and more air leakage. The same analogy will be true for the transmission factors used for other materials.
4. Also, wind velocity affects the transmission factor; the higher the wind velocity, the greater the heat loss. Use a factor of 0.75 to 0, if the house is covered with a double layer of PE film with an air space of at least $\frac{3}{4}$ " but not more than $\frac{4}{2}$ ". Use a factor

between 1.1 to 1.4, if the greenhouse is glass glazed. Add 10 percent to the values obtained if the house is located in a windy location and there are many leaks for air infiltration. If the house were very highly constructed and fairly large panels were used and, if the house were protected by a wind brake of some kind then you can use a lower heat transmission factor of about 1.0. Then calculate the heating input required and use its value to determine the pipe length in steam and hot water systems or the size of the unit heaters. If a central boiler is used, add at least 25 percent to determine boiler size to allow for heat losses in the distribution system.

5. Another factor to consider is the efficiency of the heating unit. Most manufacturers of heating equipment show both input and output BTU/hr. Calculations on equipment size must be based on output capacity.
6. In conclusion, successful heating of greenhouses is dependent upon correct sizing and installation of the heating system, proper controls and methods of obtaining uniform heat distribution. A type of greenhouse construction, crops to be grown and temperature levels to be maintained are all important factors to consider in the selection and design of any greenhouse heating system.
7. Heating system should allow for easy expansion of the range in the future, and the system should have sufficient capacity to offset the heat loss from the greenhouse under most severe conditions. Normally design for temperatures slightly above minimum 15 to 25 year lows as shown by local weather records.
8. Provide an adequate system of automatic controls. The most important control in most heating systems is the thermostat, which is used to control the operation of the heating system. For this reason, the thermostat should be placed at plant level, and shielded from direct rays of the sun, and it should sense "line air." Thermostats for greenhouses should be accurate to within at least 2-3 °F. It is not enough to have good control over the heating system. An operator must know what degree of temperature control is necessary for the type of plants being produced.
9. If possible, select a heating system that will allow you to convert from one fuel source to another.



Lesson 18 Cooling, Shedding and Ventilation Systems of Greenhouse

18.1 INTRODUCTION

Environmental control for heating and cooling uniformity is a very important design consideration to maintain desired environmental set point conditions inside a greenhouse. However, the distribution of heat or cooling is difficult, and a uniformly controlled environment may not result. Non uniform environments cause differential plant growth rates, potential disease problems, unpredictable results with nutrition or hormonal application, and generally a more difficult plant production system to manage.

For the most effective and uniform cooling and heating, the rows of plants should be arranged in the direction parallel with the ridge or gutters of the greenhouse structure. For ventilation, this assumes that the ventilation system (fans and air inlets) would be located on the end walls (perpendicular to the direction of the gutters). If airflow is restricted and non-uniform, then the ventilation system cannot effectively cool the plant, nor provide the sufficient air exchange for humidity reduction (disease control) and replenishing carbon dioxide. Evaporative cooling systems, whether fan and pad, or high-pressure fog, are highly dependent upon effective and uniform ventilation, as well.

18.2 VENTILATION

Greenhouses can be mechanically or naturally ventilated. Mechanical ventilation requires (louvered) inlet openings, exhaust fans, and electricity to operate the fans. When designed properly, mechanical ventilation is able to provide adequate cooling under a wide variety of weather conditions.

Natural ventilation (Figure 18.2.1) works based on two physical phenomena: thermal buoyancy (warm air is less dense and rises) and the so-called “wind effect” (wind blowing outside the greenhouse creates small pressure differences between the windward and leeward side of the greenhouse causing air to move towards the leeward side). All that is needed are (strategically located) inlet and outlet openings, vent window motors, and electricity to operate the motors. In some cases, the vent window positions are changed manually, eliminating the need for

motors and electricity, but increasing the amount of labour since frequent adjustments are necessary. Compared to mechanical ventilation systems, electrically operated natural ventilation systems use a lot less electricity and produce (some) noise only when the vent window position is changed. When using a natural ventilation system, additional cooling can be provided by a fog system.

Unfortunately, natural ventilation does not work very well on warm days when the outside wind velocity is low (less than 200 feet per minute).

Keep in mind that whether using either system with no other cooling capabilities, the indoor temperature cannot be lowered below the outdoor temperature. Due to the long and narrow design of most free standing greenhouses, mechanical ventilation systems usually move the air along the length of the greenhouse (the exhaust fans and inlet openings are installed in opposite end walls), while natural ventilation systems provide crosswise ventilation (using side wall and roof vents; fig 18.2.2). In gutter-connected greenhouses, mechanical ventilation systems inlets and outlets can be installed in the side- or end walls, while natural ventilation systems usually consist of only roof vents. Extreme natural ventilation systems include the open-roof greenhouse design (fig 18.2.3), where the very large maximum ventilation opening does not allow the indoor temperature to exceed the outdoor temperature. This is often not attainable with mechanically ventilated greenhouses due to the very large amounts of air that such systems would have to move through the greenhouse to accomplish the same results. When insect screens are installed in ventilation openings, the additional resistance to airflow created by the screen material has to be taken into account to ensure proper ventilation rates. Often, the screen area is larger compared to the inlet area to allow sufficient amounts of air to enter the greenhouse. Whichever ventilation system is used, uniform air distribution inside the greenhouse is important because uniform crop production is only possible when every plant experiences the same environmental conditions. Therefore, horizontal airflow fans are frequently installed to ensure proper air mixing.



Fig 18.2.1 Natural Ventilation

(Source: Both A.J ,(2008))



Fig 18.2.2 Natural ventilation providing crosswise ventilation

(Source: <http://www.nexuscorp.com>)



Fig 18.2.3 Open roof ventilation design

(Source: <http://aesop.rutgers.edu>)

18.3 COOLING

When the regular ventilation system is unable to provide sufficient cooling for greenhouse temperature control, additional cooling is needed. Two cooling systems, the fan and pad and the fog system, are commonly used in greenhouses and both make use of the cooling effect resulting from the evaporation of water (Figures 18.3.1 and 18.3.2). The process of evaporation requires heat that is removed from the air surrounding the evaporating water.

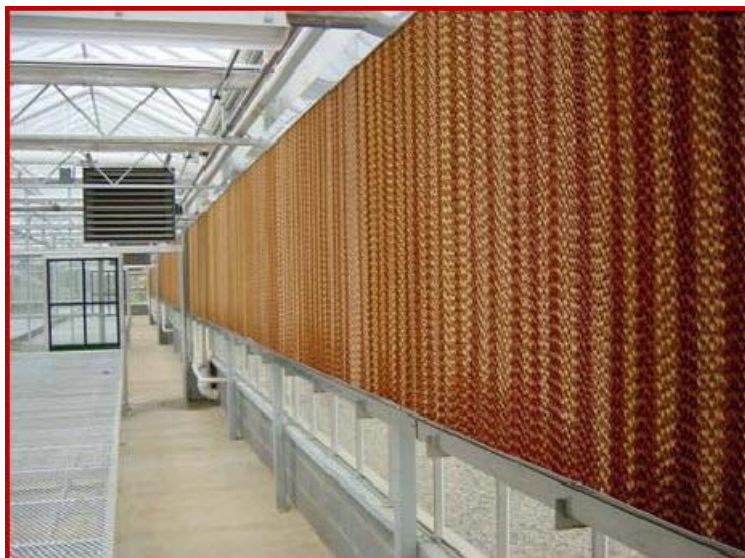


Fig 18.3.1 Evaporative cooling pad



Fig 18.3.2 Greenhouse misting system

18.3.1 Fan and pad evaporative cooling system

Fan and pad systems consist of exhaust fans at one end of the greenhouse and a pump circulating water through and over a porous pad (Figure 18.3.3) installed at the opposite end of the greenhouse



Fig 18.3.3 Pump circulating water through and over a porous pad

(Source: <http://www.gildan.co.il>)

If all vents and doors are closed when the fans operate, air is pulled through the wetted pads and water evaporates. As each gallon of water is evaporated, 8,100 BTUs of heat energy is absorbed from the air by the water during the change from liquid to vapour. Removing energy from the air lowers the temperature of the air being introduced into the greenhouse.

The air temperature reduces after passing through the pads. As the air moves across the house to the fans, it picks up heat from solar radiation, plants, and soil, and the temperature of air increases gradually. The resulting temperature increases as air moves down the greenhouse & produces a temperature gradient across the length of the greenhouse, with the pad side being coolest and the fan side warmest.

If the efficiency of the evaporative cooling system is known, the temperature of air exiting a cooling pad can be calculated by the following equation.

$$T_{cool} = T_{out} - (\% \text{ efficiency}) (T_{out} - T_{wb})$$

Where,

T_{cool} = temperature of air exiting cooling pad;

T_{out} = temperature of the outside air;

T_{wb} = wet bulb temperature of the outside air.

A well designed, properly installed and operated evaporative cooling system may have an efficiency of up to 85 percent.

18.3.1.1 Factors influencing fan and pad evaporative cooling systems:

1. Operational Considerations: It is very important to keep the building as tight as possible so entering air will be forced through the pads. Make sure that all doors and other openings are kept closed except when in use and that any gap in the greenhouse coverings is sealed.
2. Greenhouse location and orientation: Orientation of the greenhouse relative to other buildings or structures and in relation to prevailing summer winds influence the efficiency of operation. Fan arrangements and locations of the fans and pads should be determined by greenhouse location and orientation.
3. Types of cooling pad: Compare costs, life expectancy claims, cooling efficiencies, and probability of maintenance problems before selecting the one that is best for your operation.
4. Cooling pad area: The amount of pad area needed depends upon several factors including the type of pad material used. The pads should be continuous along the entire length of the wall.
5. Water flow rate: To maximize operating efficiency, you must have adequate pad surface area and an adequate water supply and distribution system. The amount of water needed will vary with the type of system used, but, normally, complete pad surface wetting occurs when about 1/3 gallon of water per foot of pad length is recirculated.
6. Problems with cooling pads: Evaporative cooling pads have severe problems. They lose efficiency due to clogging from impurities in the water, algae growth and decay. If the pad material is clogged or decomposed its ability to function as designed is impaired.
7. Airflow through cooling pads: The required face velocity of the air will depend upon the pad material. Follow manufacturer's suggestions. This velocity will determine the number of square feet of pad area needed for a house of a given configuration.
8. Fans: Regardless of the type of pad material used, the fans should have the capacity to provide a minimum of one air change per minute in the greenhouse. Equip the fans with automatic shutters to eliminate back drafts when a fan is not operating (Figure 18.3.4).



Fig 18.3.4 Ventilation and cooling fans equipped with anti-back draft shutters.

(Source: <http://www.digood.com>)

18.3.1.2 Location of fan and cooling systems

The best distance between the pad and exhaust fans is a tradeoff between the optimum dimensions of the greenhouse (based on efficiency, function, and operation) and the tolerance of the crop to higher temperatures. The greater the range of the crop's temperature tolerance, the greater the distance between pad and fans can be. It is not practical to separate the pad and exhaust fans by more than 200 feet. A distance of 150 feet or less is preferred.

18.3.2 Fog Cooling System

The fog evaporative cooling system (Fig 18.3.5), introduced in green houses in 1980, operates on the same cooling principle as the fan and pad cooling system but uses quite different arrangement. 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 does not take place in fan and pad system due to bigger droplet size, whereas in the fog cooling system, complete evaporation takes place because of the minute size of the water droplets. Thus lesser the dryness of the air, greater evaporative cooling is possible.



Fig 18.3.5 Fog evaporative cooling system

(Source: <http://mistafog.com.au>)

18.4 SHADING

- Greenhouse shading is a procedure for cooling which attempts to reduce the amount of solar radiation which reaches the plants. By reducing the solar load on the greenhouse, the air temperature difference is smaller, making the absolute air temperatures inside the greenhouse closer to the outside temperatures.
- Secondly, the leaf surface temperature can be significantly reduced. This may be the more important factor, since it affects the plant processes such as photorespiration, an unwanted process that consumes the stored energy reserves within the leaf.
- When leaf temperature is not a limiting factor to net photosynthesis, shading may reduce the growth and development rate of the plants by limiting photosynthesis as a result of lowered light intensity. This could prolong the plant growth time needed to reach maturity or inhibit plant quality for certain crops.
- Typically during the time of the year when shading is needed for the purpose of cooling, solar radiation is not a limiting growth factor. However a good control system could prevent most shade related problems. It can easily deploy an automated shade curtain only at desired times of the day. This control could be based on the measured solar radiation intensity or more simply on the time of the day.
- The traditional way for shading is to apply a semi-permanent shading compound to the outer glazing of the greenhouse. In glasshouses and more recently polyethylene greenhouses, a white liquid is used which could easily be applied by spraying. (Fig 18.4.1)



Fig 18.4.1 Greenhouse shading with white paint

(Source: <http://www.interiordesigninspiration.net>)

- Another procedure for shading consists of attaching a black polypropylene mesh screening on the outer glazing (Fig 18.4.2). The density of the mesh determines the amount of shading desired. Shading can be obtained from 30 to 92%. The material can be made in widths from 1.8 to 7.3 m (6 to 24 feet).



Fig 18.4.2 Greenhouse shading with black polypropylene mesh screening

(Source: <http://www.harpstarps.com>)

- Application and removal of either of these shading procedures is typically completed once for each season. They do not allow for a choice of shading on a day-to-day basis, should it be necessary.
- More recently, internal shading systems have been installed (Fig 18.4.3). They may be the same system which is utilized as the energy saving curtain in the night.



Fig 18.4.3 Internal shading system of greenhouse

(Source: <http://www.gothicarchgreenhouses.com>)

- These are typically attached to mechanisms for deploying and retracting the curtain after sunset and prior to sunrise. However they can be utilized during the day for shading assuming that light transmission is not severely reduced. In some instances, a separate system for shading, in addition to the energy curtain is installed. Each would be used independently.
- Retractable roof greenhouse designs (Fig 18.4.4) can be utilized as shade structures. Retractable roof greenhouses can be covered with translucent, water-impermeable plastic materials, and be completely opened to the outside environment, or closed to provide a traditional plastic greenhouse structure and environment. They may also be covered with a woven, water-porous, shade curtain material, and be completely opened to the outside, or closed to provide a traditional shade greenhouse environment.



Fig 18.4.4 retractable roof greenhouse

(Source: <http://www.freshplaza.com>)

- The exciting feature in both of these designs is for protected plant growth, with the option for an open cover plant growth similar to outdoor production. The challenge to these structures is that they are open to insect pests.

Module 12. Carbon dioxide generation and monitoring and lighting systems

Lesson 19 Carbon dioxide generation and monitoring and lighting systems

19.1 INTRODUCTION

19.2 CARBON DIOXIDE ENRICHMENT

19.2.1 CO₂ Concentration and plants

Photosynthesis is the process of plants using light energy to convert absorbed carbon dioxide (CO₂) and water into sugars. Plants use these sugars for growth through the process of respiration. Plants absorb CO₂ through their stomatal openings located mainly on the underside of leaves. Although light, moisture, temperature and humidity level all affect the rate of CO₂ absorption, the concentration of CO₂ outside the leaves is a significant influence.

The concentration of CO₂ in ambient outside air commonly varies from 300 to 500 parts per million (ppm) or more by volume depending on the season, time of day and the proximity of CO₂ producers such as combustion or composting, or CO₂ absorbers such as plants or bodies of water. Plants growing in greenhouses, particularly “tight” double-layer structures with a reduced air infiltration rate, can reduce CO₂ levels to well below ambient levels, greatly reducing the rate of photosynthesis. Conversely, enriching the concentration of CO₂ above ambient levels will significantly increase the rate of photosynthesis. In general, a drop in CO₂ levels below ambient has a stronger negative effect on plant growth than the positive effects of enriching CO₂ levels above ambient.

Daily CO₂ levels in un-enriched greenhouse environments will climb to several hundred ppm above outdoor ambient at night due to CO₂ produced by plant and microbial respiration. CO₂ levels drop quite rapidly after sunrise as the crop’s photo-synthetically driven consumption of CO₂ exceeds the basic rate of respiration. In the absence of some other source, CO₂ levels remain low all day limiting plant growth. At dusk, plant and microbial respiration once again begins to accumulate CO₂ in the greenhouse.

CO₂ is added in some greenhouses to increase growth and enhance crop yields. The ideal concentration depends on the crop, light intensity, temperature and the stage of crop growth.

19.2.2 How CO₂ concentration is monitored?

Most growers do not monitor CO₂ levels in the greenhouse because they have no intention of controlling it. As long as their crops are growing and developing to their satisfaction, this is a reasonable approach.

CO₂ levels in the greenhouse may be monitored using relatively low-cost dual beam infrared CO₂ gas monitors. These monitors may be linked to climate control systems that integrate

other factors such as indoor & outdoor air temperature, humidity & light intensity. More expensive monitors with higher

accuracies are available, but in most applications reliability and economical cost are the most important factors.

Although basic CO₂ dosing may be applied without monitoring CO₂ levels, the relatively low cost of a good CO₂ metering system pays for itself in the form of cost savings from supplemental CO₂ sources.

19.2.3 When CO₂ enrichment needed?

CO₂ enrichment is not required as long as the crops are growing and developing to the complete satisfaction of the grower, or if high ventilation rates make CO₂ enrichment uneconomical. CO₂ enrichment should be considered, however, if crop production and quality are below required levels. In general, crop production times from late fall through early spring increases the potential need for CO₂ enrichment as it coincides with reduced ventilation rates due to colder outdoor air temperatures. As ventilation rates are increased for cooling and dehumidification from late spring to early fall, the cost of CO₂ enrichment escalates while the benefit to the crop may be minimal or reduced. As photosynthesis and CO₂ consumption happens only during daylight hours, CO₂ enrichment at night is not required. In general, CO₂ enrichment systems should be turned on 1 or 2 hours after sunrise, and turned off several hours before sunset, however, additional CO₂ enrichment may be needed if supplemental grow-lighting is used.

19.2.4 How are CO₂ levels enriched?

1. **Maximize Natural (Free) CO₂ Supply:** Maximize ventilation rates whenever possible starting 1 or 2 hours after sunrise when the overnight build-up of CO₂ has been depleted. Improve horizontal air flow to distribute available CO₂ evenly throughout the crop and to reduce the leaf boundary layer, which will improve the diffusion of CO₂ into the stomatal openings of each leaf. Keep plants healthy and well-watered so they are not forced to close their stomatal openings due to stress. Depending on the crop, consider using natural sources of CO₂ such as decomposing straw bales and/or organic soil mixes in your production system.
2. **Liquid or Bottled CO₂ Gas:** When outside air conditions are too extreme for ventilation, additional CO₂ is available in the form of liquid or bottled CO₂ gas. Specific processes are required for the safe & proper handling as well as the effective use of CO₂ from these sources. Liquid CO₂ must be fully vaporized before delivering into the greenhouse, and manufacturers' instructions and local codes should be strictly adhered to.
3. **CO₂ from Carbon-Based Fuels:** Gas-fired appliances generate CO₂ and water vapour as primary by-products of combustion. These appliances include equipment that is specifically designed & certified as CO₂ generating appliances, un-vented forced-air primary space heaters, and hot water boiler heating systems with flue gas condensers specifically designed for CO₂ enrichment.

Achieving complete combustion is the key to success of CO₂ enrichment through appliances burning natural or propane gas. Incomplete combustion may occur due to relatively common factors such as improper or fluctuating gas pressure, impurities in the gas supply, inadequate oxygen for combustion, wind

disturbance in the burner and clogged gas orifices. Harmful by-products of incomplete combustion include Nitrogen Oxides, Carbon Monoxide and Ethylene.

To increase the likelihood of complete combustion, it is recommended to use only gas-fired appliances that are certified by 3rd-party testing agencies to meet nationally recognized safety standards. Agency-certified appliances should only be used for the applications that they are certified for, and the appliances should include installation, operating & maintenance instructions with the product. These instructions should be strictly adhered to and saved in a convenient place.

As water vapour is also a primary by-product of combustion, un-vented gas appliances have the potential to create difficulties in the naturally humid greenhouse environment. Condensation due to high humidity promotes many plant diseases. Condensation from combustion is also slightly acidic, which may prematurely corrode metal structures, equipment and wiring on contact.

Building codes and manufacturers of un-vented gas appliances typically require minimum rates of air changes in the greenhouse per volume of fuel burned. Although introducing fresh outside air will increase greenhouse heating costs in colder weather, these ventilation rates are necessary to ensure adequate supplies of oxygen for complete combustion, and to prevent the build-up of unwanted water vapour and/or contaminants due to incomplete combustion.

19.2.5 Is CO₂ enrichment safe?

CO₂ is harmless to human at all reasonable dosing levels, and OSHA has established workplace standards for worker exposure. While humans can work safely at these elevated CO₂ levels, many crops start to show undesirable growth responses at CO₂ concentrations above 1,200 to 2,000 ppm.

For gas-fired CO₂ generators, adequate ventilation air should be introduced to provide enough oxygen for complete combustion, and to limit the build-up of water vapour and other potential contaminants in the greenhouse.

19.2.6 General tips for CO₂ enrichment

CO₂ enrichment can be a useful tool for maximizing the quantity and quality of your greenhouse product. Healthier crops and higher yields helps to satisfy customers, command higher prices and reduce costs, all of which makes a greenhouse operation more competitive. The decision to proceed with CO₂ enrichment should follow a thorough cost/benefit analysis, and success depends on each grower developing a strategy based on their unique combination of greenhouse structure, crop type, local weather, stage of production and capital/operating budgets. Once a CO₂ enrichment strategy is selected, always follow the instructions and installation & service manuals of equipment and/or chemical

manufacturers. Make sure national and local codes covering greenhouse operations are adhered to, and use qualified & experienced service agencies and technicians for installing and maintaining CO₂ enrichment systems.

19.3 LIGHT MANAGEMENT

Light regulation is practised in a greenhouse for the following reasons: (i) to alter the length of daylight hours (ii) to interrupt the darkness at night (iii) to extend or reduce the dark period of the night using artificial light or darkening screens; (iv) to increase photosynthesis and (v) to decrease the light intensity.

The objective is to maximize photosynthesis by maximizing the light interception (PAR) by the greenhouse, which involves optimizing its design and orientation. In order to make the radiation useful for photosynthesis it must be intercepted by the crop, which will require the crop rows to be appropriately orientated (north-south) and a proper arrangement and density of the plants (lower in winter than in high radiation seasons), depending on the species, cultivar and crop conditions.

Under normal conditions, the LAI (leaf area index) is an indicator of the light interception. During the first stages of the crop a high plant density allows for better light interception, so early production will increase (in relation to a normal density). Once the crop covers all the available space the plant density is less relevant. A high planting density involves a decrease in the quality of the product in most species, and beyond a certain threshold a decrease in yield, when expressed on a per unit area basis.

When the solar radiation is insufficient, it may be complemented with artificial light, to increase the PAR level above the radiation compensation point and maintain an active growth. The positive effect of an increase of the PAR on the growth is more relevant at low PAR levels. Artificial light may also be used to extend the period of photosynthetic activity in the winter season.

19.3.1 Light increase

Inside the greenhouse, various techniques have been used to improve the availability of light to the crop, such as: (i) painting the greenhouse structural components white; (ii) applying a white plastic film as soil and (iii) in general making extensive use of other light reflecting materials. A usual practice is to use reflecting walls. Several reflection devices have been proposed to increase radiation, but they are usually uneconomic. However, the reflectors perform well with direct light and not with diffuse light, and unfortunately the highest interest for increasing the light availability is in the winter months when diffuse radiation prevails. Artificial light is the most reliable and effective method to increase the light availability.

19.3.2 Artificial light to increase the illumination

In commercial production, artificial light sources are used in a variety of ways:

- **Replacement lighting** - complete replacement of solar radiation for indoor growth rooms and growth chambers

Design and Maintenance of Green House

- **Supplemental or production lighting** – used in greenhouses to supplement periods of low natural light.
- **Photoperiod lighting** – used to stimulate or influence photoperiod dependant plant responses such as flowering or vegetative growth

The need for and quality of artificial illumination required is determined by a number of factors including:

1. The light requirements of the species being grown
2. The natural day length
3. The average hours of sunlight
4. The sun angle and intensity (latitude and weather)
5. The amount of structure-induced shading

19.3.2.1 Supplemental Lighting

For commercial greenhouse production, supplemental lighting is most beneficial in areas that receive less than 4.5 hours average daily sunshine. In many greenhouse growing regions this occurs in winter as a result of the combination of high northern or southern latitudes and overcast weather.

19.3.2.2 Types of lamps

Conventional horticultural light sources can be grouped into three categories:

- Incandescent
- Fluorescent
- Discharge

INCANDESCENT LAMPS

Incandescent lamps typically emit light as a result of the heating of a tungsten filament to about 2500°C. At this temperature, the emission spectrum from the filament includes a substantial amount of visible radiation. Only about 15% of the energy (watts) applied to an incandescent lamp is radiated in the PAR (photosynthetically active radiation) range of 400-700 nm. 75% is emitted as infrared (850-2700) nm, and the remaining 10% is emitted as thermal energy (> 2700 nm).

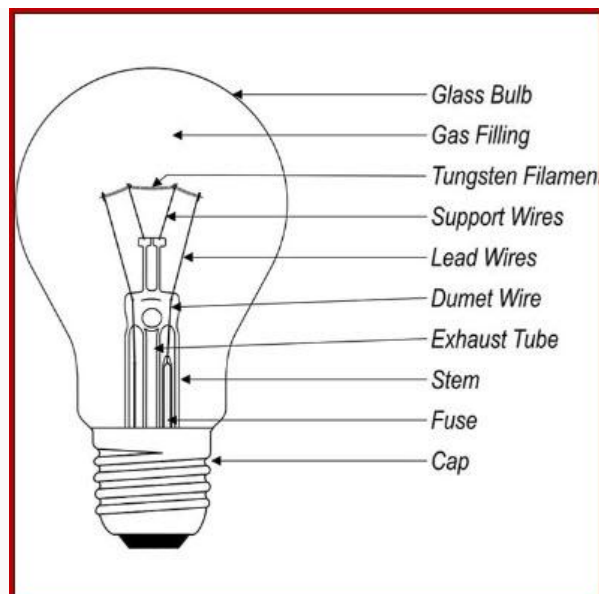


Fig 19.3.1 Incandescent lamps

(Source: www.brightubengineering.com)

Since they are not very light efficient and they have a relatively short lamp life, incandescent lamps are usually not the most effective radiation sources for providing supplementary light for photosynthesis. They are, however, useful for phytochrome-dependent photoperiod control since they are relatively inexpensive to install and operate, they can be cycled on and off frequently, and they produce large amounts of red and infrared radiation. This is why incandescent sources are often the lamp of choice for night break, and long day lighting applications, particularly when other supplementary lighting sources are not installed.

Typically, incandescent lights are used to break the night into two or more short dark periods thereby stimulating a long day growth and development response in the crop. This may be used to promote flowering in long day species such as asters, azaleas, and fuchsias, or to delay flowering in short day species such as chrysanthemums, begonias, and poinsettias.

Since plant photoperiod response occurs under relatively low light intensities, less power is needed for photoperiod lighting than for supplemental lighting. The long standing recommendation for maintaining vegetative growth in chrysanthemum crops has been to place strings of 60 watt bulbs spaced 1.2 meters apart and suspend them 1.5 meters above the crop. This will provide sufficient photoperiod lighting for a 1.2 meter bed or bench. Similarly, any combination of incandescent lamp wattage, spacing, and mounting height that can produce an output of at least 10 foot-candles evenly on the crop will work. This corresponds to about 16 electrical input watts per square meter (rated bulb wattage divided by the area illuminated). Special reflector bulbs are available to focus most of the radiation downwards or do-it-yourself reflectors are often fashioned from aluminium foil pie plates.

FLUORESCENT LAMPS

Unlike incandescent lamps, which emit light from the heating of a metal filament, fluorescent lamps produce light from the excitation of low pressure mercury vapour in a mixture of inert

gases. A high voltage differential at the electrodes on opposite ends of the lamp tube produces an arc through the gas mixture exciting the mercury ions, which in turn emit short wavelength (primarily UV) radiation as they drop back to a ground state. Special fluorescent coatings on the glass tube walls are activated by this short wavelength radiation producing a discharge of visible spectrum radiation from the lamp. By altering the composition of the fluorescent coatings, variations in spectral output are accomplished.

Florescent lamps are more light efficient than incandescent lamps and they have a much longer life span. They also run cooler and produce a fairly balanced spectrum in the PAR range. They operate best in warm temperatures with peak light output occurring when the lamp wall reaches about 38°C. As the temperature decreases, light output falls dramatically to only 50% when the lamp wall temperature is 16°C. Light output also declines as fluorescent lamps age, falling to about 60% after 10,000 hours.

Fluorescent lamps are available in three load types: normal output 400 mA (normal output), 800 mA (high output), and 1500 mA (very high output).

One disadvantage of fluorescent lamps is their relative bulk in relation to output. Even the very high output fixtures and the new slimmer T8 tubes, when configured in sufficient densities for supplemental lighting, can cast considerable shadows that can interfere with ambient lighting. They are however, useful in growth chambers and particularly in multiple tier applications since their relatively cool operating temperatures allow them to be mounted in close proximity to plant surfaces.

Fluorescent lamps are available in a range of spectral qualities. Relatively inexpensive cool white lamps are fine for supplementary lighting, and 'full spectrum' lamps are available for replacement lighting applications.



Fig 19.3.2 Fluorescent lamps

(Source: www.msue.anr.msu.edu)

HIGH INTENSITY DISCHARGE LAMPS (HID)

Modern high intensity discharge lamps are similar to fluorescent lamps in that they introduce an electrical arc into an elemental gas mixture. This produces a spectral discharge that is characteristic of the elements in the arc. However, they differ from fluorescent lamps in that no fluorescing powders are used on the lamp glass, and the elemental gases are heated under much higher vapour pressures and temperatures. The light intensities and efficiencies obtained by high intensity discharge are higher than either incandescent or fluorescent lamps. The two most common discharge lamps used in modern horticulture are metal halide and high pressure sodium lamps.



Fig 19.3.3 High Intensity Discharge lamps

(Source: <http://archiandesigns.files.wordpress.com>)

Metal Halide (MH)

Metal halide lamps use mercury vapour in a quartz arc tube and various iodide mixtures of sodium, thorium, or thallium. The electrical arc vaporizes the halides, heating them to a plasma state, whereupon they emit line spectra characteristic of the elements in the plasma. Metal halide lamps produce a relatively full spectrum of white light that is often preferable to the yellowish light of high pressure sodium when used in public or retail horticultural environments. They provide the best overall spectral distribution of all horticultural lamps, but are not quite as efficient in energy conversion as high-pressure sodium lamps in the PAR range, particularly in the yellow-red spectra



Fig 19.3.4 Metal Halide lamps

(Source: <http://archiandesigns.files.wordpress.com>)

High Pressure Sodium (HPS)

High pressure sodium has become the most popular lamp type for commercial supplemental lighting in horticulture. They are the most efficient in the PAR range with the exception of low pressure sodium lamps which, although more efficient in their conversion of watts to lumens, produce a spectral distribution so narrow that they are of little horticultural use. High pressure sodium lamps produce light from an arc-induced discharge in a mixture of sodium vapour and mercury vapour. The emission spectrum is highly concentrated in the yellow-orange-red range (500-650 nm) but is fairly low in the blue range. Used as a replacement light source, HPS lamps may require supplementation with fluorescent, mercury vapour, metal halide, or other light sources high in blue light. However, they are fine as a supplemental source since adequate amounts of blue light are usually available from ambient light to sustain blue-light-specific plant morphogenic responses. HPS lamps have a long life, and are available in a range of wattage sizes as well as ballast/reflector configurations optimized for horticultural production.



Fig 19.3.5 High Pressure sodium lamps

(Source: <https://www.sylvania.com>)

19.3.2.3 Radiant efficiency for supplementary irradiation

The following table summarizes the relative radiant efficiencies for the standard illumination sources used in horticulture.

Radiation Source	Efficiency Lumens per Watt	Average Life (Hours)
Incandescent	12-26	1000-3000
Metal Halide	80-90	8000-20000
High Pressure Sodium	117	15000-24000
Fluorescent	52-84	12000
Mercury Vapour	50-60	24000+

19.3.2.4 Luminaire Placement and Light Distribution Uniformity

The degree of growth uniformity in a crop is influenced directly by the uniformity of light falling onto the crop canopy. The manufacturers of horticulture luminaires often recommend specific grid and spacing patterns for various intensities and lighting configurations. These are determined by the specific lamp output, crop requirements, and luminaire reflector designs. Often, an overlapping pattern is designed with some additional modifications to lamp placement and density at the crop margins to produce the most uniform lighting over the entire cropping surface.

19.3.2.5 Supplementary illumination levels and duration

It has long been accepted that it is more efficient to provide a lower amount of irradiation over a longer period than a high amount over a short period. For example, it is usually better to light a crop at 5 Wm^{-2} for 18 hours, than at 10 Wm^{-2} for 9 hours, provided there are no photoperiod requirement conflicts. Not only do the plants use the light more efficiently, but the total number of luminaires and electrical service loading can be reduced, thereby reducing capital investment costs.

It has also been shown that the maximum incremental benefit of supplementary illumination occurs when the plants are lit beyond the daylight period, so lighting at night is generally more effective than lighting during the day period. During periods of low ambient light levels, it is a common strategy to light during the day wherever levels fall below a predetermined set point, and to extend the lighting duration period to the maximum recommended for the crop. For example, cucumbers and roses can be lighted for 24 hours per day, while tomatoes and most bedding plants should only be lit for 16 - 18 hours to avoid problems with flower delay.

In greenhouses, supplementary light levels have been suggested ranging from 3 W m^{-2} for ferns and other low light crops, to 20 W m^{-2} for vegetable crops and propagation areas.

19.3.2.6 Supplemental illumination control

Lighting systems can be operated automatically using simple time clocks or sophisticated integrated controllers. Some greenhouses with large installations may not have sufficient electrical service to operate all of their lights at the same time, so they may need to be staged in accordance with available electrical power. When integrated controllers are used it is possible to control the operation of supplemental light systems by a number of parameters including:

- **Time** - cyclical lighting (for photoperiod control) - supplemental lighting duration control
- **Light** - integrated daily light levels - instantaneous radiation set points
- **CO₂ synchronization**

Cyclical lighting is normally only used with incandescent lamps only to provide photoperiod control by cycling a series of relatively short duration lighting periods in the night. By using

this method, it is possible to use less overall illumination time and electricity consumption than with conventional long day illumination. It is not recommended for use with HID lighting, since these luminaires are not designed for frequent cycling.

For supplemental lighting, regardless of the control method, it is best to operate the lights for extended periods, since short cycling of these luminaires will greatly reduce the lamp and ballast life. Therefore, when setting up programs based on available instantaneous or accumulated light energy it is best to set up some conditions that prevent cycling.

These can include a proving time, where the need for either turning the lights on or off must be sustained for a desired period. This prevents the lights from cycling on and off in partially cloudy weather. Another method of preventing cycling when using light based control is to provide for a minimum on and off time override.

A typical integrated control strategy for HID lighting operation might include the following:

- **Lighting window** - allow the light to be turned on between 5:00 am and 10:00 pm.
- **Lighting set point** - allow lights to be turned on during the lighting window period if light levels are below 200 Wm^{-2} .
- **Light accumulation** - turn off lights (or don't allow them to be turned on) if the daily accumulated light exceeds 5.0 kWh.
- **Proving time** - light levels must be below the lighting set point for 30 minutes.
- **Minimum on time** - once the lights are turned on, to prevent cycling, they must remain on for 2 hours, regardless of other conditions.

Other additional strategies could be used alone or in conjunction with the above illustration. For instance, to get the maximum value from CO_2 supplementation it is necessary to have adequate light levels. A separate program could be set up to ensure that crops always receive a minimum light level during CO_2 supplementation periods.



Module 13. Instrumentation and & computerized environmental control systems

Lesson-20 Portable Instruments to Control the Greenhouse Environment

20.1 INTRODUCTION

“Measurement of environmental conditions accurately” is a basic key technique to understand the crop performance in greenhouse. Technology development of instrumentation (sensing, recording, and controlling) has contributed to expanding what we can do in controlled environment agriculture. This chapter deals with the portable, hand held, field quality instruments commonly used to diagnose greenhouse environment.

20.2 TEMPERATURE

Air temperature can be measured with a common thermometer. A thermometer indicates the temperature of the exposed sensor tip, or bulb, which has reached equilibrium with the surrounding environment. The sensor tip must not be exposed to radiant energy, such as from direct sunlight or a heating system radiator, as this will increase the sensor tip temperature. In that case, the measurement taken would not be representative of the surrounding air temperature. An aspirated box is recommended for shielding permanently installed greenhouse sensors from solar heat gain. Be sure that the temperature you measured is representative of the air in the area directly surrounding the plants.

A simple maximum-minimum thermometer(fig 20.2.1) that can be left in the area of interest is an inexpensive tool that can help determine whether wide temperature swings occur over a period of time. Digital thermometers are becoming more common. They are easier to read, offer remote sensing capabilities in hard-to-reach areas, and sometimes have data logging capabilities. However, digital readouts may offer a false sense of accuracy. For example, some sensors have an accuracy of ± 3 percent, yet the readout displays temperature to an astonishing resolution of one-tenth of a degree.

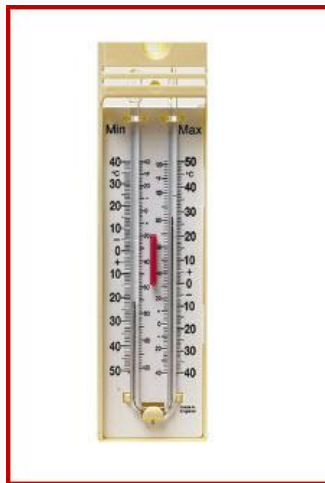


Fig 20.2.1 Maximum - Minimum thermometer

(Source: www.rapidonline.com)

20.2.1 Surface Temperature

In cases where large differences in temperature exist between greenhouse plants and surrounding surfaces such as walls, glazing, and floor, the radiant temperature of those surfaces can influence the effective plant temperature. Surface temperatures are often ignored in environmental analyses but can have a significant impact on plants. For example, the hot air volume near the roof of

the greenhouse can provide a large radiant load on the plants below. On the other hand, very cold surrounding surfaces can chill plants even though the surrounding air temperature seems adequate. Even a surface outside the structure can cause heat or cold stress if the plants can “see” it. For example, the black sky during a clear, cold winter night can cause the plants to radiate enough energy through the greenhouse structure to induce severe cold stress. These examples of radiant load would not be detected by an aspirated, dry-bulb thermometer.

Radiation is a very strong form of heat transfer, yet is purely a surface phenomenon that can be characterized by the surface temperatures of the objects radiating to each other. An object must “see” another surface in order to feel its radiant heat transfer effect. “Line-of-sight” is a straight, unobstructed pathway where radiant energy wavelengths can travel. Temperatures of the surrounding walls, glazing, and floor influence the plants, even though they have limited or no contact with these surfaces. Plant leaf surface temperature is an important indicator of the amount of incoming and outgoing radiation. Leaf temperature has a significant impact on the rate of photosynthesis. Therefore, leaf temperature measurements reveal important information about plant status.

An infrared thermometer (fig 20.2.2) measures surface temperature. This is a line-of-sight instrument and detects the radiant temperature of object(s) it can “see”. Infrared thermometers look like hand-held hair dryers with a small, circular sensing element that is aimed at a surface. It does not touch the surface, but it detects the wavelength of thermal energy emitted from that surface, which is displayed as a radiant temperature. The instrument’s field of view widens with increasing distance between the object of interest and the instrument. Therefore, be sure that it is not also detecting adjacent surfaces. Measuring the surface temperature of small objects will require having the instrument close up. A large object, such as a ceiling, can be evaluated while standing several feet away. Be sure to evaluate all surfaces the plants can “see” from their vantage point.



Fig 20.2.2 Infrared thermometer

(Source: www.whisperparanormal.info)

20.3 HUMIDITY

The traditional way to measure relative humidity is a two-step process: First obtain wet bulb and dry bulb temperatures, and then convert it to relative humidity using a psychrometric chart. The dry bulb temperature is commonly measured with a standard thermometer. The wet bulb temperature is determined from a standard thermometer modified with a wetted fabric wick covering the sensor bulb. Sufficient airflow is provided over the wick material so that as water evaporates from the wet wick, the temperature falls and the thermometer reading reflects the wet bulb temperature. A clean bulb wick soaked with distilled water (to prevent salt build up on the wick) provides the best accuracy. The wick will have to be wet continuously if continuous measurements are required. With a wet wick, measured temperatures must be above freezing. Air movement can be provided through an aspirated box (with a fan) or by whirling the dry bulb/wet bulb thermometer through the air.

The traditional relative humidity instrument, called a sling psychrometer(fig 20.3.1), contains both dry bulb and wet bulb thermometers. The sling around swiftly (creating an air speed of approximately 900 feet per minute [fpm] around the thermometer bulbs) on a jointed handle for about three minutes to obtain sufficient air movement needed to extract an accurate wet bulb temperature. A mechanically aspirated psychrometer operates on the same principles as the sling psychrometer, except that a battery powered fan moves air over the wet wick. Air speed over the wet wick is better controlled by an aspirated psychrometer than it is by whirling a sling psychrometer. In order to take a reading with a sling psychrometer, the psychrometer must be stopped, which immediately begins to change the properties of the wet wick. Hence, the mechanically aspirated readings are usually more reliable. Accuracy of the thermometers, careful reading of temperatures, and psychrometric chart interpretation are important.



Fig 20.3.1 Compact sling psychrometer

(Source: www.education.nachi.org)



Fig 20.3.2 Aspirated psychrometer

(Source: www.belfortinstruments.com)

Relative humidity can be measured directly by using hygrometer (fig. 20.3.3). Newer hygrometers determine relative humidity with solid-state devices and electronics. The sensor is a matrix material in which electrical properties change as water molecules diffuse into or out of the matrix material in response to air moisture content. The sensor materials may not tolerate conditions near saturation. So reliability of many relative humidity sensors is questionable when the relative humidity rises above 95%. Condensation on the hygrometer surface coats the matrix material so that water molecules no longer diffuse in or out. Until the condensation is evaporated, the hygrometer will often display inaccurate humidity readings or there may be a permanent change in electrical properties.



Fig 20.3.3 Digital Thermo Hygrometer

(Source: R-Tech Instruments, New Delhi)

For greenhouse use, look for sensors that can withstand condensing conditions. Most hygrometers also provide a measure of dry bulb temperature. Hygrometers offer the advantage of direct relative humidity measurements and are available in several categories based on price and accuracy. More accurate hygrometers (with an accuracy of ± 1 percent) are preferred but are more expensive. Generally, hygrometer prices have gone down and reliability has improved over the past several years. On some models, maximum and minimum temperature and relative humidity can be captured over a pre-determined time period.

20.4 AIR SPEED

Air speed is measured with an anemometer. Two types of anemometers are common, depending on the type of airflow being measured: vane anemometers and hot-wire anemometers. Both instruments are composed of two connected parts: one is the sensing probe and the second displays air speed. One key concern in using an anemometer is to take measurements while air speed and direction are minimally altered by the instrument's placement. In addition, the operator should stand away (as much as possible) from the airflow being measured. For reference, air moving less than 50 fpm is considered still air.

A hot-wire anemometer (fig 20.4.1) has a very fine, short wire, often the thickness of a human hair, positioned between two supports. A more rugged design uses a thicker wire, which incorporates a temperature-sensing thermistor. The wire is heated by electronic circuitry and air flowing over the wire causes its temperature to decrease. By detecting this temperature decrease, or by evaluating the amount of current supplied to keep the temperature of the wire from decreasing, the anemometer determines the speed of the passing air. The hotwire portion of the instrument is fragile and care must be taken to protect it from physical damage, which can be caused, for example, by large airborne dirt particles. A hotwire anemometer is the instrument of choice for low air speed measurements. Air that is virtually still (< 50 fpm) exists in many greenhouses, especially away from ventilation inlets and outlets. Due to their small size, hot wire anemometers can be used in small places, such as the inlet opening of a ventilation system, or in hard to reach spaces, such as ducts.



Fig 20.4.1 Hot wire anemometer

(Source: www.tecpel.com.tw)

A vane type anemometer (fig 20.4.2) is more rugged and usually less expensive than a hotwire anemometer. It is well suited to evaluate several agricultural applications. Designs vary, but most have a three inch-diameter vane propeller, which starts turning when the propeller is held in an air stream. Since it takes air speed measurements based on a larger area than the hot-wire anemometer, it is better for determining airflow over the face of a fan, in a large duct, or across a large ventilation inlet opening. Vane anemometers do not measure low air speeds because the mass of the vane requires a fair amount of air movement to induce rotation. Vane anemometers are not considered accurate below 50 to 70 fpm, even though the meter displays a velocity at these low air speeds. Vane anemometers must be used in air streams that are at least as wide as the vane diameter. They will not accurately measure narrow inlet air jets that are smaller than the diameter of the vane anemometer propeller. Vane anemometers with small, one-inch diameter vane heads are available for small air stream measurements, yet they still cannot detect low air speeds. For low speed (< 50 fpm) air measurements, a hotwire anemometer is required. One of the available options on a vane anemometer is an averaging mode where velocity is displayed as a running average value over time. This is a helpful feature when scanning a fluctuating air stream.



Fig 20.4.2 Vane type anemometer

(Source: www.vitcolab.com)

Velocity manometers may be used in well-defined air streams of relatively high velocity air (> 400 fpm). A Pitot tube is positioned so airflow directly affects the sensing tip, and therefore streamlined air is more desirable than turbulent flow. A velocity pressure is detected, from which air speed is determined. A floating ball in the instrument's air tube indicates the velocity reading.

20.5 AIRFLOW VISUALIZATION

It is sometimes helpful to visualize airflow to determine how air is mixing or where it forms dead zones. Unusual air leaks (open doors and windows, or cracks in the structure) affect the operation of a ventilation system. Visualizing streamline patterns in greenhouses has some limitations, but nevertheless several methods can be used. Devices that generate smoke are the most common and come in gun, stick, candle, and bomb formats, with an increasing amount of smoke, respectively.

Smoke candles (Fig 20.5.1) are rated according to their duration and volume of smoke they produce. Smoke bombs have been used, but the abundant smoke quickly obscures visualization of the airflow patterns and is frequently an irritant to humans. Smoke bombs are sometimes used to release fumigants in plant production facilities to control various pests. Plants should not be present if harmful techniques are used, but since their presence usually affects how airflow patterns develop under normal conditions, their removal may provide unrealistic airflow patterns. It is best to keep the plants in place and use compatible airflow visualization methods. The above mentioned smoke devices use combustion to produce smoke, so they also generate heat. This thermal effect tends to produce rising smoke.

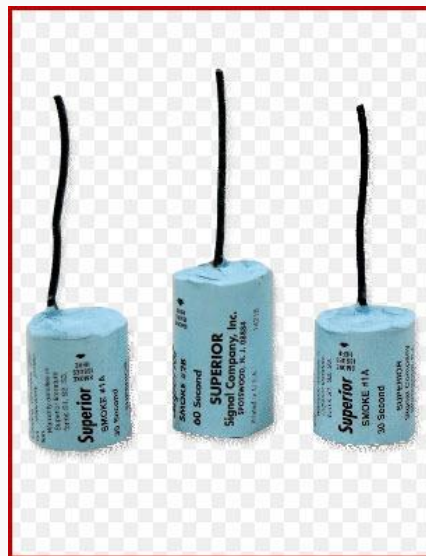


Fig 20.5.1 Smoke candles

(Source: www.clenair.com)

Smoke sticks (Fig 20.5.2) and guns use chemical reactions to produce smoke, so they exhibit few thermal effects. Smoke sticks produce the equivalent of several cigarette's smoke and look like glass tubes filled with cotton. They produce smoke for several minutes once the end

is broken off with a cap on the tip) provides small smoke puffs. This allows smoke to be produced intermittently, rather than the unstoppable stream provided by the combustion devices. A rubber bulb on the handle of a smoke gun provides smoke in puffs or in a continuous stream. The disadvantage is that the small amount of smoke dissipates quickly and may not visualize well, especially in bright light. In addition, the smoke is irritating and the stored sticks can be corrosive once broken. Even rubber parts of the smoke gun may deteriorate from chemical corrosion.



Fig 20.5.2 Smoke stick

(Source: www.hayes-uk.com)

Very small, neutrally-buoyant soap bubbles, filled with helium and released with compressed air, can last long enough to show airstreams within an enclosure. The soap bubbles are surprisingly durable in a free air stream but will not tolerate many impacts with obstructions. The apparatus used to generate bubbles is cumbersome and expensive compared to other airflow visualization devices. Children's soap bubble toys are the least expensive option and can be useful in faster-flowing airstreams but they are not neutrally buoyant. These bubbles exhibit downward gravitational effects (due to the weight of the soap film), which obscures accurate visualization of the true airflow. Theatrical smoke units produce large quantities of a non-irritating fog through the heating of glycol fluid. This is the atmosphere enhancing fog used for special effects in a theatre (dry ice may also be used). Since the theatrical smoke is warmer than ambient air it will exhibit upward convection. The unit is rather large, being similar in size to a breadbox, relatively expensive, and heavy at about 30-pounds.

A set of air speed streamers (Fig 20.5.3) may be used to detect air speed at various greenhouse locations. Threads of string or ribbons of plastic tape can be "calibrated" to a specific size so that they blow horizontally at a particular airflow of interest. Attached to small posts, these inexpensive free to-spin streamers can be positioned in many locations as indicators of the local airflow and direction. As conditions are changed in the structure under investigation, a quick survey of the streamers will indicate which areas are receiving the desired airflow. For example, if a mechanical ventilation system inlet air speed of 700 fpm or faster is desirable, streamers which have been "calibrated" to blow horizontally at 700

fpm are positioned at various inlet locations to observe whether inlet air speeds are indeed at least 700 fpm.

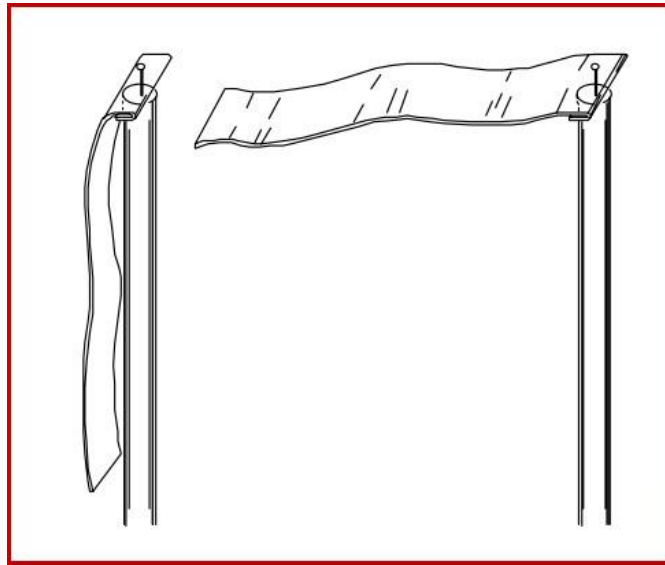


Fig 20.5.3 Air speed streamers

(Source: Both A.J 2002)

20.6 GASES

Carbon Dioxide: Plants use carbon dioxide [CO_2] to grow and develop in a process called photosynthesis in which they convert carbon dioxide and water into necessary building blocks. They use (solar) radiation as their energy source and produce oxygen during the conversion process. Greenhouse growers frequently increase plant production through supplementation of carbon dioxide in the greenhouse environment. The carbon dioxide concentration is commonly expressed in units of parts per million (ppm), i.e., the number of molecules of carbon dioxide per one million molecules of air. The so-called ambient carbon dioxide concentration is around 350 to 400 ppm. Growers usually enrich the greenhouse environment to a level of around 1,000 ppm. This moderately elevated carbon dioxide concentration has no ill effects on animals or humans. During the night (without light for photosynthesis) or during periods when ventilation is required to maintain the target indoor temperature, carbon dioxide enrichment is discontinued.

Continuous monitoring of CO_2 concentration is done as part of some greenhouse environmental control systems. Most carbon dioxide sensors determine the carbon dioxide concentration by measuring the absorption of infrared light as an air sample passes through a small detection chamber. Portable carbon dioxide monitors (Fig 20.6.1) can be even more expensive than permanently mounted units.



Fig 20.6.1 Portable CO₂ monitor

(Source: www.4hydroponics.com)

Contaminant Gases: Carbon monoxide [CO] and NO_x (nitric oxide NO, and nitrogen dioxide NO₂) gases are common by-products of the incomplete combustion of fossil fuel in heating systems. Proper maintenance and operation of heating systems should prevent the accumulation of these gases in greenhouses. Ethylene [C₂H₄] gas is a by-product of plant metabolism. It is considered a plant hormone because it can stimulate stem elongation and flowering, and promote ripening of fruits. In properly ventilated plant production facilities, ethylene concentrations rarely cause problems, but in closed germination rooms ethylene accumulation can cause undesirable plant responses (e.g., leaf epinasty and flower abortion).

A portable and relatively inexpensive way to detect gas levels is with a hand-held sampler pump. This manually operated, piston-type pump draws an accurate sample of ambient air through a detector tube. It is very important to hold the pump so the air pulled in through the detector tube comes from the location of interest; this means holding it near the plant during the sampling period for plant-level measurements. Remote sampling is possible for hard-to-reach areas. Dozens of gas and vapor-specific detector tubes are available, including ones for carbon dioxide, carbon monoxide, NO_x, and ethylene. Several types of sampling pumps are available, such as a design with rubberized bulb that is squeezed for sampling. The pump and detector tubes must be compatible. As with other instruments, the sampling pump needs to be periodically checked for leakage and calibration.

The thin glass detector tube is specific to the type of gas that is being measured. For example, if the presence of carbon monoxide is a concern in the boiler room, a detector tube filled with a carbon monoxide-sensitive material would be attached to the pump. The contents of the tube react with the air contaminants and change color. The length or shade of the color change in the detector tube indicates the concentration of gas in the sample. Tubes come in a choice of measurable ranges so that accurate analysis is possible. Each tube is used once to obtain a reading and then discarded. Diffusion tubes are an option for monitoring gas levels over a long period of time rather than the spot check provided by the sampler pump and tubes. Diffusion tubes are glass tubes filled with a reactive material specific to the gas of interest. Once both glass end tips are broken off, the tube is placed into the greenhouse

environment for a number of hours (tube directions will help determined sampling time by type of tube and anticipated gas level in the environment). The average gas level over the measured time period is easy to calculate based on the distance of color change in the tube. This is a lower cost solution compared to the sampler pump and tube system, is equally reliable, and provides an indication of average gas level over a longer time interval.



Fig 20.6.2 Gas sampler pump and detection tube

(Source: www.equipcoservices.com)

20.7 LIGHT LEVEL

Although not distinctly a part of the aerial environment, light level has such a major impact on greenhouse aerial environment that it is hard to ignore. Instruments for measuring light are available in a variety of formats which emphasize the wavelengths of light being measured. Various wavelengths of radiation are designated into ranges of interest for specific applications such as visible light, ultraviolet light, photo synthetically active radiation, etc. The units of measurement may appear confusing as different light meters may measure in different units that are not easily convertible to wavelengths of interest for plant growth.

Of most interest for plant growth is a meter that measures photo synthetically active radiation (PAR). These quantum sensors (Fig 20.7.1) measure light wavelengths from 400 to 700 nm, which approximate the photosynthetic response of plants. Units of measure are micromoles per square meter per second ($\mu\text{mol m}^{-2}\text{s}^{-1}$). Special- Quantum Sensor sized manufacturers offer quantum sensors.



Fig 20.7.1 Quantum sensors

(Source: www.helsinki.fi)

More commonly found light meters measure visible light are known as photometric sensors (approximately 380 to 770 nm). These meters measure light radiation as perceived by the human eye. Units of measure include foot-candle (fc), which is the U.S. system unit of measure, or lux, which is the S.I. measure [1 fc = 10.76 lux]. Many visible light meters offer display of light readings in both fc and lux. Visible light is similar in range of wavelength to PAR with more visible light meters available at less cost than quantum meters. A pyranometer measures solar irradiance that includes ultraviolet, visible, and infrared wavelengths (approximately 280 to 2,800 nm). Units of measure are energy units (Wm^{-2})



Fig 20.7.2 Photometric meter

(Source: www.en.wikipedia.org)

Expose the sensor to the light level of interest. Avoid shading the sensor and keep it level. It is important to stand away from the sensor as a human body can not only cast shadow on the sensor but provides a dark surface from which little diffuse light reflects. Place the sensor near the top of the plant canopy to determine light level. Obviously, the light level will be brighter near the top of a plant canopy or near the greenhouse glazing. More sophisticated sensors provide a choice to display the light intensity based on the light source (e.g., sunlight, incandescent, fluorescent, or high intensity discharge (HID) such as high pressure sodium and metal halide) Combination Instruments In the past few years, instruments with a modest price tag have been developed which incorporate sensors for several environmental features.

Humidity combined with temperature has been common but more affordable and reliable instruments are now available which monitor relative humidity directly rather than from wet bulb and dry bulb calculations. A small headed vane anemometer has been included in units that sense air speed, temperature, and relative humidity.

20.8 DUST

Dust is a difficult environmental parameter to measure and the appropriate equipment is expensive. Dust particles need to be separated by size to determine the respirable portion.

Design and Maintenance of Green House

This dust goes directly to the lungs and contributes to health problems. Dust, in general, is detrimental to animals, workers, equipment with moving parts, and, in extreme cases, to plants as well. Air samples may be taken and submitted to a lab where a cascade impactor, or similar device, is used to determine dust levels in a range of sizes.

This ON and OFF type instruments are time consuming, vulnerable to human error and hence, less accurate and unreliable.

Thus greenhouse needs sophisticated set up equipped to react most of the climate changes occurring inside. It works on a feedback system which helps it to respond to the external stimuli efficiently. This set-up overcomes the problems caused due to human errors.



Lesson 21 Computerised Environmental Control of the Greenhouse

21.1 INTRODUCTION

In new modern state of the art greenhouses, a computerised plant control system which controls the heat and ventilation of the greenhouse is used. It is likely that there are different requirements for the system throughout the year. Alteration on the computer programme will allow the greenhouse environment to be adjusted which will help the growth of certain plants. Building a state of the art greenhouse with a computerised environmental control system aids in creating the best possible conditions for the plants. There is an array of climate condition which the ventilation control creates. Moreover a computerised environmental control system helps towards greater savings of energy and additionally helps the progress of growth and plant management through a computerised control system.

21.2 IMPORTANCE OF GOOD CONTROL

Problem in greenhouse climate control is that temperature changes occur rapidly and are depending on solar radiation, outside temperature, relative humidity and production systems. These changes affect the overall energy efficiency of greenhouse production systems. The aim of every producer is to reduce the energy input per unit of production, and maintain and increase the quality of

the final product.

Accurate controlling systems and their coordination can reduce direct energy inputs enclosed in fuel and electricity for heating. Automated controls increase the productivity of workers enabling them to attend to more important tasks. This can improve the overall energy efficiency of greenhouse system. The most important function of good controlling system is the information available to the grower that can be used in terms of better management decisions. Growers report reduction of overall water use as much as 70% if operating with good controlling equipment. In terms of water management significant savings were obtained in fertilizer application and its effectiveness.

More precise control of temperature and relative humidity helps in minimizing plant stress and diseases reducing the need for fungicides and other chemicals.

Advantages of good climatic control can be seen in healthier plants, less susceptible to diseases and insects. In terms of technical systems and equipment, good control prevents over-cycling of equipment and increasing of its operating hours.

21.3 REGULATION AND CONTROL SYSTEMS

The general principle of regulation is as follows:

1. The value of the parameter to be regulated is quantified, by direct measurement or by calculation. For instance, to regulate the opening of the vents as a function of the greenhouse air temperature, the air temperature is measured, which happens to be 25°C.
2. This measured value is compared with the parameter's set point, which can be predefined by the user or be the result of a calculation or the application of a pre-established rule. The air temperature set point value, in this example, can be fixed in 23°C, which is lower than the measured value (25°C).
3. Finally, by means of one or several actuators, one or more pieces of equipment begin to operate, to decrease the difference between the measured and the set point values of the parameter. In this example, the motors opening the vents would start operating, opening the vents to ventilate and approximate the air temperature of the greenhouse to the set point (23°C).

21.3.1 Input-Output System

In classical control, the processes to be regulated are considered as input-output systems. It may occur that there is more than one input or output (Fig. 21.3.1). The inputs can be of two types: (i) control inputs; and (ii) exogenous inputs (or disturbances).

Figure 21.3.1 schematizes an input-output system (Fig. 21.3.1a), an input-output system with a disturbance (Fig. 21.3.1b), and the inputs and outputs for the climate control of a greenhouse (Fig. 21.3.1c). In this last case, CO₂ enrichment, heat supply and vent opening for ventilation are considered as inputs of the system. The disturbances are the outside temperature, the outside wind direction and velocity, and the external global radiation, humidity and CO₂. The outputs are the inside temperature, humidity and CO₂. Considering radiation as a disturbance, even though it is essential for photosynthesis, is due to the fact that it is not a value that can be controlled by the user.

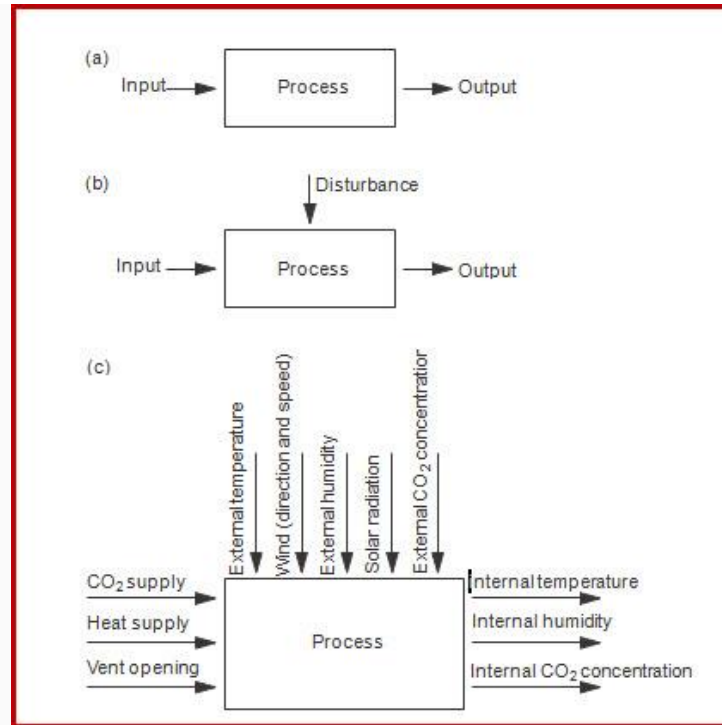


Fig 21.3.1 Scheme of control systems: (a) input-output system; (b) input-output system with a disturbance; (c) greenhouse climate control system that details the inputs, outputs and the disturbances (external climate parameters)

(adapted from Castilla, 2013)

21.3.2 Regulation methods

There are two methods of regulation: manual and automatic. Manual regulation is not in use for the central boiler heating system and for fertigation, but it is still used for ventilation, shading and humidification. The disadvantages of manual regulation are: (i) that it is not possible without an operator; (ii) it is imperfect if there are no measurement instruments; and (iii) manual switches are imprecise (e.g. to set the duration of humidification, or the opening rate of the vents). However, manual regulation is essential when the climate conditions are exceptional (e.g. intense frost); its possible use must be foreseen.

Automatic regulation can be electromechanical or electronic. In electromechanical regulation, the parameter in question is regulated as a function of the set point value of the parameter. In electronic regulation, the parameter can be regulated as a function of the values of one or several parameters (i.e. night air temperature as a function of the previous day's radiation).

There are two types of regulation: 'closed loop' or 'open loop'. 'Closed loop' regulation takes into account only the average values of the parameter to be regulated. 'Open loop' regulation also considers the values of other parameters (e.g. to regulate the air temperature, it also considers the wind velocity or radiation).

21.3.3 Application to climate management

Climate management allows for simultaneously maintaining the set of climate factors (temperature, humidity, CO₂) close to pre-established set point values, respecting certain rules (absolute or conditional prohibitions, priorities, time delays) imposed by the user. The climate computer manages the climate. We can distinguish several levels of climate management:

- Level 1: (base level) The time scale is very short (about 1 min). It excludes processing of the information. Most of the actual climate control computers employ this level of management nowadays.
- Level 2: The time scale is of the order of 1 h or a whole day. The objective is the management of the physiological functions involved in the growth and development of the plants in the short term (photosynthesis, transpiration). It involves the use of models.
- Level 3: The time scale is longer than 1 day. This level is the bio-economic optimization and strategic decision support. It allows solutions to be obtained that are close to the economic optimum, in each case. The realization of level 3 is ideal and has not yet been achieved in practice.

21.3.4 Types of controllers

The controllers can be classified depending on the type of regulation, which is the way in which the correction calculation can be made.

There are two main types of regulators: (i) non-progressive controllers that only regulate fixed positions of the controlled device; and (ii) progressive controllers that control any position.

21.3.4.1 Non-progressive controllers

In the 'on/off' type, the actuator can only take two positions: on or off. Mechanical ventilation, for instance, starts if the interior temperature exceeds 23°C and stops if it decreases below 20°C, pre-fixed set values. A set point value can be used for a 'dead zone', detailed later.

The 'on/off' mode is usual in dynamic ventilation, CO₂ injection, humidification, shading and hot air heating.

A disadvantage of the 'on/off' mode is the frequent starts and stops around the set point value. There are three ways to avoid it:

1. Using a time delay: After the equipment starts, it cannot stop until a certain minimum time has lapsed. It is used, for instance, in air heating. Once the equipment starts (for example, because the air temperature is at 14°C, lower than the fixed set point of 15°C) it has to operate, for instance, for 5 min before stopping,

although the set point is reached again before this period ends. Therefore, the air temperature will exceed the set point value, delaying the next start.

2. Using a dead zone: Around the set point value a dead zone is fixed (x), so the regulated equipment for a certain set point (c) starts when the value ($c - x$) is reached and stops when ($c + x$) is exceeded. In this way frequent starts and stops can be avoided. In the previous example, we could fix a set point value (c) at 15°C , and the dead zone (x) at 1°C , so the system would start at 14°C and stop at 16°C .
3. Using average values: These are used for those parameters that can change a great deal, such as wind velocity or the light. As average values are used as set points, the variability is highly cushioned. For instance, as the wind velocity oscillates a lot because the wind is frequently gusty, the average value of the measurements of a set period is used instead of the last instantaneous air velocity measurement.

21.3.4.2 Progressive controllers

In the progressive type of controllers, the operation of the equipment is modulated to maintain the parameter values to be controlled inside the interval of pre-established set point values.

The most common progressive controllers are: (i) the proportional control (P); (ii) the proportional integrated control (PI); and (iii) the proportional integrated derivative control (PID).

21.3.4.3 Proportional regulation

In the ventilation process of high temperature or high humidity, when the temperature or the humidity reaches the set point the vent opening is operated. If this opening is operated proportionally to the measured temperature or humidity excesses, in relation to the threshold value, a proportional regulation is applied. Thus, if the difference is small, the vents will open a little and if the difference is very large they will open 100%.

The band of proportionality opening must be defined. If the band is 6°C and the set point temperature is 20°C , the vents will open 50% when the greenhouse temperature is 23°C , and will open 100% when it is 26°C . These band values may be increased or decreased, depending on the external temperature and wind velocity. Proportional regulation is also used in thermosiphon heating systems although in a more complex way.

21.3.4.4 Proportional Integrated Control (PI)

In a proportional controller (P) the amplitude of the action (the percentage opening of the vents in the previous ventilation example) is proportional to the difference between the average value and the set point value (temperature in the ventilation example).

In a PI the amplitude of the action is proportional to the integral of the differences between the average value and the set point. It eliminates the deviations step by step (Fig. 21.3.2).

In a similar way, the PI control is used in thermo syphon heating systems. If the interior temperature control is not linked to the external climate conditions (temperature and wind velocity), the control operates in feedback mode, so it only acts when the interior temperature changes and induces, after checking the set point, activation of the equipment if applicable. If, on the contrary, the alteration of the external climate parameters influences *a priori* the control (before it affects the internal temperature) the control operates in 'feed forward' mode. For example, a heating system by feed forward control can start or increase the energy supply induced by an increase in the wind velocity (which contributes to the cooling of the greenhouse), although the interior temperature has not yet decreased (which will happen after a certain time). In these cases, the rule or model that relates the wind velocity with the later predictable greenhouse air temperature changes must be prefixed.

The PID control improves the performance of the PI control. In the control process of a certain parameter, the control system starts the actuators or equipment when it must correct the values of the parameter. The values of the parameter are still periodically measured and this information allows, if necessary, to correct the actions. In this way, the system can correct the control actions by means of 'feedback' control.

When a disturbance occurs, and its effect on the parameter being controlled is known, immediate action can take place, preventatively. This action is the 'feed forward' control, as already detailed.

Frequently, in the management of the process both feedback and feed forward intervene simultaneously. For instance, when the temperature of a greenhouse exceeds the set point, due to a radiation increase, the computer opens the vent (feedback). If later the wind velocity or the external temperature increases, the control system can adjust the vent opening in advance (feed forward).

Another type of control configuration is the cascade configuration that is used in complex processes.

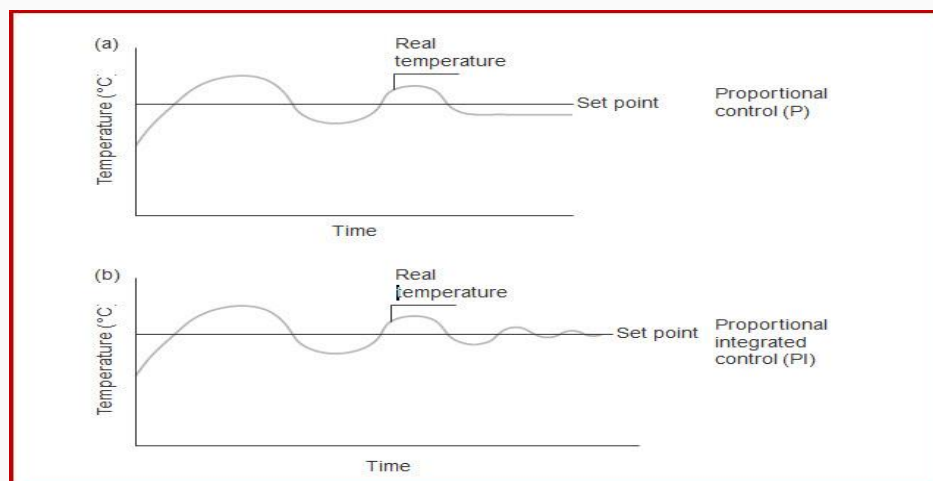


Fig 21.3.2 Graphical representation of the performance of a good ventilation control system depending on the temperature. (a) Proportional control (P); (b) proportional integrated control (PI).

21.3.5 Selection of the type of automatic control

In the simplest systems, non-progressive controllers (on/off) can be used. To select the type of progressive controller, it is recommended to choose the P type (simple proportional control) whenever possible. If the set points are not to be exceeded, the PI controllers must be used. When the speed of the process requires it, PID must be used.

Once the type of controller has been chosen, the management value of the parameters to control must be selected.

21.3.6 Models

21.3.6.1 Introduction

A model is a simplified representation of a system or one of its parts. The greenhouse, the crop and its management constitute a system. Normally, a model is represented by a number of mathematical equations.

There are a large number of model types. A *static model* is a set of equations that relate several aspects such as, for instance, heat losses, or ventilation, that occur at a time when, essentially, the system is balanced; thus, a static model can be considered a *steady-state model*. In these models the equations are based on physical laws, so they are called *mechanistic models*.

A *dynamic model* incorporates the time variable. These models are necessary when a process whose response is slow is represented, such as the heating of the soil. They are *stochastic models*.

The term heuristic or stochastic refers to the mediums used in the resolution of the models, thus, heuristic models are solved by exploration or by means of trial and error, whereas stochastic models are solved using statistical methods.

The feed forward control systems use models, which determine the predictable effects of a disturbance in the regulated process and, preventatively, adjust the set points to this new situation.

In greenhouses, two groups of models can be distinguished: (i) *physical* models, which focus on the greenhouse microclimate as a function of the external climate; and (ii) *physiological* models that focus on the plants and their relations with the greenhouse microclimate.

Simulation models can be of any kind, from the simplest to the most complex, and are of great use, if they are well conceived and validated, to simulate several real situations at a low cost. A very simple example, in Mediterranean greenhouses, is the simulation model of transmissivity to solar radiation (Soriano *et al.*, 2004b). This has been of great use in designing new low-cost greenhouse structures that are more efficient in capturing solar radiation at a low cost. At a more complex level, there is a diversity of simulation models, both for energy balance and for crop growth and production.

21.3.6.2 Use of models

Models have constituted a very useful tool for research of the greenhouse physical environment and the crop's growth and production (Challa, 2001).

At the beginning, obviously, simple stationary models were used. The use of models in the design and management of control systems has been widespread and very positive, but its application on a commercial scale has been limited and restricted to well-equipped greenhouses (Gary, 1999).

The simplest models, such as the rule of thumb, and scale models, have been used in Mediterranean greenhouses (Soriano *et al.*, 2004b). In these greenhouses, at different levels of complexity and from the practical point of view, the models which have attracted the most interest are those of irrigation control and analysis of yield potential of the crops. Nowadays, in well-equipped greenhouses, the control of the air temperature (that is regulated depending on the available light) is widely used and this is based on a simple model.

However, there are reservations in using models, from the user's side, and these stem from the need for simple, robust and universal models (Bailey, 1999). In addition, previous work gathering relevant information (for instance, on assimilates distribution) needs to be done prior to the application of a model, and in many cases this information is not available (Gómez *et al.*, 2003).

A primary aspect to be considered in greenhouse climate control models is that the grower's goal is to maximize the profit. Therefore, and given the normally existing variability in a crop, the grower/user must be the one who finally makes the decisions.

21.4 Computer Climate Management

21.4.1 Controls performed by greenhouse management systems

In heating, the primary goal of the control systems is to adapt the heat supply to the crop requirements. The secondary goal is to dehumidify the air. The main goal of ventilation regulation systems is to avoid the interior air temperature exceeding the fixed threshold. Secondary objectives are to dehumidify and favour the input of CO₂. Temperature, humidity and CO₂ sensors are needed for their management. They may be limited by the rain or the wind.

The only function of the shading control system is to decrease radiation, normally to reduce the temperature at times of high radiation load.

The supply of CO₂ is only practised during the daytime, with intervention of the CO₂, radiation and vent-opening sensors. Humidification tends to maintain the hygrometry, using humidity and air temperature sensors.

For the regulation of all these systems (thermal screens, dehumidification systems) several sensors can be used. The simplest control systems use clocks.

21.4.2 Digital control systems

Systems developed during the Second World War enabled analogue technology, which used electrical circuits to obtain inputs (measurement of environmental parameters) and calculate, automatically, outputs, to control mechanisms and equipment. The arrival of digital control systems, which could manage more complex systems at lower cost, has helped digital control systems to supersede analogue control systems.

A digital control system is basically composed of: (i) the controller, that is, the climate computer; (ii) the correction equipment (heating, ventilation, etc.); and (iii) sensors, to measure the different parameters to be regulated.

21.4.3 The climate control computer

The climate control computer controls different processes to regulate, mainly, temperature, humidity, light, CO₂ and air circulation. Its functions are to measure different parameters, perform calculations with resident programs, and give activation orders to existing equipment, to maintain the regulated parameters within the desired values (set points).

When sensors are monitored using analogue technology, the signals must be converted into digital information before they can be interpreted by the computer. For this, an analogue-digital converter (ADC) is used. When a sensor generates a measurement signal that is not interpretable by the ADC, an interface that adapts the signal (to make it readable by the ADC) is used. For instance, a solar radiation sensor generates a potential difference, which is proportional to the incoming radiation, in the form of an analogue signal that is converted into a digital signal by the ADC converter in order to be interpreted by the computer.

The activation orders of the computer or output signals, at low tension (24 volts), activate relays that operate the different correction equipment. Until now, different computers performed the fertigation and climate management. Nowadays, the trend is to integrate them, which allows for a better joint management.

21.4.4 Functions of climate control computers

It is impossible to provide a full list of all the possible functions of climate control computers, because each user has specific requirements. The ones detailed below are the minimum required for a well-equipped greenhouse.

The set points are generally different during the day and the night, and can vary even during the same period (day or night). A clock can perform the day/night changes, or changes can be triggered by measurements of the radiation or by calculations of sunrise and sunset (depending on the latitude and date; i.e. the astronomical clock).

21.4.4.1 Temperature control

In the simplest systems, the user normally fixes a temperature below which the heating system is activated (heating set point), being common to use different set points during the day and the night. In addition, the user indicates a maximum temperature, above

which the vents open (ventilation set point). Equally, the system can control water evaporation equipment (fog, pad and fan) or a shading screen. Nowadays, most systems can adjust the set points for several independent periods or recalculate them periodically.

The temperature set point can be modulated as a function of other parameters, such as radiation, increasing the set points as radiation increases. It is usual to fix the night set point temperature as a function of the radiation of the previous day.

In thermosyphon heating systems, the temperature of the heating pipes is usually controlled independently from that of the air, it being usual to maintain a minimum pipe temperature, to achieve a leaf temperature higher than that of the air with the aim of avoiding *Botrytis* (induced by water condensation).

The presence of a thermal screen affects the temperature set points. If soil or substrate heating is available, besides air heating, they must be controlled in coordination with each other. The management of the screens can be done with a clock, by radiation or by temperature. The opening of screens must be gradual.

In exceptional cases (heavy frost) the set points can be unreachable due to insufficient capacity of the existing heating system. In these cases survival temperature set points, lower than the usual are used.

Hot-water heating systems have considerable thermal inertia. Therefore, their operation should be scheduled in advance, using a proportional controller. In air heating systems the on/off control is used.

A typical example of the changes in heating and ventilation set point temperatures is represented in Fig. 21.4.1, in thermosyphon heating systems. The set point temperatures change before sunrise. At sunrise transpiration increases quickly raising the humidity whereas temperature increases more slowly, causing condensation on the plants that favours fungal attacks. To avoid this situation the heating set point must be progressively increased before sunrise (point A, Fig. 21.4.1). At sunset a similar procedure is followed, for energy-saving purposes, progressively decreasing the heating set point from point C (Fig. 21.4.1).

In case of contradiction between the ventilation control orders as a function of temperature and humidity, priority control by humidity is usually established.

For control of high temperature by ventilation a proportional controller is normally used. As the ventilation rate is difficult to measure, a temperature set point is used instead, corrected by the wind velocity and the interior-exterior temperature difference (Fig. 21.4.2). The vent opening percentage is measured or estimated. Knowledge of the wind direction allows for choosing which vents to be opened: that is, the windward vents (facing the wind) or the leeward vents (opposite to the wind). Normally, the leeward vents open first. Maximum and minimum vent openings (in degrees) must be pre-established, in case of storm, frost or rain.

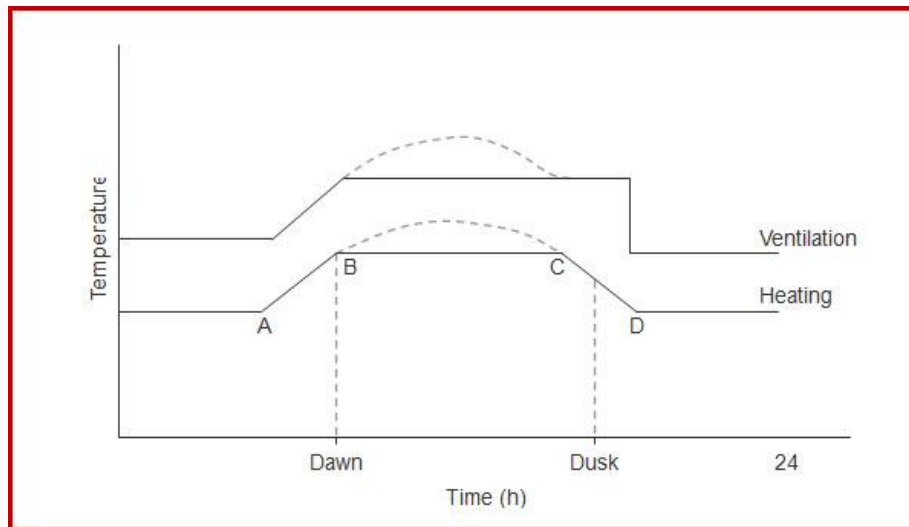


Fig 21.4.1. Scheme of the set point temperatures for heating and ventilation management in a climatized greenhouse over 24 h.

(A, Starting point of the set point increase; B, sunrise (final point of the set point increase); C, starting point of the set point decrease (near sunset); D, final point of the set point decrease; dotted lines, possible high temperatures during daylight hours. The set points for heating and ventilation are calculated with regard to sunrise and sunset, when solar radiation begins and finishes, respectively (adapted from Bakker *et al.*, 1995).

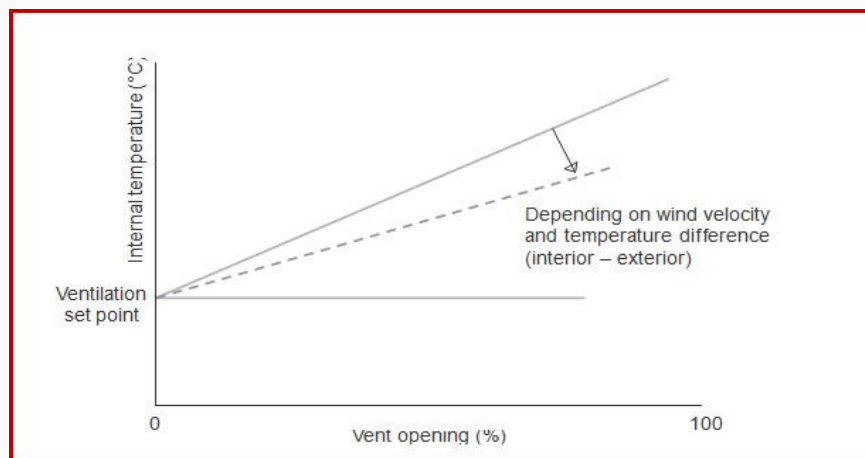


Fig 21.4.2 Scheme of the proportional control of the vent opening to ventilate, depending on the internal temperature. The slope of the line depends on the wind velocity and of the internal-external temperature difference (adapted from Bakker *et al.*, 1995).

21.4.4.2 Hygrometry control

If the greenhouse has a dehumidification system, which is quite infrequent, it can be activated with a humidity set point, to decrease the humidity.

If the greenhouse does not have a heating system the only way to limit the humidity is to ventilate. When heating is available, the humidity excesses can be avoided by heating and ventilating, although at a high energy cost. The humidity set points are different during the day and the night.

In some crops, such as tomato, this simultaneous heating and ventilation is performed every morning to decrease the RH and avoid condensation on the plants.

The fog or pad and fan systems can be activated when the hygrometry is low, normally during the daytime.

21.4.4.3 Light control

Photoperiodic illumination and darkening screens are managed with clocks. Shading screens are controlled by means of maximum radiation or temperature thresholds. It is usual to maintain openings or slits in the screen, to avoid affecting the ventilation and to maintain the 'chimney effect' of ventilation. As the screens are sensitive to the wind, screens cannot be deployed when the wind is above a certain speed.

Artificial lighting, for photosynthesis, is activated by a clock or by temperature set points.

21.4.4.4 CO₂ management

The CO₂ set point can be modulated as a function of the temperature and the radiation. In practice, it can be modified depending on the wind velocity and direction and the degree of vent opening.

21.4.4.5 Screens control

Thermal screens are deployed during the night and gathered in during the day. The deployment is done when the temperature difference (between the greenhouse and the exterior) exceeds a pre-fixed value.

The opening of the screen is done, at the pre-fixed time or depending of the light level, gradually to avoid a sudden fall of the cold air mass over the crop. When humidity is excessive the screen can slightly open to evacuate the excess humidity.

Shading screens are managed with two light levels, one to deploy and one to retract. When the interior temperature is excessive, an opening must be left to avoid excessive blockage of ventilation.

Darkening screens are controlled by clock and must perfectly block the light in order to effectively shorten the day length.

21.4.4.6 Alarms control

Alarms are essential to prevent crop and property damage. The control systems usually incorporate a series of security functions, whose thresholds are fixed by the user.

The most important climate alarms are the ones announcing a violation of the minimum and maximum temperature set points. Other alarms relate to the humidity, CO₂ and screens set points.

The existence of alarms does not eliminate the need for preventative maintenance (verifying probes, circuits, etc.). The system must be protected against electromagnetic and electric

disturbances, especially in zones where storms are common (e.g. To avoid damage by lightning).

21.4.4.7 Communication with the user

The user can change the program set points and also identify the factors that must be considered to respect the set points, intervention priorities, and intervention delays. Communication with the user allows for remote control of equipment when the appropriate communication interface is available. The most commonly used systems are wireless communication (by radio-frequency), and phone and wire (with conventional cable) communication.

An essential aspect to take into account in communication with the user is the alarm notification in case of serious failure.

All the data registered during the day can be stored. In addition, the system may have the usual performance of a personal computer, providing it with the required elements (data visualization screens, data downloading, printer, etc.).

21.4.4.8 Integrated control

Integrated management of fertigation and climate control is already used in some modern commercial greenhouses.

In the future, in order to optimize control in well-equipped greenhouses it will be necessary to also integrate plant growth management and economic aspects of production with the climate control and fertigation, so that the new generation of growers will have to be experts in interpreting and using technical information in decision making (Papadopoulos and Hao, 1997a, b). Before this happens, it will be necessary to generate the required information about plant growth and other non-documented aspects of the local conditions.



Module 14. Watering, fertilization, root substrate and pasteurization

Lesson 22 Watering, Fertilization, Root substrate and Pasteurization

22.1 INTRODUCTION

Watering is the greenhouse operation that most frequently accounts for loss in crop quality. When performed correctly it is simple operation otherwise it results either into underwatering or overwatering. A wide variety of inexpensive automatic watering systems are available today.

Fertilizers are designed to provide the elements necessary for plant growth. About 90% of the plant weight is made up of water. The remaining mass constitutes the plant dry weight, which is made up primarily of 17 elements that are required for plant growth.

Root medium pasteurization is a standard practice for virtually all greenhouses today. It is generally done on annual basis, although number of growers are pasteurizing their media every crop. The summer has been a preferred time for pasteurization because crop production is usually at a low point, root media are warmer and in case of steam pasteurization, all or much of boiler capacity is available at this time. Root medium pasteurization, in addition to eliminating disease organisms, is used to control nematodes, insects and weeds. Pasteurization may be accomplished by injecting steam into the soil or by injecting one of several chemicals such as methyl bromide chloropicrin.

22.2 WATERING

1. Judge watering requirements by substrate look, feel, and weight
2. Plant symptoms of underwatering:

- Wilting
- Slowed growth
- Smaller leaves
- Possible leaf burn

3. Plant symptoms of overwatering:

- Excess growth
- Soft growth
- Possible root damage
- Wilts easily under strong light

22.2.1 WATERING SYSTEMS

Water is primarily supplied to the system through water mains installed underground or overhead. Two-inch PVC pipes are commonly used in 20,000 sq. ft. greenhouses, and 3-inch pipes are used in 50,000 sq. ft. greenhouses. Double water mains may need to be installed for fertilizer application. Water efficiency can be improved with use of pulse watering system, where plants receive maximum water without runoff (i.e., boom watering).

22.2.1.1 Hand watering

- Not economical due to labour costs
- Beneficial for spot watering
- Water supplied through hand-held field hose
- Water breaker should be installed on end of hose

22.2.1.2 Perimeter Watering

- Plastic polyethylene or PVC pipe run along bench edges
- Water is sprayed under foliage through nozzles that are staggered along the pipe
- Nozzles can spray 180°, 90°, or 45°
- Water is projected farther into bed by 90° and 45° nozzles
- Nozzles are attached by holes punched

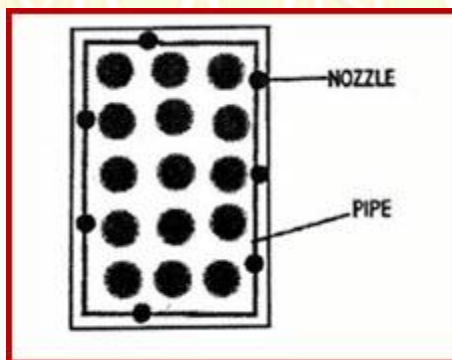


Fig 22.2.1 Perimeter Watering

22.2.1.3 Twin-Wall Watering

- Good for long or sloping benches
- Constant water pressure along tube
- Tube consists of two sections:

- Outer chamber

- Inner chamber
- Water first enters the tube in the outer chamber through a special pipe fitting connected to the water supply
- Water moves down the length of the tube until it reaches the end, where it begins to enter small pores along the tube leading to the inner chamber

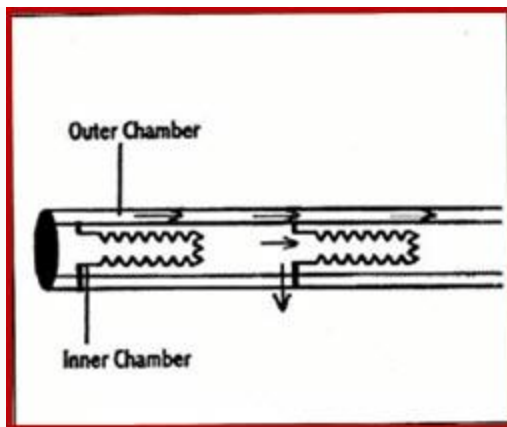


Fig 22.2.2 Twin Wall Watering

22.2.1.4 Tube Watering

- Polyethylene micro-tubes run from water supply to each individual pot.
- Emitters are attached to the end of the tube.
- Water is supplied by $\frac{3}{4}$ -inch polyethylene or PVC pipes run along the centre of the bench
- Tubes are attached to the pipe through drilled holes.
- Consistent tube length is required.
- Benches should be level to insure even watering.
- Method can also be used for hanging plants.

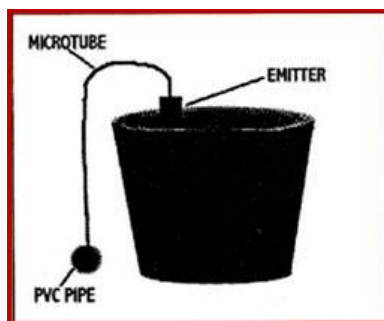


Fig 22.2.3 Tube Watering

22.2.1.5 Overhead Watering

- Water is applied through 360° nozzles attached to top of riser pipes
- Nozzles may be designed to rotate 360°
- Riser pipes are periodically attached to a pipe run along the centre of the bed
- Riser pipes reach well above plant tops

22.2.1.6 Boom Watering

- Boom runs along rails attached down centre of greenhouse
- Boom is propelled by an electric motor
- Can be programmed to water one side only or to skip sections of the greenhouse
- Good example of pulse watering

22.2.1.7 Mat Watering

- Good for several pot sizes
- Polyethylene sheets are placed on benches
- A 3/16 to 1/2 inch thick moist mat is placed on top of the sheets
- Pots are placed on the mat, then take up water through holes on the bottom through capillary action
- Very important that pots have bottom holes
- Once pot is lifted from mat, capillary action is broken and it becomes necessary to re-water pot from top to re-establish capillary action
- Benches should be level to insure even watering
- To prevent algae, perforated polyethylene may be placed on top of mat for pots to sit on
- Watering tubes placed 2 feet apart run down the length of the bench to supply water to the mat

22.2.1.8 Ebb-and-Flood Watering System

- Pots are placed in a level, watertight bench
- The bench has channels in the bottom and a hole in the centre for the water to enter and exit
- A filter and a tee valve are installed in the hole

Design and Maintenance of Green House

- Water is pumped into bench to a level of $\frac{3}{4}$ to 1 inch over 10 minutes
- Pots are allowed to sit in water for 10-15 minutes
- Water is drained out over 10 minutes
- Easy to change pot sizes
- High humidity may cause problems

22.2.1.9 Flood Floor Watering System

- Greenhouse floor is paved with a slight slope toward the centre on either side or a lip that runs along the perimeter
- A drain hole is installed in the centre
- Hot-water heating pipes are installed to speed up the time needed to dry the floor to lower relative humidity
- Flood greenhouse with water
- Time required to flood greenhouse will vary

22.2.1.10 Trough Watering

- Troughs containing one row of plants are placed parallel down the greenhouse with spaces in between
- Reduces humidity
- Promotes dryer foliage
- Troughs are slightly sloped for the water to drain into a gutter where it is returned to a holding tank

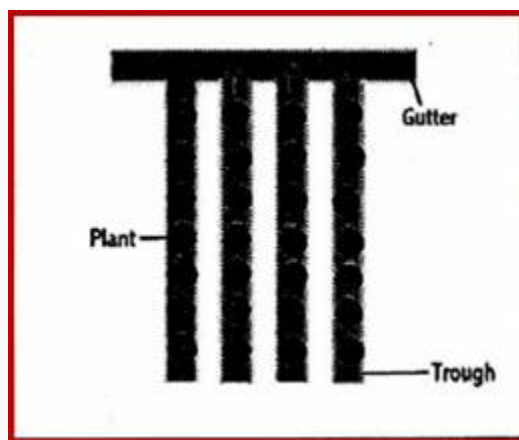


Fig 22.2.4 Trough Watering

22.3 FERTILIZATION

In protected cultivation, the cost of fertilization is small in relation to the vegetable production costs, so fertilization has been usually high, as growers have no incentives to save fertilizers and pretend, mistakenly in many cases, that the crop did not suffer any kind of nutrient deficiency. Nevertheless, nowadays, the trend to minimize the environmental impact has resulted in the adoption of the so called 'Good agricultural practices (GAP) code'.

22.3.1 The nutrients cycle (soil cultivation)

In horticulture, and especially in greenhouses, there is more leaching of nitrates than in other agricultural systems, due to the high supplies, the high contents of organic matter in the soil and the surplus irrigation in relation to the ETc (Dasberg,1999b). Its environmental impact can be notable, mainly, in the surface and underground aquifers.

The applications of nitrogen fertilizers in the greenhouses normally exceed the crop's requirements, increasing the risks of nitrate leaching to the aquifers (Thompson et al., 2002).

Phosphorus does not usually cause pollution problems, except in exceptional cases of soils with low phosphorus fixation capacity or when large quantities of animal manure are applied over many years.

The potassium leachate is, normally, limited and does not cause important problems of environmental impact, as it is retained in the soil in high proportions.

Other macronutrients, such as calcium and magnesium, do not cause environmental problems, as they are natural components of the soil, which retains them in large quantities.

22.3.2 Nutrient Extraction

It is necessary to know the fertility characteristics and nutrient levels in the soil, making the pertinent soil analysis, to schedule fertilization. Normally, if the nutrient level is good, fertilization in practice is based on supplying the crop's uptake, corrected for the use efficiency, which allows for maintaining, after the crop cycle, a proper fertility and nutrient level. If the levels of any nutrient are high, or if the irrigation water contains it in sufficient amount, the inputs must be consequently corrected.

As a guide, Table 22.3.1 summarizes the approximate nutrient uptakes of some horticultural crops.

It is important to know the nutrient absorption dynamics, to adapt the inputs to the extraction rates, which vary through the cycle and are influenced by the climate conditions, especially by soil temperature and radiation.

When the availability in the soil of some nutrients is high, over consumption may occur (in potassium) or it may negatively affect the quality (nitrogen) of the fruits, in extreme cases being possible to induce salinity, or even phytotoxicity. The availability of nutrients must be balanced and adapted to the plant requirements, to avoid antagonisms and

possible restrictions to the nutrient absorption, which allow for optimum fertilization. Therefore, it is frequent to maintain predetermined relations between all or some of the nutrients

Table 22.3.1 Approximate nutrient uptake of some horticultural crops (compiled from very diverse sources).

Crop	Yield (t/ha)	Plant Uptake (Kg/ha)				
		N	P ₂ O ₅	K ₂ O	CaO	MgO
Tomato	80	250	80	500	300	70
Pepper	40	180	60	180	160	50
Aubergine	50	250	40	300	150	25
Melon	60	230	80	400	300	70
Cucumber	200	320	160	600	250	100
Squash	40	70	70	390	-	-
Lettuce	40	100	50	250	50	12
Green bean	45	150	15	60	30	6

22.3.3 Tolerance to salinity

The tolerance to salinity of the crops may be assessed in several ways. The most extensively used method (Ayers and Westcot, 1976) quantifies the tolerance (Table 22.3.2) by the percentage of the maximum yield that would be obtained for a certain level of electric conductivity of the saturated extract of the soil (EC_e) or the irrigation water (EC_w) used. For greenhouse crops the tolerance to salinity can be quantified (Sonneveld, 1988) by means of the irrigation water salinity threshold below which there is no problem, and the percentage of yield decrease experienced by the crop per unit increase of salinity in the irrigation water, above the threshold value. This method is more useful for substrate crops. Table 22.3.3 summarizes the data in this respect. The specific growing conditions (cultivar, evaporative demand, management, and microclimate) may affect these threshold values (Cohen, 2003). In Mediterranean greenhouses, Magan (2003) estimated the salinity threshold value of the nutrient solution to decrease the fresh weight tomato harvest between 4 and 5 dS m⁻¹.

The importance of the water quality to minimize the leaching fraction is enormous, influencing its environmental impact potential. Poor quality water will require considerable leaching and, as a consequence, will generate more negative impact than good quality water.

Table 22.3.2 Tolerance level of some crops to salts (dS m⁻¹), expressed as the expected yield (in percentage of the maximum yield).

(Source: Ayers and Westcot, 1976.)

Percentage of maximum yield									
Crop	100%		90%		80%		50%		Max EC _e ^a
	EC _w	EC _e	EC _w	EC _e	EC _w	EC _e	EC _w	EC _e	
Climbing bean	0.7	1.0	1.0	1.5	1.5	2.3	2.4	3.6	6.5
Broccoli	1.9	2.8	2.6	3.9	3.7	5.5	5.5	8.2	13.5
Melon	1.5	2.2	2.4	3.6	3.8	5.7	6.1	9.1	16.0
cucumber	1.7	2.5	2.2	3.3	2.9	4.4	4.2	6.3	10.0
Potato	1.1	1.7	1.7	2.5	2.5	3.8	3.9	5.9	10.0
Lettuce	0.9	1.3	1.4	2.1	2.1	3.2	3.4	5.2	9.0
Onion	0.8	1.2	1.2	1.8	1.8	3.2	2.9	4.3	8.0
Pepper	1.0	1.5	1.5	2.2	2.2	3.3	3.4	5.1	8.5
Spinach	1.3	2.0	2.2	3.3	3.5	4.9	5.7	8.6	15.0
Strawberry	0.7	1.0	0.9	1.3	1.2	1.8	1.7	2.3	4.0
Tomato	1.7	2.5	2.3	3.5	3.4	5.0	5.0	7.6	12.5

Table 22.3.3 Tolerance of some vegetables to salinity in greenhouses

	Threshold value EC _w (ds m ⁻¹)	Yield decrease by salinity (%)
Tomato	1.8	9
Pepper	0.5	17
Cucumber	1.5	15
Green Bean	0.5	20
Lettuce	0.6	5

22.3.4 Fertigation

This practice of joint application of irrigation and fertilization is known as fertigation. The control centre of a localized irrigation facility must have the necessary equipment to fertigate. This involves the use of soluble or liquid fertilizers, allowing for adjustable dosing and fractioning of the inputs which optimizes their use.

22.3.4.1 Criteria of fertigation

Traditionally, the fertigation criterion of supplying the nutrients as a function of the expected uptake by the plants prevailed.

Nowadays, the criterion of providing nutrients based on an ionically balanced physiological solution, used in soilless crops, is extending to conventional soil cultivation, when a suitable automated irrigation head is available.

In soilless cultivation the correction of the nutrient solution is performed based on its analysis. In soil cultivation, the classic method of analysing the saturated soil extract is being replaced by the use of suction probes, with which a sample of the soil solution is extracted for analysis. However, information on the ideal nutrient levels to use with this method is still scarce.

22.3.4.2 A practical example: a soil-grown tomato crop

Depending on each case's specific conditions (soil fertility, climate and irrigation type), there is notable variation in tomato fertilization (Castilla, 1995). Preliminary analysis of the soil is necessary. In general, fertilizers are applied depending on the crop's estimated nutrient uptake. Although the variability in nutrient uptake is enormous, values that refer to harvest unit are in general lower.

- Between 2.1 and 3.8 kg of N t⁻¹ of harvest;
- Between 0.3 and 0.7 kg of P t⁻¹ of harvest;
- Between 4.4 and 7.0 kg of K t⁻¹ of harvest;
- Between 1.2 and 3.2 kg of Ca t⁻¹ of harvest; and
- Between 0.3 and 1.1 kg of Mg t⁻¹ of harvest.

The differences in nutrient uptakes are influenced by the type of pruning and, especially, by the timing of the removal of the axillary shoot. It is advisable to prune shoots as soon as possible to minimize the wasteful uptake of nutrients by the crop.

The scheduling of fertilizer application must rely on the type of fertilizer used, on the irrigation technique and on the soil conditions, among other factors. In sandy soils, with low water storage capacity, supplies must be frequent with the irrigation (conventional), whereas in heavy soils it is only necessary to apply part of the nitrogen as a top dressing (Geisenberg and Stewart, 1986).

With surface irrigation, the most common practice is to apply the phosphorus with the pre-planting fertilization, for example when applying manure (around 30 t ha⁻¹), and at a time when half of the potassium is applied. The rest of the potassium and nitrogen are applied in alternate weeks after transplanting until 1 month before the end of the cycle (Nisen et al., 1988). With drip irrigation, all fertilizers can be applied by fertigation, although it is common that at least part of the phosphorus is applied with the manure.

In drip irrigation, it is essential to know the absorption rhythm of the mineral elements in order to schedule fertilization (Zuang, 1982). In Mediterranean unheated greenhouse crops for autumn-spring cycles, fertilization rates higher than 0.3 g N m⁻² day⁻¹ do not seem advisable (Castilla, 1985). The fertilizer's content of the irrigation water is, in some cases, notable and must be taken into account for the fertilization schedule.

Nitrogen excesses negatively affect fruit quality, and maintaining an N:K ratio at 1:2 (or even 1:3) during the fruit enlargement stage, with drip irrigation, favours their quality (Geisenberg and Stewart, 1986). Equally, the balance between other nutrients, especially between calcium (when its supply is required) and potassium, and magnesium is necessary, as well as between the different forms of nitrogen (nitric/ammoniacal).

In drip irrigation, the amount of salts in the water must be limited, if possible, to 2 g l⁻¹ (which is not feasible, in some cases, when saline water is used), to decrease possible dripper blockage problems. When using good quality water, it is a usual practice to add sodium chloride (common salt) to the water, up to the indicated limit, to improve tomato quality, because the soluble solids content increases with salinity which contributes to the improvement of its internal quality, although the fruit size is reduced.

A good irrigation efficiency is, logically, required for efficient fertigation and also contributes to a significant reduction in the environmental impact of fertilizer (nitrogen, especially) residues.

Foliar fertilization, in tomato crops, is usually limited to microelements, when deficiencies are forecasted or observed. Leaf analysis (of the limb, petiole or the whole leaf) is a good auxiliary index on which to base the scheduling of fertilization, being more common than sap analysis, as the latter displays a wider variability and requires more thorough sampling (Chapman, 1973; Van Eysinga and Snilde, 1981; Morard, 1984).

In greenhouse crops, low soil temperatures (15°C) in winter may limit absorption of nutrients, especially phosphorus (Wittwer, 1969) and nitrates (Cornillon, 1977). On the other hand, high temperatures favour nutrient absorption, although the nutrient uptake per harvest unit is not affected, as previously thought (Nisen et al., 1988).

22.3.4.3 Fertigation of soilless crops

22.3.4.3.1 The nutrient cycle in soilless crops

Soilless crops, with free drainage, have similar problems to soil cultivation regarding the nutrient cycles. The management conditions (leaching percentage, characteristics of the nutrient solution) of the soilless crop (open system) will determine its environmental impact, which will be similar to that of crops grown in soil if the leachates are similar. If

leachates are recirculated (closed system) the salinity and pathology problems must be considered and the nutrient concentrations must be well monitored and controlled.

22.3.4.3.2 Preparation of the nutrient solution

In an ideal soilless growing system there are no mineral inputs from the substrate, and therefore, all nutrients must be supplied together with the water, in the nutrient solution. The preparation of the nutrient solution requires prior analysis of the irrigation water, to allow for the formulation of the best nutrient solution depending on the crop to be grown. The preparation of this nutrient solution will also depend on the technical characteristics of the available fertigation hardware (and, possibly, software). In the simplest case, one concentrated solution tank is available and another tank for the acid. Most facilities have two tanks for solutions (A and B), one of which already contains the acid. In this case, tank A has most of the acid to correct the pH (usually, nitric or phosphoric, and rarely sulphuric), the phosphates and the sulphates, as well as the microelements, except for iron. In this tank A, part of the potassium nitrate can be incorporated, but no calcium salts must be added, to avoid precipitates. Tank B contains the calcium nitrate and the potassium nitrate (all or only a part), as well as some nitric acid to regulate the pH and the iron chelates. The magnesium nitrate is usually added in tank B, but neither sulphates nor phosphates must ever be added, to avoid precipitates.

When three tanks are available, one of them is destined only for the acid that is usually nitrous acid, although sulphuric or phosphoric acids can be used. In sophisticated facilities, managed by means of a computer, several tanks are usually available, containing solutions of individual fertilizers.

The injection systems of concentrated solutions in the irrigation water flux are of such complexity or simplicity in agreement with the type of tanks used.

In mixing the fertilizers their solubility and compatibility must be taken into account, not forgetting that it depends on temperature (Tables 22.3.4 and 22.3.5). The literature on the preparation of simple solutions is extensive (e.g. Cadahía, 1998).

Table 22.3.4 Solid fertilizers most commonly used in fertigation: analysis and solubility at 20°C.

Fertilizer	Analysis of N-P ₂ O ₅ -K ₂ O-others ^a (%)	Solubility (g/l)
Calcium nitrate 4H ₂ O Ammonium nitrate	15.5-0-0-26.6 (CaO) 33.5-0-0	1200 1700b
Ammonium sulfate	21-0-0-22 (S)	500
Urea	46-0-0	500
Potassium nitrate	13-0-46	100–150
Potassium sulfate	0-0-50-18 (S)	110

Mono potassium phosphate	0-52-33	200
Mono ammonium phosphate	12-60-0	200
Magnesium sulfate 7H ₂ O	16 (MgO)-13 (S)	700
Urea phosphate	17-44-0	150
Magnesium nitrate 6H ₂ O	11-0-0-9.5 (Mg)	500

The first three values in each entry refer to N-P₂O₅-K₂O. Where there is a fourth entry this refers to other compounds. The exception is the entry for magnesium sulphate which has no N-P₂O₅-K₂O and contains 16 (MgO)-13 (S) as indicated. b Steep water temperature decrease for concentrations above 250 g l⁻¹.

Table 22.3.5 Chemical compatibility of the mixture of some common fertilizers in fertigation: I, incompatible; C, compatible. (Source: Cadahía, 1998.)

	NO ₃ NH ₄	Urea	(NH ₄) ₂ SO ₄	(NH ₄) ₂ HPO ₄	(NH ₄)H ₂ PO ₄	KCL	K ₂ SO ₄	KNO ₃	(CaNO ₃) ₂
NO ₃ NH ₄	-								
Urea	C	-							
(NH ₄) ₂ SO ₄	C	C	-						
(NH ₄) ₂ HPO ₄	C	C	C	-					
(NH ₄)H ₂ PO ₄	C	C	C	C	-				
KCL	C	C	C	C	C	-			
K ₂ SO ₄	C	C	C	C	C	C	-		
KNO ₃	C	C	C	C	C	C	C	-	
(CaNO ₃) ₂	C	C	C	C	C	C	C	C	-

22.3.4.3 Parameters of fertigation with soilless crops

The proper management of fertigation requires the periodic analysis of the nutrient solution to assess its goodness of fit to the requirements of the crop and to perform necessary adjustments to its composition. In addition, it is necessary to frequently monitor (automated or manual) the pH and EC (electrical conductivity) of the nutrient solution and the leachate, to prevent any anomaly.

In practice, when a computer is available, a certain threshold of EC of the nutrient solution is fixed, for instance 2.5 dS m^{-1} , modulated as a function of the solar radiation, decreasing it by 0.1 dS m^{-1} for each 30 W m^{-2} of solar radiation that exceeds 400 W m^{-2} (Urban, 1997b). Obviously, these rules must adapt to the specific conditions of each operation.

Normally, the pH is not regulated but a certain value is fixed. The EC and pH sensors must be duplicated, at least, to prevent an eventual failure. In addition, the system must be fitted with alarms. Other complementary analyses are carried out on the substrate solution (extracted with a syringe) and the drainage, to correct the nutrient solution.

Analysis of vegetable tissue and sap provide information on the nutrients that are really absorbed by the plants (Cadahia, 1998). The analysis of the conducting tissues is usually preferable to that of the leaves, whose composition varies slowly. In these analyses, the time variations are more relevant than the absolute values (Morard et al., 1991).

22.3.4.3.4 Pathogens in the drainage waters

The recirculation of the drainage water requires the use of good quality water and its disinfection, to suppress pathogens (bacteria, fungi and virus) in the recirculation water.

The use of ozone, UV sterilization, thermal treatment and ultrafiltration are effective to a varying extent, but the last technique has the drawback that only 70–80% of the drainage water is recovered (Dasberg, 1999b). The use of bleach in recirculation water disinfection gives good results. Treatment with UV radiation is effective, but it is necessary to pre-filter the water so the radiation penetrates well (Dasberg, 1999b).

22.3.4.3.5 Automation

The use of computers, with several degrees of automation to manage the fertigation, is growing among greenhouse growers. It must be expected, in the future, that these systems will become integrated with climate control systems, in those greenhouses in which the technological level allows for it, for combined optimization.

22.4 ROOT SUBSTRATE

22.4.1 Functions of substrates

- Serves as a reservoir for plant nutrients
- Serves as a reservoir for water available for plants
- Must provide gas exchange between roots and the atmosphere outside the root substrate
- Provides anchorage or support for the plant

22.4.2 Limitations of materials

- Sand : excellent support and excellent gas exchange but poor water and nutrient-holding capacity

Design and Maintenance of Green House

- Clay: high nutrient- and water-holding capacity plus excellent support but poor gas exchange
- Water : water and nutrients; can even supply gas exchange, but offers no support; if plants are given support
- Field soils (when placed in a pot) : excellent support, nutrient-holding capacity, and water-holding capacity, but poor gas exchange

22.4.3 Desirable properties of a substrate

- **Stability of organic matter**
 - decomposition of organic components = smaller particle size = finer texture = smaller pores = reduced gas exchange and reduced aeration also means a loss of substrate volume
 - straw and saw dust (excluding some like redwood) are examples of materials with poor stability
- **Carbon-to-nitrogen ratio**
 - Organic materials are broken down by microbes
 - Microbes require N for decomposition
 - If C : N ratio > 30 C : 1 N, & substrate contains
 - If organic materials decomposes rapidly, the microbes will utilize N
 - The C : N of sawdust is about 1000 : 1
 - Pine bark has a C : N of about 300 : 1, yet is still suitable to use...
- **Dry bulk density**
 - oven-dry weight of substrate particles ÷ volume given in lb/ft³
 - useful for predicting materials handling
 - if too low, as the substrate dries out, top-heavy pots topple over
- **Wet bulk density**
 - weight of substrate at container capacity ÷ volume reported in lb/ft³
 - container capacity is moisture content of substrate just after complete saturation and loss of gravitational water
 - $([\text{volume needed to saturate} - \text{drainage volume}] \div \text{total volume of container}) \times 100$

- usually reported as % of total volume

- **Moisture retention and aeration**

- goal is a substrate with adequate available water +sufficient aeration + acceptable wet and dry bulk densities
- substrate at container capacity composed of : solid particles
- pores filled with : unavailable water & available water (micropores), air (macropores)

- **Unavailable water (hygroscopic water)**

- held by solid particles so “tightly” that it is unavailable to roots common.
- roots would have to create a suction > 15 bars to separate water from the particles

- **Available water**

- volume of water at container capacity – volume of water remaining at 15 bars pressure

- **Cation exchange capacity**

- many substrate components have fixed negative electrical charges
- will attract and hold positive-charged cations
- CEC = milliequivalents per 100 cc of dry substrate
- 6 to 15 me/100 cc is desirable
- clay, peat moss, and coir have higher CEC's

- **pH**

- most greenhouse crops = 6.2 to 6.8 in soil-based substrates (20% or more soil) and 5.4 to 6.0 in soilless substrates

22.5 ROOT MEDIA PASTEURIZATION

Sterilization is the killing of all living organisms on or in a material. Pasteurization is the killing of most living organisms on or in a substance. In the past, the general dogma is that pasteurization kills the harmful organisms (i.e. disease-causing fungi) in a substrate but allows most of the beneficial organisms to live. However, pasteurization does kill many of the beneficial organisms (i.e. Trichoderma, Gliocladium, nitrifying bacteria) in the substrate (or substantially population) and may actually increase the incidence of soil-borne diseases. Unless field soil is added to a substrate, or there is some reason to believe the substrate may be contaminated with weed seed, nematodes or a high level of disease-causing organisms

(i.e. with repeated monoculture in ground beds), substrates should not generally be pasteurized.

22.5.1 Methods of Substrate Pasteurization

22.5.1.1 Steam:

Steaming is the best methods for pasteurization of substrates. The basic objective is to apply the steam until the coldest area of the substrate reaches 160° F (71° C) for 30 minutes. Of course, other areas of the substrate will be at a higher temperature. The substrate should be moist and loose prior to steaming and a system that allows the steam to move into the substrate should be used.

Lime, superphosphate, inorganic fertilizers and microelements can be incorporated prior to steam pasteurization. However, slow-release fertilizers (unless otherwise indicated), manures and urea-based fertilizers should not be incorporated prior to pasteurization.

Several problems can occur as a result of steam pasteurization of substrates. Manganese toxicity can occur if a field soil containing large amounts of manganese is included in the substrate. Toxic levels of ammonium can occur when substrates with high volumes of organic matter, manures or ammoniacal nitrogen are pasteurized. This often occurs because the microorganisms involved in converting organic nitrogen to nitrate are killed by pasteurization. The ammonifying bacteria recover first followed 3- 6 weeks later by the nitrifying bacteria. During this time ammonium can build up to toxic levels. If slow release fertilizers are added prior to steam pasteurization, the coating may be damaged and fertilizer salts rapidly released. This can result in a high E.C. levels and subsequent damage to the plant root system.

22.5.1.2 Chemicals:

- **Methyl Bromide** is scheduled to be removed from the market. It is highly toxic and is most often used for field situations. When being treated with methyl bromide, the soil should be loose and moist and must be covered tightly prior to the injection of the gas. Since methyl bromide is odourless, chloropicrin is usually added as a safety precaution. Methyl bromide effectively kills soil-borne fungal and bacterial pathogens, nematodes and weed seed.
- **Chloropicrin** is also known as tear gas. It is used in a manner similar to methyl bromide.
- **Vapam** is similar to chloropicrin. It is often used in the nursery industry to pasteurize soil beds. It is most effective against weed seed.

Growers should always exercise caution when using chemicals and follow the label for the specific chemical being used. After chemical sterilization, the medium should be allowed to sit for up to 14 days before planting to allow any phytotoxic chemical residue to dissipate.

22.5.2 Important facts of Root media Pasteurization

1. Greenhouse root media should be pasteurized at least once per year and more often as required to rid them to harmful disease organisms, nematodes, insects and weed seed.
2. Numerous microorganisms develop in root media which are not harmful. These can be beneficial by providing competition for harmful microorganisms, which might otherwise proliferate. For this reason root media are pasteurized and not sterilized i.e. only some organisms are killed.
3. Root medium may be pasteurized with steam by raising it to a temperature of 140° - 160°F for 30 minutes.
4. Volatile chemicals are also used for pasteurizing root media.
5. Both steam and chemical pasteurization require that the root medium be loose and of moisture content suitable for planting amendments such as peat moss, manure and bark should be incorporated prior to pasteurization to prevent introduction of diseases or pests.
6. Pasteurization can result in ammonium and manganese toxicities in certain situations. If the root medium contains organic matter rich in nitrogen, such as manure, steam and chemical pasteurization can result in an excessive release of ammonium, particularly in the period of two six weeks after pasteurization. Either these materials should be avoided or an adjustment should be made in the watering practice to ensure adequate leaching of ammonium. Many soils contain large levels of manganese, most of which is unavailable. Steam pasteurization causes conversion unavailable manganese to an available form. A toxic level is sometimes reached. This is another reason for pasteurizing root media at low temperature and for only the necessary length of time.
7. Pasteurization of root media is designed to eliminate harmful organisms. It does not protect against future infestations. Good sanitation practices must be employed to maintain clean conditions. Some considerations include disease free seeds and plants, sterilization of containers and tools, a pesticide program, foot baths, a clean working area, sanitation outside the greenhouse, and proper control of temperature and humidity.



Module 15. Containers and benches

Lesson 23 Containers & Benches

23.1 INTRODUCTION

The duration of crop in greenhouse is the key to make the greenhouse technology profitable or the duration of production in greenhouses should be short. In this context, use of containers in greenhouse production assumes greater significance. The containers are used for the following activities in greenhouse production.

- Raising of seedlings in the nursery
- Growing plants in greenhouses for hybrid seed production of flowers
- Growing plants for cut flower production.
- Growing potted ornamental plants.

Choosing greenhouse bench materials and design can be a difficult decision, due to wide choice of products available to the grower today. In this chapter we will learn common designs, materials and considerations in choosing containers, benches for commercial application.

23.2 BENCHES

23.2.1 Floor as benches

Growing plants directly on the floor in conjunction with ground floor heating systems using the floor for growing plants is gaining popularity, but the cement must be laid exactly level in order to achieve an even distribution of water when flooding floors. Porous concrete floors may be expanded in width to serve as “benches”. The main advantage is the porosity offered and the lowered cost from bypassing above ground structures. This system works well for some species. However, the added fatigue on employees may not be worth the initial savings when considering the strain of working at an awkward position.

23.2.2 Raised Benches

23.2.2.1 Bench arrangements

Maximum utilization of growing facilities is largely based on the amount of growing area achieved. Benches in the peninsular design (fig 23.2.1) may result in a greater growing area than if they were in a longitudinal arrangement. The peninsular design also allows many species to be conveniently segregated, which can be a real advantage for retail growers. However, many growers have found routine tasks such as watering much easier on longitudinally placed benches

Lastly, non-stationary benches, which provide even more growing space, are gaining popularity with growers. Movable benches (fig 23.2.2), known as rolling benches, can increase efficiency up to 90 percent of the floor space. Bench platforms are moved by a crank at the end of the bench from side to side. Some can be moved by hand by sliding the benches over the top of long steel poles. Aisles are created where the grower wants to work at any given time. Rolling benches are easy to move by practically any labourer, which is an added bonus. Movable benches, however, are not appropriate in a retail setting or where plants must be accessed frequently. Retailers are better served by staying with conventional benches such as the longitudinal, peninsular, or other comparable type designs.

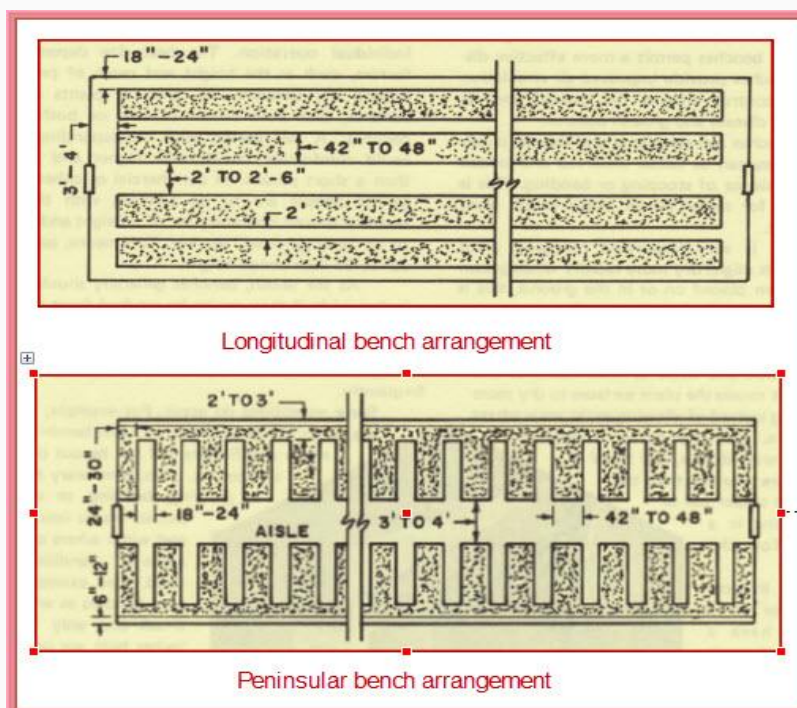


Fig 23.2.1 Bench arrangements

(Source: J.N.Walker and G.A Duncan, 1914)



Fig 23.2.2 Movable bench arrangement

(Source: www.nexuscorp.com)

23.2.2.2 Bench Space Efficiency

Benching efficiency is defined as the square feet of bench space to the entire greenhouse floor area. This number is expressed as a percentage.

Examples: A grower chooses a longitudinal bench arrangement in a greenhouse 30' x 80' or 2400 square feet of floor area. He decides to use 3-foot wide benches and 2.5-foot wide aisles and allows four feet at the end of the benches. The greenhouse has a benching efficiency of $[(5 \text{ (number of benches)} \times 72 \text{ (length of each bench)} \times 3 \text{ (width of bench)}) \div (30 \times 80 \text{ greenhouse dimensions})] \times 100 = (1080/2400) \times 100 = 45\%$.

However, if the benches were widened to four feet and 74 feet long, allowing a three-foot turn around rather than four feet as before, efficiency could be increased to 49 percent $[(4 \times 74 \times 4) \div (30 \times 80) \times 100 = 49\%]$. To further increase efficiency, the benches could be widened and the aisle widths reduced.

If the grower looks at the same greenhouse with 2400 square feet floor space, but this time designs a peninsular bench arrangement, he will find that the peninsular design will increase the growing area even more. Still greater efficiency could be realized with rolling benches.

23.2.2.3 Bench Design

An alternative to conventional benching systems is the ebb and flow (flood or sub irrigation) benches (fig 23.2.3). Metal or wood benches are replaced with watertight, molded plastic trays. Trays are periodically flooded with water and desired fertilizer concentration, which can be taken up throughout the plants via capillary action. This system has such advantages as reduced and uniform applications of water and fertilizer. Excess water and fertilizer are collected after each flood and drain cycle to be recirculated later. Up to 50 percent reductions in water and fertilizer savings have been reported. Labour costs will also be reduced since the entire bench can be watered at the same time. This may not be feasible if plants with dissimilar water requirements are grouped together on each bench. An added benefit is that foliage will stay dry and plants can be grouped closely for greater production efficiency. Ebb and flow bench manufacturers have also designed trays to be incorporated into a rolling bench system for even greater versatility. This bench system should be given serious consideration with ever increasing restrictions on water and fertilizer runoff.



Fig 23.2.3 Ebb and flow type benches

(Source: www.agratech.com)

23.2.2.4 Materials for Benches

23.2.2.5 Wooden Benches

Locust, cedar, redwood, and cypress are all woods highly resistant to decay. Paint benches before use with copper naphthenate or other preservatives to augment the natural decay resistance of the wood chosen. When redwood is chosen, iron and steel will corrode from naturally present decay inhibitors. Therefore, choose metals such as aluminum, zinc, or brass nails, screws, and bolts. Benches may be all wood or in combination with a different material for the base. Often, expanded metal or welded wire of one inch or smaller mesh is used. While expanded metal is more expensive, it does not sag like welded wire. Besides decay, wood may warp and often absorbs soils, chemicals, etc. which cannot be adequately removed. When wood is chosen, higher maintenance will be required on a regular basis.



Fig 23.2.4 Wooden benches

(Source: www.sturdi-built.com)

23.2.2.6 Concrete

Some growers built concrete forms and pour entire benches, including the legs (supports), all at once. These benches are permanent and do not allow for change later. Concrete benches are durable and will not require additional treatment to prevent decay such as with wood. They may be reinforced with steel rods, when poured, for additional durability. Lastly, consider drilling holes in the base of the bench for proper drainage.



Fig 23.2.5 Concrete benches

(source: www.westerngardner.com)

23.2.2.7 Metal

Entire metal or steel benches are used alone or in combination with another material. Advantages of galvanized metals over wood are the longevity and resistance to rot and decay. Metal benches may be expensive to install initially, but can be considered a one-time cost. Also consider the lowered maintenance costs when these types of benches are used.



Fig 23.2.6 Metal benches

(Source: <http://www.agratech.com>)

23.2.3 Temporary/Portable Benches

23.2.3.1 Plastic

Although plastics are becoming more common for bench beds, plastic frames are not always desirable. They are often not as durable or able to support as much weight as other benching materials. However, in a retail setting, prefabricated benches can be purchased which are lightweight and, thus, portable. These are also available mounted on rollers, making them particularly convenient in retail settings. Also, maintenance on plastic benches is again considerably less than for wood



Fig 23.2.7 Plastic benches

(source: www.usgr.com)

23.2.3.2 Pallets

Another portable bench system can be inexpensively constructed by placing pallets on cement blocks for support. Besides the low cost, this portable display can be easily and quickly disassembled.



Fig 23.2.8 Pallets

(Source: [www. badger.uvm.edu](http://www.badger.uvm.edu))

23.2.3.3 Bench Supports

Cement blocks are commonly used to support bench tops, particularly if they are not intended to be permanent. Permanent benches may also be supported in this fashion. Additionally, steel poles are often used for bench support. Plastic bench supports are becoming more popular, but again they are often not as strong, and in many cases are most appropriate for temporary retail displays. When wooden supports are used, it is especially critical to chemically treat them for decay, at least the area which will be submerged in the soil. The same preservatives which may be used on the growing surface of the benches are appropriate. Also, by pouring concrete footings, the structural integrity of the bench supports may be reinforced.

23.3 CONTAINERS

Selection of suitable containers depends upon the crop to be produced in greenhouse, plant characteristics like crop stage, duration, vigour, growth habit, root system, etc. Generally long duration, deep rooted and vigorous crop plants require bigger containers compared to short duration, shallow and less vigorous ones. The containers provide optimum condition for germination of seed and growth and development of transplants.

23.3.1 Advantages of containers in greenhouse production

- Increases production capacity by reducing crop time.
- High quality of the greenhouse product
- Uniformity in plant growth with good vigour
- Provide quick take off with little or no transplanting shock.
- Easy maintenance of sanitation in greenhouse
- Easy to handle, grade and shift or for transportation.
- Better water drainage and aeration in pot media.
- Easy to monitor chemical characteristics and plant nutrition with advanced irrigation systems like drips.

23.3.2 Types of containers

23.3.2.1 Plastic

The most common and inexpensive type of planter is the plastic planter. These are available in a multitude of sizes, shapes and designer colors and range in price from downright cheap to the more expensive designer lines. These planters are available with or without drainage trays and with smooth or textured surfaces. These containers are water-tight and non-porous.



Fig 23.3.1 Plastic pots

(Source: www.thisoldhouse.com)

23.3.2.2 Ceramic:

Ceramic planters are usually slightly more expensive than plastic planters. They are also available with or without water drainage trays. Trays are a must for ceramic planters which do not have sealed surfaces, as they are porous and will “bleed”. Ceramic containers come in natural, textured surfaces or painted and glossy finishes. Some are hand-formed, imperfect and artistic. Some are geometric and have a high-tech look. Ceramic planters can create a quality custom look and they come in a wide range of prices.



Fig 23.3.2 Ceramic pots

(Source: www.pinterest.com)

23.3.2.3 Wood

Wood planters are less common than other types. Custom planters commonly constructed in wood, come in a variety of finishes and can give a particular decor a natural look. These planters should be lined with a non-porous material because wood can stain and rot if water-soaked. Wooden planters can be treated with a preservative, using only products recommended for applying to wooden greenhouses and avoiding those like creosote that could harm the plants.



Fig 23.3.3 Wooden planters

(Source: www.oldvirginiawoodworking.com)

23.3.2.4 Fiberglas

Fiberglass planters are used widely in commercial plantings. The surface is durable and easily formed into different custom shapes for any look. They can be given many different surface textures and painted any colour or pattern imaginable. They are water-tight; ridges are often built into bottom surfaces to provide drainage isolation. Fiberglass planters are available to the homeowner, but primarily through designer outlets and catalogues. They are considerably more expensive than plastic planters.

23.3.2.5 Metal

Metal planters provide a nice accent for plants. The most common metals used in planter construction are brass, copper, stainless steel and aluminum. Wrought iron is also commonly used as a decorative container. Metal surfaces range from antique to highly polished to brushed. Metals require more maintenance than other surface materials. Treating of surfaces with sealants can reduce the tendency for tarnishing and minimize maintenance. Most metal containers do not provide drainage and are used primarily as outer covers for plant containers. Prices range from moderate for simple thin brass and copper containers to expensive, heavier, intricate units. Metal planters are available in all shapes and sizes.



Fig 23.3.4 Metal containers

(Source: earthly-gardener.blogspot.com)

23.3.2.6 Clay/Terra Cotta:

Clay pots can be used for interior display. Because they are porous, it is necessary to place pots on a waterproof tray to catch excess water and prevent bleeding of moisture through the pot onto carpet, floor or other surface areas.



Fig 23.3.5 Terra cotta pot
(Source: www.thefind.com)

23.4 Alternative containers

With the ever-increasing customer demand for sustainable greenhouse products, many growers are exploring ways to make their businesses more ‘green’ both in terms of environmental impact and public perception. Even though plastic containers meet the production needs of the nursery and greenhouse industry, plastic derived from petroleum is nonrenewable. Furthermore, used plastic containers are primarily disposed in landfills given limited access to recycling centres, high collection labour costs, chances of chemical contamination, photo degradation, and liability for poorly sanitized containers. Green industry stakeholders have identified the use of biodegradable container alternatives as a way to improve the sustainability of current production systems.

23.4.1 Types of Alternative Containers

Alternative containers similar to traditional petrochemical based plastic have been developed for use in greenhouse production. Alternative containers are classified based on the nature of degradability at the end of production life (Table 23.4.1).

Table 23.4.1 Types of alternative containers available in market





Name of Product	Material	Picture
Plantable		
Biopot	bamboo fiber	

Design and Maintenance of Green House

Coir pot	coconut coir fiber	
CowPot™	composted cow manure and natural fiber	
DOTPots™	spruce fiber, peat moss	
Ellepot®	Paper	
Fertil Pot	spruce wood fiber and peat moss	
Jiffy-Pot®	Peat	
Kord Fiber pot	wood and paper	
Net Pot™	rice hull	

Design and Maintenance of Green House

SoilWrap®	Mirel® (biopolymer)	
Straw Pot	rice straw	
Western Pulp pot	molded wood pulp, recycled paper	
Compostable		
Carbon Lite	Starch	
Ecotainer	plant starch (PSM)	
Kord Fiber Grow	recycled paper or cardboard	
Large Pulp Pots	wax permeated wood pulp	

TerraShellTMPot	Poly Lactic Acid (biopolymer from corn starch)	
Rice hull pot	rice hull	
Speedypot	peat and PLA biopolymer wrapper	
Wax tough pot	wood and paper coated in wax	

23.4.1.1 Recycled plastic geotextile

These containers are produced from recycled plastic bottles that would have ended up in a landfill. The used bottles are turned into a liquid and blended with biodegradable natural fibers, such as cotton, jute, vegetable fibers or bamboo to create a mixture that when heat pressed bonds to produce a fabric like geotextile that is sewn into a container to grow plants. These containers are not biodegradable or compostable but will slowly disintegrate to a point that leaves behind a much reduced carbon footprint. An example of this type of product is the Root Pouch™.



Fig 23.4.1 Root pouch

(Source: <http://www.hyjo.co.uk>)

23.4.1.2 Compostable

The containers are intended to be separated from the plant at planting and composted separately as they are not quickly or completely biodegradable in the landscape. Most bioplastics as well as hard rice hull and thick-walled paper/fiber containers intended for production of long term crops fall into this category. Industrially compostable containers may not break down in a typical backyard compost pile due to the low and inconsistent temperatures, moisture, pH, aeration and microbial populations. ASTM D6400 is the main standard developed by American Society for Testing and Materials (ASTM) for certification of industrially compostable plastics in the United States (ASTM, 2004).

23.4.1.4 Plantable

The containers are intended to be planted in the soil together with the plant. These containers are intended for short term pre-production and are expected to reduce transplanting shock, save transplanting time and cost, as well as to avoid used container disposal. For these products to live up to these claims, it is imperative that the containers do in fact break down quickly once planted into the soil to allow rooting into surrounding soil and not require removal when the bed is replanted. The rate of container biodegradation following planting depends on the container material, nitrogen, moisture, temperature, pH, microbes, etc. of the soil in which the containers are planted. The highest container decomposition was found with CowPot™, which has cellulose and nitrogen from dairy manure. More moderate degradation was found for peat, rice straw and wood pulp containers, the lowest level of decomposition observed during the trial period was associated with coconut fiber containers due to their high lignin content. Slow container degradation could cause root circling resulting in restricted water and nutrient movement and ability to adequately anchor woody perennials.

23.4.2 Sources of Alternative Containers

23.4.2.1 Pressed Fibre

There are a wide variety of hot-pressed fiber containers available in the market. These are constructed from fibrous materials such as rice hulls, wheat, peat, wood pulp, spruce fibers, coir (coconut fiber), rice straw, bamboo or mixed with composted cow manure. Fiber containers are semi porous and promote water and air exchange between the rooting substrate and surroundings. These containers may be biodegradable or compostable. Some include a natural or synthetic binding material such as resins, glue, wax, latex and even cow manure. Pressed fiber containers tend to have varying degrees of rigidity, material strength, and decay resistance.

23.4.2.2 Bioplastics

Bioplastics perform just like traditional plastics and are created from either biopolymers or a blend of bio and petrochemical based polymers. Bio based plastics are obtained using renewable raw materials such as starch or cellulose from organic feed stocks: corn, potato, cassava, sugarcane, palm fiber, beet, proteins from soybean or keratin from waste poultry feather, and lipids from plant oils and animal fats and are usually blended with fossil fuel-based polymers to reduce cost and/or enhance performance. Petrochemical-based polymers

are derived from petrochemical refining. There are 3 main types of bioplastics currently available in the market. (a) Starch-based plastics (b) Poly lactic acid (PLA) (c) poly-3-hydroxybutyrate (PHB). They can be processed easily on equipment designed for petrochemicals eliminating the need to develop new industrial machinery.



Module 16. Plant nutrition, Alternative cropping systems

Lesson 24. Plant Nutrition and Alternative Cropping System

24.1 INTRODUCTION

This chapter deals with the basics of developing a nutritional program for producing container-grown plants in greenhouses. A complete nutrition program encompasses the fertilizers, media and water used. The information about the plant nutrition and range of fertilizers available that growers need to understand will be discussed. Also alternative cropping system other than traditional systems such as hydroponic cropping technology will be discussed.

24.2 PLANT NUTRITION: THE BASICS

24.2.1 Fertilizer Salts

Fertilizers are salts. Salts are chemical compounds that contain one positively charged ion (cation) bonded to one negatively charged ion (anion). When a salt is placed into water, the two ions separate and dissolve. An example of a fertilizer salt is calcium nitrate, which contains one calcium cation and a nitrate anion. Other examples include: ammonium phosphate, magnesium sulphate, potassium nitrate and ammonium nitrate.

Fertilizer concentration (or saltiness) of a solution can be determined by measuring the ability of a solution to conduct an electrical signal (electrical conductivity). Electrical conductivity meters, often called soluble salts meters, measure the concentration of salts/ions in solution; therefore, a grower can always measure the amount of fertilizer being applied to a crop. However, electrical conductivity meters do not specifically measure which specific salts are in solution. For example, an electrical conductivity meter cannot tell the difference between table salt (sodium chloride), which is dangerous to plants, and potassium nitrate, which is useful for plants. Ions dissolved in water are taken up through the roots and distributed within the plant. Plants actually expend energy to take up most ions, however, calcium is thought to only come along for the ride, i.e., plants don't actively take up calcium, it just comes into the root with the water.

Once inside the plant, ions are recombined into compounds useful for plant growth. The most common example of plant metabolism involves photosynthesis, during which water (hydrogen and oxygen) is combined with carbon dioxide (carbon and oxygen) to form starch or sugars (carbon, hydrogen and oxygen). Another example is the chlorophyll molecule shown below that contains:

- 55 carbon atoms
- 60 hydrogen atoms
- 5 oxygen atoms

- 4 nitrogen atoms
- 1 magnesium atom

Therefore, for the plant to build one chlorophyll molecule, the leaves must take in carbon dioxide, for the carbon and oxygen; the roots must take in water, for the hydrogen and oxygen; and the roots must take nitrogen and magnesium provided from the fertilizer applied.

Once inside the plant, some nutrients can be mobilized to support new growing tissues, while other nutrients are fixed in older plant tissues. This fact helps us to diagnose some plant nutrient deficiencies. For example, if a plant is deficient in an immobile nutrient, then deficiency symptoms (yellowing/chlorosis) occur in the new growth, since the older tissues “hold” on to the immobile nutrients. In contrast, deficiencies of mobile nutrients typically occur in the older leaves, since the mobile nutrients move from the old leaves to the new leaves.

Plants require different amounts of each nutrient. Carbon, hydrogen and oxygen are required in the greatest amounts; however, these are taken up by the plant in the form of water and carbon dioxide. Nitrogen, phosphorus, potassium, calcium, magnesium and sulphur are required in large amounts, thus are called macronutrients. Iron, manganese, copper, zinc, boron, chloride, molybdenum are required in relatively small amounts, thus are called micronutrients, or minors.

24.2.2 pH

pH is a measure of the concentration of hydrogen (H^+) ions, also called protons. The greater the H^+ ion concentration, more acidic the solution, hence a lower pH. pH controls the uptake of nutrients. If the pH is not in the desired range, individual nutrients cannot be taken up, creating a nutrient deficiency, or the nutrient can be taken up too readily, resulting in a nutrient toxicity. These nutrient imbalances will occur even when proper amounts of nutrients are applied to the media, if the pH is too high or too low. Nitrogen and potassium are readily available at a wide pH range. Although phosphorus is more readily available at a low pH, phosphorus problems are not commonly observed in greenhouse crops. Calcium and magnesium are more readily available at a higher pH. At a low pH, the minor nutrients (iron, manganese, boron, zinc and copper) are readily available. Minor nutrient toxicities are relatively common at a low pH (< 5.8), while deficiencies frequently occur at a high pH (> 6.5).

24.2.3 Factors Affecting Media Solution pH:

1. Water Quality/Alkalinity: Alkalinity is one measure of the quality of water used for irrigation. Alkalinity is the measure of the concentration of bicarbonates and carbonates in water which determine the water's capacity to neutralize acids. In other words, irrigating with bicarbonates in water is equivalent to applying lime every time through irrigation. The bicarbonates react with hydrogen ions and remove them from solution. This process effectively decreases the H^+ ion concentration in the media and thus increases the media

solution pH. The reverse situation can also occur. Very pure water (low bicarbonates) can cause media solution pH to decrease over time. The pH drops, because there may not be enough bicarbonates to absorb excess hydrogen ions. Thus, the H^+ ion concentration in the media increases. The most common solution for pure water sources is to increase the amount of pulverized dolomitic limestone incorporated into the media prior to transplanting plants into the media. Another solution is to top-dress containers with the limestone. Finally, bicarbonate can be added to irrigation water in the form of potassium bicarbonate to improve the buffering capacity of the media solution (i.e., reduce pH fluctuation).

2. Media Component: Peat tends to be acidic. Pulverized dolomitic limestone ($CaMg (CO_3)_2$) is incorporated into most amended media to adjust the starting pH to ~6.0. Coarser grades of dolomitic limestone change the media pH more slowly, and thus are not often used in peat-based media. A relatively new, but popular media component, coconut coir, is less acidic than peat, so less limestone needs to be used.

3. Fertilizers Applied: Fertilizers are categorized into one of two groups: acid-residue or alkaline-residue. The fertilizers themselves are not acidic or alkaline, but they react with microorganisms in the media and plant roots to affect media solution pH. Fertilizers with ample ammonium or urea tend to acidify the media, i.e., lower the pH. Fertilizers with ample nitrates tend to raise the pH of the media solution slowly over time.

24.3 Fertilizers and Fertilization

24.3.1 Water Soluble Fertilizers

Most greenhouse fertilization programs rely on water-soluble fertilizers to provide most of the nutrients required for plant growth. Water-soluble fertilizers are often applied at the each irrigation. This is referred as a specific fertilizer program must be developed around the irrigation water, media and crops grown.

The 20-10-20 Peat-Lite Special supplies nitrogen, phosphorus, potassium and minor nutrients. The 15-0-15 fertilizer supplies nitrogen, potassium, calcium and minor nutrients. The epsom salts supply magnesium and sulphur. Rotating these three products provides all essential nutrients required for plant growth. Recently available are water-soluble fertilizers that supply all essential nutrients in one fertilizer. Examples include 15-5-15 Cal-Mag Special and 13-2-13 Plug Special.

24.3.2 Slow-Release Fertilizers

Slow-release, or controlled-release, fertilizers are usually used when crops are grown outdoors. Slow-release fertilizers are beneficial because they create less environmental pollution, e.g., fertilizer run-off, when sprinkler irrigation is used, and they continue to supply nutrients during rainy weather. Slow-release fertilizers are marketed based on the time of release, for example, 3 to 4 month longevity. The actual fertilizer release rate is determined by the temperature and water content of the media. Therefore, the actual effective release time of the fertilizer may vary from the labelled time. Slow release fertilizers can be incorporated into the media prior to filling the containers or top dressed after planting.

24.3.3 Fertilizer Labels

24.3.3.1 Nutrient analysis

The fertilizer analysis indicates the percentage of a particular nutrient contained within the fertilizer (on a percent weight basis). The fertilizer analysis typically refers to the percentage of nitrogen (N), phosphate (P_2O_5) and potash (K_2O) contained in a given fertilizer. A balanced fertilizer should provide nutrients in amounts relative to plant requirements. Since nitrogen and potassium are used in relatively similar amounts (on a weight basis), a fertilizer should have a nitrogen to potassium ratio of approximately 1:1. Phosphorus is required to a lesser degree, so the nitrogen-to-phosphorus ratio should be approximately 2:1 to 4:1. Therefore, a 2:1:2 (N- P_2O_5 - K_2O) is suitable for most greenhouse crops. An example of this type of fertilizer is 20-10-20. While 20-20-20 is still commonly used, 20-10-20 is preferred, since the N- P_2O_5 - K_2O ratio is closer to that required by plants. The extra phosphorus provided by 20-20-20 is usually wasted, thus creating potential environmental concerns.

24.3.3.2 Nitrogen Form.

Nitrogen is provided in three different forms: nitrate-nitrogen (NO_3), ammoniacal-nitrogen (NH_4) and urea-nitrogen. The nitrogen form affects plant growth and media solution pH. Ammoniacal nitrogen, sometimes called ammonium, tends to contribute to “lush” plant growth, for example, greater leaf expansion and stem elongation, whereas nitrate nitrogen produces a “hard” or well-toned and compact plant. High ammonium can be toxic to plants during cold, cloudy growing conditions. Therefore, ammonium and urea should make up less than 40 percent of the nitrogen during winter months. “Dark-Weather” or “Finisher” fertilizers tend to have high nitrate and low ammonium nitrogen.

The following equation demonstrates how to calculate the percentage of the total nitrogen that is in the ammoniacal form.

$$\% \text{ N in ammonium form} = (\% \text{ Ammonium} + \% \text{ Urea}) \div \% \text{ Total N} \times 100$$

For example, a 15-5-15 label indicates the following nitrogen breakdown:

1. Total Nitrogen (N) = 15%,
2. Ammoniacal Nitrogen = 1.2 %,
3. Nitrate Nitrogen = 11.75 %,
4. Urea Nitrogen = 2.05 %

$$(2.05\% \text{ Urea} + 1.20\% \text{ Ammonium}) \div 15\% \text{ Total N} \times 100 = 21.7\% \text{ N in ammonium form}$$

24.3.3.3 Potential acidity or basicity

The potential acidity or basicity indicates how the fertilizer will affect media solution pH. A fertilizer label will indicate that the fertilizer has either a potential acidity or a potential basicity. The potential acidity refers to the fertilizer’s tendency to cause the media pH to decrease, while the potential basicity refers to the fertilizer’s tendency to cause a media pH

increase. Fertilizers high in ammonium cause the pH to decrease (become more acidic), while fertilizers high in nitrate cause the pH to increase (become more basic or alkaline). Fertilizers with a considerable percentage of the nitrogen in the ammonium form tend to leave an acid residue in the media, indicated by the potential acidity. Fertilizers that have low ammonium, and thus high nitrate form of nitrogen, tend to leave an alkaline, residue indicated by the potential basicity. The high-ammonium fertilizers tend to have very little or no calcium or magnesium, while the low-ammonium, alkaline-residue fertilizers contain higher levels of calcium or magnesium.

24.3.3.4 Proper Dilution Rate: The proper dilution rate is indicated on the fertilizer label and can be tested with a soluble salts meter. The soluble salts concentration of the fertilizer solution increases as the amount of fertilizer increases. For example, 20-10-20 Peat-Lite Special will have an electrical conductivity (EC) of 0.33 mmhos/cm for every 50 ppm of nitrogen. Therefore, a fertilizer mixed to provide 250 ppm nitrogen will have an EC of 1.65 mmhos/cm $[(250 \div 50) \times 0.33 = 1.65]$.

24.3.4 Fertilizer injectors

Injectors mix precise volumes of concentrated fertilizer solution and water together. Injectors are commonly available in a mixing range of 1:16 to 1:200. For example, 1:100 injection ratio indicates that one gallon of concentrated fertilizer will produce 100 gallons of final fertilizer solution. Injectors allow growers to have a smaller stock tank and mix their fertilizer stock solutions less frequently. However, not all fertilizers can be mixed together. Calcium and magnesium fertilizers typically cannot be mixed with phosphate and sulphate fertilizers while concentrated. A solid precipitate will form in the bottom of the stock tank if the fertilizers are not compatible. Once the individual fertilizers are diluted to their final concentration, then all fertilizers are compatible and thus can be mixed together.

24.3.5 Multiple Injectors.

Multiple injectors or multiple-headed injectors can be used to inject incompatible stock solutions. If separate injectors are plumbed serially, i.e., one after the other, then fertilizer stock solutions can be mixed at the same concentration as if one injector is being used. For example, one head can inject calcium nitrate, while the other head injects magnesium sulphate. However, if two injector heads are placed into one stock solution, then the final concentration delivered to the plants will be twice the desired concentration, unless proper dilution occurs, e.g., mix the stock solution for 100 ppm N if 200 ppm is desired.

24.4 STARTING A FERTILIZATION PROGRAM

Nutrients can be placed into the media prior to planting, i.e., a pre-plant nutrition program, and during plant growth, i.e., a post-plant nutrition program. Do not forget that irrigation water can also be a significant source of plant nutrients, especially calcium and magnesium.

Despite considerable gardening advice to the contrary, specific nutrients do not promote rooting or flowering! Specifically, phosphorus does not promote rooting and potassium does not promote flowering. Excess nitrogen can potentially reduce flowering and produce excessive vegetative growth.

24.4.1 Pre-Plant Nutrition Programs

Nutrients can be supplied in limited quantities, while the media components are being mixed. Calcium and magnesium are provided when dolomitic limestone is used to adjust the starting pH. Phosphorus and sulphur are provided with superphosphate plus gypsum (calcium and sulphur). (Single

phosphate is 50 percent gypsum by weight). Iron, manganese, zinc, copper, boron and molybdenum are provided with micronutrient formulations. Nitrogen and potassium are provided with potassium nitrate. Typical pre-plant recipe for 1 cubic yard of soilless media:

Dolomitic limestone	10 lbs.
Treble Superphosphate	2.25 lbs
Gypsum	1.5 lbs.
Micromax	1.25 lbs.
Potassium Nitrate	1 lb.

24.4.2 Post Plant Nutrition Programs

Most small to medium sized commercial greenhouses use commercially blended fertilizers for convenience and dependability; however, for some growers it is economical to buy individual fertilizers and mix them together. Following are some important notes about each of the essential plant nutrients:

24.4.2.1 Nitrogen (N)

Sources: ammonium nitrate, urea, calcium nitrate, potassium nitrate, magnesium nitrate.

The concentration applied is determined by the amount of leaching. For example, in a constant liquid feed program using a sub-irrigation system (0 % leaching) 100 ppm N may produce adequate growth, while 300 ppm N may be needed if overhead irrigation results in 25 percent leaching.

24.4.2.2 Phosphorus (P)

Sources: Ammonium phosphate, urea phosphate.

A nitrogen-to-phosphate (P_2O_5) ratio of 2:1 is acceptable for most crops. Fertilizers with high concentrations of ammonium phosphate, such as 9-45-15, appear to promote stem stretching.

24.4.2.3 Potassium (K)

Sources: Potassium nitrate, potassium sulphate

A nitrogen-to-potash (K_2O) ratio of 1:1 is acceptable for most crops.

24.4.2.4 Calcium (Ca) and Magnesium (Mg)

Sources: Dolomitic limestone, irrigation water, calcium nitrate, magnesium sulphate (Epsom salts), magnesium nitrate.

Calcium and magnesium provided by dolomitic limestone are released slowly over several months. These two nutrients can have an antagonistic relationship (i.e., they compete within the plant), thus a Ca: Mg ratio of 3:1 to 5:1 is desirable. Calcium and magnesium are commonly found in irrigation water, especially high alkalinity water. Calcium and magnesium deficiencies are most common when the pH is low (less than 5.8). Calcium and magnesium fertilizers cannot be mixed in the concentrated form with phosphate or sulphate fertilizers, thus calcium and magnesium are frequently omitted from commercial fertilizers. A few relatively new fertilizers contain calcium and magnesium along with the nitrogen, phosphorus and potassium. These fertilizers often list five numbers in the analysis. These numbers represent N, P₂O₅, K₂O, Ca and Mg, respectively.

24.4.2.5 Micronutrients

Micronutrients are sold in different formulations; for example, Micromax, Esmigran and Soluble Trace Element Mix contain only inorganic sources, while Compound 111 contains chelated sources. Chelated forms are superior in that the micronutrients are more soluble, therefore more readily available to the plant. Consequently, chelated micronutrients are applied at lower rates. Compound 111 and STEM are labelled for use in constant liquid feed programs.

The rates are based on adding a certain amount of micronutrient mix per 100 ppm of N used in the fertilization program.

Micronutrient deficiencies are closely related to media pH. High pH (greater than 6.5) can produce deficiencies, while low pH (less than 5.8) can cause toxicities. Adjusting the media pH is the best solution to avoid micronutrient toxicities or deficiencies.

24.5 FERTILIZER CALCULATION

Calculate the parts per million for a fertilizer application

$$\text{Actual ppm} = \text{pounds fertilizer} \times \%N \times \frac{Z}{\text{gallon stocks} \times \text{Proportioner ratio}}$$

For N, Ca, Mg, Fe, Z=1200

For Phosphorus (P), Z= 528

For Potassium (K), Z= 996

1. Calculate the concentration (ppm) of nitrogen applied when 1 pound of 15-0-15 is mixed into a 5 gallon stock tank and a 1:16 ratio is used.

$$\text{ppm of Nitrogen} = 1 \times 15 \times \frac{1200}{5 \times 16}$$

$$= 225 \text{ ppm}$$

2. Calculate the concentration (ppm) of potassium applied when 1 pound of 15-0-15 is mixed into a 5 gallon stock tank and a 1:16 ratio is used.

$$\text{ppm of Potassium} = 1 \times 15 \times \frac{996}{5 \times 16}$$

$$= 186.75 @ 187 \text{ ppm}$$

3. Calculate the concentration (ppm) of calcium applied when 1 pound of 15-0-15 is mixed into a 5 gallon stock tank and a 1:16 ratio is used. (Note: 15-0-15 contains 11% calcium). Also note that the irrigation water has 15 ppm calcium.

$$\text{ppm of Calcium from fertilizer} = 1 \times 11 \times \frac{1200}{5 \times 16}$$

$$= 165 \text{ ppm}$$

$$\text{Additional ppm of calcium from water} = 15 \text{ ppm}$$

$$\text{Hence, Total calcium applied} = 165 + 15 = 180 \text{ ppm}$$

24.6 ALTERNATIVE CROPPING SYSTEM

24.6.1 Hydroponic Technology

Soilless (Hydroponic) culture which was initially developed for studying plant mineral nutrition is thought to be one of the main elements of sustainable cropping systems under greenhouse conditions. In fact implementation of closed hydroponics may reduce drastically the use of water and fertilizers and the environmental pollution associated to over irrigation which is quite common in protected horticulture. However, the application of closed loop hydroponic technology is scarce on commercial scale. The main technical features of the hydroponic technology are illustrated below.

24.6.1.1 Technology

Hydroponic is a broad term that includes all techniques for growing plants in media other than soil or in aerated nutrient solution. The classification of soilless culture considers the type of substrate and container, how the nutrient solution is delivered to the plant (drip irrigation, subirrigation, flowing, stagnant or mist nutrient solution culture) and the fate of the drainage nutrient solution: open (free drain) or closed (recirculating water) systems. The most widely used soilless techniques are drain to waste substrate cultivation, while water cultivation systems

such as nutrient film technique (NFT), floating culture and aeroponics are widely used for research work but much less on commercial scale.

Table 24.6.1 Characteristics of various hydroponic techniques

	Substrate and drip irrigation	Substrate and subirrigation	NFT	Floating system	Aeroponics
Application for commercial production	Large	Large	Scarce	Increasing	Rare
Type of crops	Fruit vegetables Strawberry Cut flowers	Pot plants	Leafy vegetables	Leafy vegetables Bulb flowers	Vegetables
Growing media	Yes (Organic/inert)	Yes (organic)	No	No	No
Recirculating solution	Yes/no	Yes	Yes	Stagnant or fairly static	Yes
Investment costs	Moderate/high	High	High	Low	Very high
Running costs	Moderate/high	Moderate/high	Moderate	Low	Fair/high
System's buffer	High	High	Low	High	Very low
Growing risks	Moderate	Moderate	High	Moderate	Very high

24.6.1.2 Substrate Culture

Substrate culture is generally used for row crops such as fruit vegetables, strawberry and cut flower. Different containers (Figure 24.6.1) such as banquette, pots, bags, slabs are used filled with inorganic or organic substrate or a combination of two or three different materials such as peat perlite or peat pumice mixture. An excess of nutrient solution is typically supplied to the crop by drip irrigation. In the cultivation of pot ornamentals, sub irrigation is increasingly adopted; the posts are cultivated in gullies with an intermittent flow of nutrient solution or in ebb and flow benches. Both open and closed system may be set up for drip irrigated substrate culture. In closed system the drainage water is captured and reused following the adjustment of pH and nutrient concentration and eventually disinfection to minimize the risk of root-borne diseases (Fig 24.6.2).



Fig 24.6.1 Long cycle tomato culture in pertile bags in a greenhouse

(Source: Giuliano Vox *et al.*2010)

Peat is largely used for pot ornamentals and propagation materials (seedlings, cuttings and micro propagated plantlets). In mixture with perlite it is largely used for bag culture of strawberry (fig 24.6.3). The most popular growing media for growing row crops are perlite and rock-wool, which are easy to handle, sterilise and re-use for few years.



Fig 24.6.3 Suspended bag culture of strawberry

(Source: Giuliano Vox *et al.*2010)

24.6.1.3 Water Culture

The most used water culture methods are floating raft systems, NFT, aeroponics. These are closed systems.

24.6.1.3.1 Floating rafts growing technology (Fig. 24.6.4) is certainly the most water conscious system among existing hydroponic growing systems. One of its key feature is the

use of a large volume of water allowing enormous buffer for fertilization and oxygen control and economic plants' transportation by flotation. This large buffer brings a level of security and easiness that no other growing system can match. This system is mostly used for leafy vegetables, herbs, bulb flowers.



Fig 24.6.4 Floating raft system

(Source: www.randyshydroponics.com)

24.6.1.3.2 Nutrient film technique (NFT)(Fig. 24.6.5) is a hydroponic technique wherein a very shallow stream of water containing all the dissolved nutrients required for plant growth is re-circulated past the bare roots of plants in a watertight gully, also known as channels. In an ideal system, the depth of the recirculating stream should be very shallow, little more than a film of water, hence the name 'nutrient film'. This ensures that the thick root mat, which develops in the bottom of the channel, has an upper surface, which, although moist, is in the air. Subsequent to this, an abundant supply of oxygen is provided to the roots of the plants. A properly designed NFT system is based on using the right channel slope, the right flow rate, and the right channel length. The main advantage of the NFT system over other forms of hydroponics is that the plant roots are exposed to adequate supplies of water, oxygen and nutrients. NFT, because of its design, provides a system wherein all three requirements for healthy plant growth can be met at the same time, provided that the simple concept of NFT is always remembered and practiced. The result of these advantages is that higher yields of high-quality produce are obtained over an extended period of cropping. A downside of NFT is that it has very little buffering against interruptions in the flow, e.g., power outages, but, overall, it is one of the more productive techniques.

The same design characteristics apply to all conventional NFT systems. While slopes along channels of 1:100 have been recommended, in practice it is difficult to build a base for channels that is sufficiently true to enable nutrient films to flow without ponding in locally depressed areas. As a consequence, it is recommended that slopes of 1:30 to 1:40 be used. This allows for minor irregularities in the surface, but, even with these slopes, ponding and water logging may occur. The slope may be provided by the floor, or benches or racks may hold the channels and provide the required slope. Both methods are used and depend on local requirements, often determined by the site and crop requirements.

The high installation costs, the small buffering capacity and some still unresolved problems, like those related to both non parasitic and parasitic diseases of root system, have hampered the commercial application of NFT, which are generally used for short season crops.

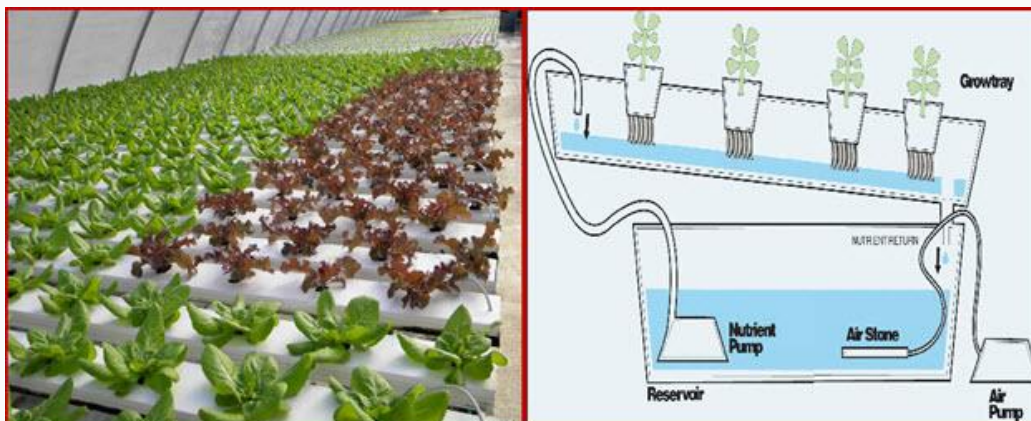


Fig 24.6.5 NFT system

(Source: www.hydroponicphd.wordpress.com , www.cropking.com)

24.6.1.3.3 Aeroponics (Fig.24.6.6) is the process of growing plants in an air or mist environment without the use of soil or an aggregate medium (known as geponics). The word "aeroponic" is derived from the Greek meanings of *aero-* (air) and *ponos* (labour). Aeroponic culture differs from conventional hydroponics, aquaponics, and in-vitro (plant tissue culture) growing. Unlike hydroponics, which uses a liquid nutrient solution as growing medium and essential minerals to sustain plant growth; or aquaponics which uses water and fish waste, aeroponics is conducted without a growing medium. Because water is used in aeroponics to transmit nutrients, it is sometimes considered a type of hydroponics.

The basic principle of aeroponic growing is to grow plants suspended in a closed or semi-closed environment by spraying the plant's dangling roots and lower stem with an atomized or sprayed, nutrient-rich water solution. The roots of the plant are separated by the plant support structure. Many times closed cell foam is compressed around the lower stem and inserted into an opening in the aeroponic chamber, which decreases labour and expense; for larger plants, trellising is used to suspend the weight of vegetation and fruit.



Fig 24.6.6 Aeroponics system

(Source: www.farmxchange.org)

24.6.1.3.3.1 Types of aeroponics

A. Low-pressure units

In most low-pressure aeroponic gardens, the plant roots are suspended above a reservoir of nutrient solution or inside a channel connected to a reservoir. A low-pressure pump delivers nutrient solution via jets or by ultrasonic transducers, which then drips or drains back into the reservoir. As plants grow to maturity in these units they tend to suffer from dry sections of the root systems, which prevent adequate nutrient uptake. These units, because of cost, lack features to purify the nutrient solution, and adequately remove continuities, debris, and unwanted pathogens. Such units are usually suitable for bench top growing and demonstrating the principles of aeroponics.

B. High-pressure devices

High-pressure aeroponic techniques, where the mist is generated by high-pressure pump(s), are typically used in the cultivation of high value crops and plant specimens that can offset the high setup costs associated with this method of horticulture. High-pressure aeroponics systems include technologies for air and water purification, nutrient sterilization, low-mass polymers and pressurized nutrient delivery systems.

C. Commercial systems

Commercial aeroponic systems comprise high-pressure device hardware and biological systems. The biological systems matrix includes enhancements for extended plant life and crop maturation.

Biological subsystems and hardware components include effluent controls systems, disease prevention, pathogen resistance features, precision timing and nutrient solution pressurization, heating and cooling sensors, thermal control of solutions, efficient photon-flux light arrays, spectrum filtration spanning, fail-safe sensors and protection, reduced maintenance & labour saving features, and ergonomics and long-term reliability features.

Commercial aeroponic systems, like the high-pressure devices, are used for the cultivation of high value crops where multiple crop rotations are achieved on an ongoing commercial basis.

Advanced commercial systems include data gathering, monitoring, analytical feedback and internet connections to various subsystems.



Module 17. Plant tissue culture

Lesson 25 Plant Tissue Culture: History, Terminologies and Laboratory Requirements

25.1 INTRODUCTION

Plant tissue culture is a technique of culturing plant cells, tissues and organs on synthetic media under aseptic environment and controlled conditions of light, temperature, and humidity. The development of plant tissue culture as a fundamental science is closely linked with the discovery and characterization of plant hormones, and has facilitated our understanding of plant growth and development. Furthermore, the ability to grow plant cells and tissues in culture and to control their development forms the basis of many practical applications in agriculture, horticulture industrial chemistry and is a prerequisite for plant genetic engineering.

25.2 HISTORY

History of plant tissue culture is a record of systematic efforts by botanists to culture excised plant tissues and organs to understand their growth and development under controlled conditions.

25.2.1 Cell Culture

The idea of experimenting with the tissues and organs of plants in isolation under controlled laboratory conditions arose during the latter part of the nineteenth century. German botanist Gottlieb Haberlandt was the first person to culture isolated, fully differentiated cells in 1898. He selected single isolated cells from leaves and grew them on Knop's (1865) salt solution with sucrose. Haberlandt succeeded in maintaining isolated leaf cells alive for extended periods but the cells failed to divide because the simple nutrient media lacked the necessary plant hormones. Although he could not demonstrate the ability of mature cells to divide, he was certain that in the intact plant body, the growth of a cell simply stops due to a stimulus released by the organism itself, after acquiring the features required to meet the need of the whole organism. Haberlandt's vision was to achieve continued cell division in explanted tissues on nutrient media; that is, to establish true, potentially perpetual tissue culture. This goal was attained only after the discovery of auxins. Although Haberlandt was unsuccessful in his attempts to culture cells, he foresaw that they could provide an elegant means of studying morphogenesis and the result of such culture experiments should give some interesting insight into the properties and potentialities which the cell as an elementary unit of life possesses.

25.2.2 Organ Culture

In the early part of the 20th century, efforts in growing excised plant tissues in culture continued with the development of sterile working methods and discovery of the need for vitamin B and auxins for tissue growth. In 1922, Robbins (USA) and Kotte (Germany) reported some success with growing isolated root tips. The first successful experiment to maintain growth and cell division in plant cell culture was conducted by White (1934) who

established cultures of isolated tomato roots under aseptic conditions. White's medium was simple, containing only sucrose, mineral salts and yeast extract, which supplied vitamins. The cultured roots maintained their morphological identity as roots with the same basic anatomy and physiology. This happened only because excised plant organs on nutrient media are capable of synthesizing hormones necessary to maintain cell division. Ball (1946) obtained whole plants from cultured shoot meristem. This heralded the present day method of *in vitro* vegetative multiplication. Ball is considered the father of so called micro propagation. Morel and Martin cultured shoot meristem of virus-infected plants to raise healthy plants from *Dahlia*. The cells of the shoot tip of virus infected plants are free of virus or contain a negligible number of virus. Axillary bud proliferation has immense practical applications for large scale clonal propagation of plants of importance in agriculture, horticulture and forestry.

25.2.3 Tissue or Callus Culture

A mass of unorganized protoplasmic (undifferentiated living) cells is known as 'callus' (Figure 25.2.1).



White (1939) cultured tissue of plant tumors (galls) that were produced by a hybrid between *Nicotiana glauca* and *N. langsdorffii* on the same medium that was used for tomato roots. Proliferated cell masses from the original explants were divided and subcultured. Gautheret and Nobecourt in 1939 reported unlimited growth of cultures derived from carrot tap root tissue, using indole-3-acetic acid (IAA). The goal at that time was to establish unlimited growth of a culture by repeated subcultures. Much effort was devoted to determine the nutritional requirements for sustained growth. White and Braun (1942) initiated studies on crown gall and tumour formation in plants and Skoog (1944) initiated work on organogenesis in tobacco callus. Although continuously growing cultures could be established in 1939, the objective of Haberlandt to induce cell division in isolated vegetative cells, was not achieved, because the tissues used by them were not meristematic in nature. The most significant event that led to advancement in the field was the discovery of the nutritional properties of coconut milk. Van Overbeek and his coworkers (1941) cultured isolated embryo of *Datura* on a medium containing coconut milk. The combination of 2, 4-D (2, 4-dichlorophenoxy acetic acid) and coconut milk had a remarkable effect on stimulating growth of cultured carrot and potato tissues [6–8]. In a search for cell division factor, Skoog's group located such a factor in degraded DNA preparation. It was isolated, identified as 6-

furfurylaminopurine, and named it Kinetin. The related analogue, 6-benzylaminopurine, was then synthesized and that too stimulated cell division in cultured tissues. The generic term 'cytokinin' was given to this group of 6-substituted amino purine compounds that stimulate cell division in cultured plant tissues. Later Zeatin was discovered as a natural plant hormone. Skoog and Miller advanced the hypothesis that shoot and root initiation in cultured callus can be regulated by specific ratios of auxin and cytokinin. The availability of cytokinins made it possible to induce divisions in cells of mature and differentiated tissues. At this stage, the dream of Haberlandt was realized partially, for he foresaw the possibility of cultivating isolated single cells. Only small pieces of tissue could be grown in cultures. Further progress was made by Muir who transferred callus of *Tagetes erecta* and *Nicotiana tabacum* to liquid medium (culture medium devoid of agar-agar) and agitated the cultures on a shaking machine, to break the tissue into single cells and small cell aggregates. Muir *et al.* (1954) succeeded in making single cells to divide by placing them individually on separate filter papers resting on top of a well-established callus culture. Callus tissue separated from the cells by thin filter paper, supplied the necessary factor(s) for cell division. Jones (1960) *et al.* designed a micro-chamber for growing single cells in hanging drops in a conditioned medium (medium in which callus has been grown previously). Using a micro-chamber and replacing the conditioned medium with a fresh medium containing coconut milk, Vasil and Hildbrandt (1965) raised whole plants starting from single cells of tobacco. They transferred single tobacco hybrid cells to a drop of culture medium on a slide, and observed separately under phase contrast microscope and photographed their observations. Cells were observed to divide and form callus which differentiated into roots and leafy shoots. However, they did not prove that the whole plants were the direct product of a single cell, rather than the product of a tissue mass within which somaclonal or other genetic changes might have taken place during growth. Finally, Haberlandt's prediction, that one could successfully cultivate artificial embryos from vegetative cells, was proved by the research of Backs-Husemann and Reinert in Berlin. They mounted isolated single cells on microscope slides and photographed repeatedly. Isolated cells divided to form a mass of embryogenic and parenchyma cells which developed into heart shaped and torpedo-shaped embryos with recognizable cotyledons, hypocotyls and radicles. Tuleke (1953) cultured pollen grains of *Ginkgo biloba* in a medium containing vitamins and amino acids and obtained cell clumps, some of which looked similar to embryos. Yamada *et al.* reported that culture of *Tradescantia reflexa* anther produced haploid tissues. Guha and Maheshwari reported that immature pollen grains produced embryos. Colchicine treatment can transform them into diploid fertile plants. Klercker (1892) and Kuster (1909) reported isolation and fusion of protoplasts, respectively. Cocking developed enzymatic method of protoplast isolation. The method involved the enzymatic digestion of cell wall by cellulase and pectinase enzymes extracted from the fungus *Myrothecium verrucaria*. Cultured protoplasts regenerated new walls, developed colonies and eventually plantlets [16]. Protoplasts are now used for creation of somatic hybrids within and between species and genera. The first hybrid between *N. Glauca* and *N. langsdorffii* was produced by Carlson. In 1978, Melchers *et al.* produced a hybrid between potato and tomato, but the hybrid was sterile. Novel application of protoplast fusion is called cybrid production, where cytoplasm of two species or genera is fused with nuclear genome of only one cell (nuclear-cytoplasmic combination)

25.3 ADVANTAGES OF TISSUE CULTURE

- The biochemical engineer can grow plant cells in liquid culture on a large scale bioreactor.
- The production of dihaploid plants from haploid cultures shortens the time taken to achieve uniform homozygous lines and varieties.
- The crossing of distantly related species by protoplast isolation and somatic fusion increases the possibility for the transfer and expression of novel variation in domestic crops.
- Cell selection-increases the potential number of individuals in a screening program.
- Micro-propagation using meristem and shoot culture techniques allows the production of large number of uniform individuals of species from limited starting material.
- Genetic transformation of cells enables very specific information to be introduced into single cells which can then be regenerated

25.4 TERMINOLOGIES OF TISSUE CULTURE

- **Adventitious-** Developing from unusual points of origin, such as shoot or root tissues from callus or embryos, from sources other than zygotes.
- **Agar-** a polysaccharide powder derived from algae used to get a medium. Agar is generally used at a concentration of 6-12 g/liter.
- **Aseptic-** Free of microorganisms.
- **Aseptic Technique-** Procedures used to prevent the introduction of fungi, bacteria, viruses, mycoplasma or other microorganisms into cultures.
- **Autoclave-** A machine capable of sterilizing wet or dry items with steam under pressure. Pressure cookers are a type of autoclaves.
- **Callus-** An unorganized, proliferate mass of differentiated plant cells, a wound response.
- **Chemically Defined Medium-** A nutritive solution for culturing cells in which each component is specifiable and ideally of known chemical structure.
- **Clone-** Plants produced asexually from a single source plant.
- **Clonal Propagation-** Asexual reproduction of plants that are considered to be genetically uniform and originated from a single individual or explant and will support the continued cell division of mature cells, leading to the formation of callus.
- **Coconut milk-** The liquid endosperm of coconut contain the cytokinin zeatin

Design and Maintenance of Green House

- **Contamination-** Being infested with unwanted microorganisms such as bacteria or fungi.
- **Culture-** plant growing in vitro.
- **Detergent-** Increasing the efficiency of sterilization.
- **Differentiated-** Cells that maintain, in culture, all or much of the specialized structure and function typical of the cell type in vivo. Modifications of new cells to form tissues or organs with a specific function.
- **Explant-** Tissue taken from its original site and transferred to an artificial medium for growth or maintenance.
- **Horizontal laminar flow unit-** An enclosed work area that has sterile air moving across it. The air moves with uniform velocity along parallel flow lines. Room air is pulled into the unit and forced through a HEPA (High Energy Particulate Air) filter, which removes particles 0.3 μm and larger.
- **Hormones-** Growth regulators, generally synthetic in occurrence that strongly affects growth (i.e. cytokinins, auxins, and gibberellins).
- **Internode-** The space between two nodes on a stem
- **Media-** Plural of medium
- **Medium-** A nutritive solution, solid or liquid, for culturing cells.
- **Micropropagation-** In vitro Clonal propagation of plants from shoot tips or nodal explants, usually with an accelerated proliferation of shoots during subcultures.
- **Node-** A part of the plant stem from which a leaf, shoot or flower originates.
- **Pathogen-** A disease-causing organism.
- **Pathogenic-** Capable of causing a disease.
- **Petiole-** A leaf stalk the portion of the plant that attaches the leaf blade to the node of the stem.
- **Plant Tissue Culture-** The growth or maintenance of plant cells, tissues, organs or whole plants in vitro.
- **Regeneration-** In plant cultures, a morphogenetic response to a stimulus that results in the products of organs, embryos, or whole plants.
- **Somaclonal Variation-** Phenotypic variation, either genetic or epigenetic in origin, displayed among somaclones.

- **Somaclones** - Plants derived from any form of cell culture involving the use of somatic plant cells.
- **Sterile** - (A) Without life. (B) Inability of an organism to produce functional gametes. (C) A culture that is free of viable microorganisms.
- **Sterile Techniques** - The practice of working with cultures in an environment free from microorganisms.
- **Subculture** - See "Passage". With plant cultures, this is the process by which the tissue or explant is first subdivide, then transferred into fresh culture medium.
- **Tissue Culture** - The maintenance or growth of tissue, in vitro, in a way that may allow differentiation and preservation of their function.
- **Totipotency**- A cell characteristic in which the potential for forming all the cell types in the adult organism are retained.
- **Undifferentiated** - With plant cells, existing in a state of cell development characterized by isodiametric cell shape, very little or no vacuole, a large nucleus, and exemplified by cells comprising an apical meristem or embryo.

25.5 LABORATORY REQUIREMENTS FOR TISSUE CULTURE

25.5.1 General Organization

Localize each portion of the tissue culture procedure in a specified place in the laboratory. An assembly line arrangement of work areas (such as, media preparation, glassware washing, sterilization, microscopy, and aseptic transfers) facilitates all operations and enhances cleanliness.

25.5.2. Glassware

Use glassware that has only been used for tissue culture and not for other experiments. Toxic metal ions absorbed on glassware can be especially troublesome. Wash glassware with laboratory detergent, then rinse several times with tap water and, finally, rinse with purified water.

25.5.3 High-purity Water

Use only high-purity water in tissue culture procedures. Double glass distilled water or deionized water from an ion-exchanger are acceptable. Water should not be stored, but used immediately. Regular maintenance and monitoring of water purification equipment are necessary. Purified water for tissue culture can also be purchased.

25.5.4 Plant Material

Plants used in tissue culture need to be healthy and actively growing. Stressed plants, particularly water-stressed plants, usually do not grow as tissue cultures. Insect and disease-free greenhouse plants are rendered aseptic more readily, so contamination rate is

lower when these plants are used in tissue culture procedures. Seeds that can be easily surface sterilized usually produce contamination-free plants that can be grown under clean greenhouse conditions for later experimental use.

25.5.5 Aseptic Technique

The essence of aseptic technique is the exclusion of invading microorganisms during experimental procedures. If sterile tissues are available, then the exclusion of microorganisms is accomplished by using sterile instruments and culture media concurrently with standard bacteriological transfer procedures to avoid extraneous contamination. Media and apparatus are rendered sterile by autoclaving at 15 lbs/inch² (121°C) for 15 minutes. The use of disposable sterile plastic ware reduces the need for some autoclaving. Alternative sterilization techniques such as filter sterilization must be employed for heat-labile substances like cytokinins. Aseptic transfers can be made on the laboratory bench top by using standard bacteriological techniques (i.e., flaming instruments prior to use and flaming the opening of receiving vessels prior to transfer). Aseptic transfers are more easily performed in a transfer chamber such as a laminar flow hood, which is also preferably equipped with a bunsen burner (Bottino, 1981). If experimental tissues are not aseptic, then surface sterilization procedures specific to the tissues are employed. Common sterilants are ethyl alcohol and/or chlorox with an added surfactant. Concentration of sterilants and exposure time are determined empirically.

25.6 APPLIED ASPECTS OF PLANT TISSUE CULTURE

Establishment of plant tissue culture techniques has enabled botanists to introduce this method in major areas of plant sciences such as plant breeding, industrial production of natural plant products, conservation of germplasm and genetic engineering.

25.6.1 Plant Breeding

Establishment of cellular totipotency, callus differentiation and vegetative multiplication under *in vitro* conditions has opened up new dimensions in the applied field of plant sciences. Rapid vegetative propagation or micropropagation of plants of elite characteristics is possible through axillary shoot induction (*Figure 1b*) and rooting them (*Figure 1c*) *in vitro* to raise complete plantlets. Somatic embryogenesis and organogenesis (callus differentiation) are other methods of micropropagation. Seedlings (*Figure 1d*) derived from mature seeds can also be used as a source for large-scale multiplication of rare and endangered plant species. Virus-free plants can be raised using apical meristems of virus-infected plants. Homozygous plants can be obtained in a single generation by diploidization of the haploid cells such as pollen grains. Protoplast technology has made it possible to develop somatic hybrids and cybrids of distantly related plant species and genus. Protoplasts are also a suitable material for genetic engineering of plants in a manner similar to gene transfer into bacteria. Cell culture may be an important source of induction and selection of cell variants for production of new varieties of economically important plants

25.6.2 Industrial Production of Natural Plant Products

Plants produce a variety of natural compounds that are used as agricultural chemicals, pharmaceuticals and food additives. Cell culture technique is being used as an efficient

system for production of high-value natural plant products at industrial level. In the 1950s and 1960s, great efforts were made by the Pfizer Company to culture plant cells in liquid medium (suspension culture) similar to culture of microbes for production of natural plant products as an alternative to whole plants. Different kinds of bioreactors have been designed for large-scale cultivation of plant cells. Culture of hairy roots produced by transformation with *Agrobacterium rhizogenes* has been shown to be a more efficient system than cell culture for the production of compounds which are normally synthesized in roots of intact plants. The first tissue culture product to be commercialized by Mitsui Petrochemical Co. of Japan is shikonin, a natural colouring substance, from the cell cultures of *Lithospermum erythrorhizon*.



Lesson 26 Plant Tissue Culture: Basic Process and Techniques Used

26.1 INTRODUCTION

Plant tissue culture may be defined as *in vitro* (in glass vessels) culture of an **explant** (any plant part used to initiate *in vitro* culture; e.g. shoot tip, leaf, petiole etc.), under **aseptic conditions** (sterile; free from microorganisms), under **controlled environment** (uniform temperature, humidity, light duration etc.), on a **specific medium** (which provides nutrient for plant growth and usually contains one or more plant growth regulators), for a **specific purpose** (e.g. for mass multiplication, genetic transformation, production of disease free plants, etc.).

Totipotency forms the basis of successful plant tissue culture. The theory of **Totipotency** states that each cell has the ability to regenerate into a complete plant. Each somatic cell has the same genetic constitution (DNA sequence) as that of a zygote, and hence, also has the potential of expressing all the properties of an organism. Since, handling a single cell is practically difficult, therefore, usually a tissue or an organ from the plant is used to initiate the tissue culture work and hence Plant Tissue Culture is often also called as Plant Cell, Tissue and Organ Culture.

26.2 THE BASIC STEPS INVOLVED IN PLANT TISSUE CULTURE

A flow chart of the basic steps involved in plant tissue culture is given in Fig. 26.1.

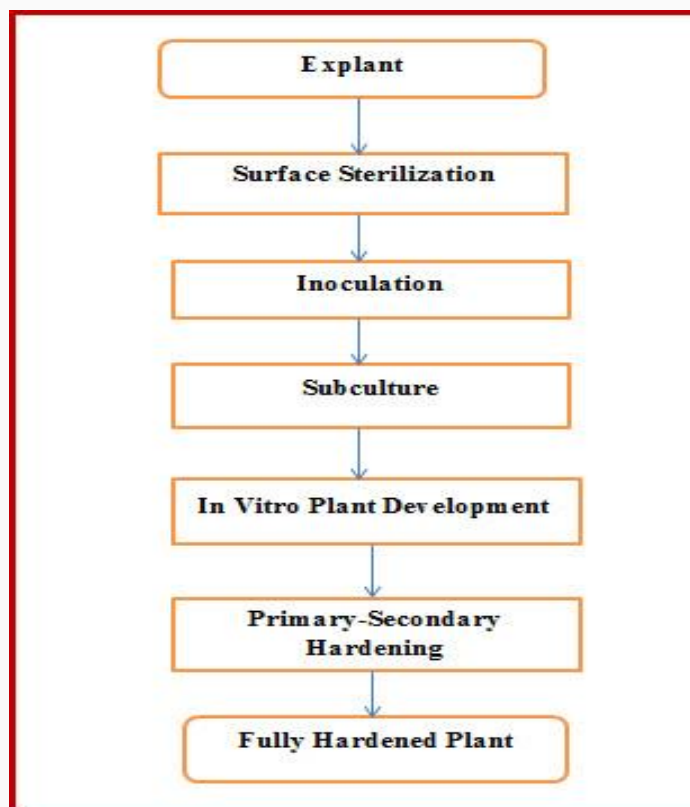


Fig 26.1 The Basic Steps Involved in Plant Tissue Culture

The following is a brief description of the tissue culture process and some terminologies:

26.2.1 Explant:

Any plant part used to initiate the tissue culture is known as an Explant. Theoretically any plant part may be used as an explant, however, the selection of an explant largely depends on the purpose of doing tissue culture, suitability of an explant for initiating cultures and availability of an explant.

26.2.2 Sterilization:

Sterilization is the process of making any thing free from microorganisms (i.e. aseptic). Since the process of tissue culture involves culturing plants on a nutrient rich medium, proper sterilization is a pre-requisite. The sterilization processes vary with the material to be sterilized.

Explant → Surface sterilization → Chemical Treatment (Ref. Table 1)

Media → Autoclaving (steam sterilization, at 121°C and 15 psi)

Heat labile PGRs / Hormones → Filter sterilization (0.22 µm filter)

Air → HEPA filters / Lamina air flow units

Forceps / blade handles & other tools → Flame sterilization

Rooms → Fumigation & UV radiation

Laminar Airflow hood → UV radiation

Table 1: Commonly used disinfectants for surface sterilization of the explant in plant tissue culture:

Sr. No.	Disinfectant	Concentration (%)	Exposure (min)
	Calcium hypochlorite	9-10	5-30
	Sodium hypochlorite*	0.5-5	5-30
	Hydrogen peroxide	3-12	5-15
	Ethyl alcohol	70-95	0.1-5.0
	Silver nitrate	1	5-30
	Mercuric chloride	0.1-1.0	2-10
	Benzalkonium chloride	0.01-0.1	5-20

*Commercial bleach contains about 5% sodium hypochlorite, and thus may be used at a concentration of 10-20%, which is equivalent to 0.5-1.0% sodium hypochlorite.

26.2.3 Inoculation:

Placement of an explant (after surface sterilization) on a sterilized establishment medium under aseptic conditions.

26.2.4 Subculture:

Transfer of the growing/ multiplying explant/(s) from one medium to another under aseptic conditions. It is usually done at an interval of 21 days, as the media usually gets used up for plant growth within this duration or to change the course of plant growth.

26.2.5 Media:

The MS medium of Murashige and Skoog (1962) salt composition is very widely used in different culture systems. It was demonstrated that not only the presence of necessary nutrients but also the actual and relative concentrations of various inorganic nutrients are of crucial significance. Any success with a medium is due to the fact that the ratios as well as concentrations most nearly match the optimum requirements for the cells or tissues for growth and/or differentiation.

The nutritional medium generally consists of inorganic nutrients, carbon and energy sources, vitamins, phytohormones (growth regulators), and organic supplements which include organic nitrogen, acids and complex substances.

26.2.6 Inorganic nutrients

Mineral elements are very important in the life of a plant. For example, calcium is a component of the cell wall, nitrogen is an important part of amino acids, proteins, nucleic acids, and vitamins, and magnesium is a part of chlorophyll molecules. Similarly iron, zinc and molybdenum are parts of certain enzymes. Besides, C, H, N, and O, 12 other elements are known to be essential for plant growth. If the elements required by plants in concentration greater than 0.5 mmol/l are referred to as macro-elements and those required in concentration less than that are microelements. The example of macro are N, K, P, Ca, S, and Mg and the microelements are iron (Fe), manganese (Mn), boron (B), copper (Cu), zinc (Zn), iodine (I), molybdenum (Mo) and cobalt (Co). For most purposes a nutrient medium should contain from 25 to 60 mM inorganic nitrogen. Nitrate is used in the range of 25-40 mM and ammonium in the range of 2-20 mM.

26.2.7 Carbon and energy source

Without exception, the standard carbon source is sucrose or glucose. Fructose can also be used but is less efficient. The sucrose in the medium is rapidly converted into glucose and fructose. Glucose is then utilized first, followed by fructose. Sucrose is generally used at a concentration of 2-5%. Other carbohydrates which have been tested include lactose, maltose, galactose and starch, but these compounds are generally much inferior to sucrose or glucose.

Most media contain myo-inositol at a concentration of ca. 100 mg/l, which improves cell growth.

26.2.8 Vitamins

Normal plants synthesize the vitamins required for growth and development. But plant cells in culture have a requirement for vitamins. There is an absolute requirement for vitamin B1 (thiamine). Growth is also improved by the addition of nicotinic acid (B4) and vitamin B6 (pyridoxine). Some media contain pantothenic acid, biotin, folic acid, p-amino benzoic acid, choline chloride, riboflavin (B2) and ascorbic acid (Vit-C).

26.2.9 Growth regulators

Hormones are organic compounds naturally synthesized in higher plants, which influence growth and development. They are usually active at a site different from where they are produced and are only present and active in very small quantities. Apart from natural compounds, synthetic compounds have been developed which correspond to the natural ones. These are collectively called growth regulators. There are two main classes of growth regulators that are of special importance in plant tissue culture. These are the auxins and cytokinins, while the others viz. gibberellins, abscisic acid (ABA), ethylene, etc. are of minor importance. Some of the naturally occurring hormones are the auxin - indole acetic acid (IAA) and the cytokinin - zeatin, while the others are synthetic growth regulators.

26.2.9.1 Auxins

A common feature of auxins is their property to induce cell division and formation of callus. Auxin causes cell division, cell elongation and swelling of tissues, and the formation of adventitious roots. It often inhibits adventitious and axillary shoot formation. At low auxin concentrations, adventitious root formation predominates, whereas at high auxin concentrations, root formation fails to occur and callus formation takes place. The compound most frequently used and highly effective is 2,4-dichlorophenoxy acetic acid (2,4-D). Other auxins in use include naphthalene acetic acid (NAA), Indole acetic acid (IAA), indole butyric acid (IBA), 2,4,5-trichlorophenoxy acetic acid (2,4,5-T), p-chlorophenoxy acetic acid (pCPA) and picloram (4-amino-3,5,6-trichloropicolinic acid).

26.2.9.2 Cytokinins

Cytokinins are derivatives of adenine and have an important role in shoot induction. The compounds that are most frequently used are kinetin, benzyl adenine (BA) or 6-benzyl amino purine (BAP), zeatin, and isopentenyl adenine (2iP). These are often used to stimulate growth and development. They usually promote cell division, if added together with an auxin. At higher concentrations (1 to 10 mg / l), adventitious shoot formation is induced but root formation is generally inhibited. They promote axillary shoot formation by decreasing apical dominance. Stock solutions of IAA and kinetin are stored in amber bottles or bottles covered with a black paper and kept in dark since they are unstable in light.

26.2.9.3 Other hormones

Gibberellins are normally used in plant regeneration. GA₃ is essential for meristem culture. Gibberellins induce elongation of internodes and the growth of meristems or buds in vitro. Gibberellins usually inhibit adventitious root as well as shoot formation.

Abscisic acid is an important growth regulator for induction of embryogenesis. Ethylene is produced by cultured cells, but its role in cell and organ culture is not known.

26.2.10 Organic supplements

26.2.10.1 Organic nitrogen

Cultured cells are normally capable of synthesizing all the required amino acids, but it is often beneficial to include organic nitrogen in the form of amino acids such as glutamine and asparagine and nucleotides such as adenine. For cell culture, it is good to add 0.2 to 1.0 g/l of casein hydrolysate or vitamin-free casamino acids. The amino acids when added should be used with caution, since they can be inhibitory. The amino acids included in the media and amount in mg / l are: glycine (2), asparagine (100), tyrosine (100), arginine (10) and cysteine (10). Sometimes adenine sulphate (2-120 mg/l) is added to the agar for morphogenesis.

26.2.10.2 Organic acids

Plant cells are not able to utilize organic acids as a sole carbon source. Addition of TCA cycle acids such as citrate, malate, succinate or fumarate permits growth of plant cells on ammonium as the sole nitrogen source. The cells can tolerate a concentration of upto 10 mM of the acid.

26.2.11 Complex substances

A variety of extracts viz. protein hydrolysate, yeast extract, malt extract, coconut milk, orange and tomato juice have been tested. With the exception of protein hydrolysate and coconut milk, most others are used as the last resort. Coconut milk is commonly used at 2 -15% (v/v). The present trend is, however, towards fully defined media and the use of complex mixtures is losing favour.

Activated charcoal at concentrations of 0.2 to 3.0% (w/v) is used where phenol-like compounds are a problem for growth of cultures. It can adsorb toxic brown/black pigments and stabilizes pH. Besides activated charcoal, polyvinylpyrrolidone (250-1000 mg/l), citric acid and ascorbic acid (100 mg/l each), thiourea or L-cysteine are also used to prevent oxidation of phenols.

Phloroglucinol, a phenolic compound, is sometimes added to inhibit the enzyme IAA oxidase responsible for the breakdown of IAA.

26.2.12 Gelling agents

Agar, a seaweed derivative, is the most popular solidifying agent. It is a polysaccharide with a high molecular mass and has the capability of gelling media. Solubilized agar forms a gel that can bind water and adsorb compounds. It has been proved that the higher the agar

concentration, the stronger the binding of water. Agar is used at a concentration of 0.6 to 1.0% (w/v), although other forms of agar (agarose, phytagar, flow agar, etc.) are also becoming popular. Growth may be adversely affected if the agar concentration is too high. With higher concentrations, the medium becomes hard and does not allow the diffusion of nutrients into the tissues.

Besides agar, the following alternatives are also available.

- i. Alginate can be used for plant protoplast culture.
- ii. Gelrite at 0.2% can be used for solidification of media. Gelrite gels are remarkably clear in comparison to those formed by agar.
- iii. Synthetic polymer biogel P200 (polyacrylamide pellets) or a starch polymer can be used.

26.2.13 pH

pH determines many important aspects of the structure and activity of biological macromolecules. Nutrient medium pH ranges from 5.0 to 6.0 for suitable in vitro growth of explant. pH higher than 7.0 and lower than 4.5 generally stops growth and development. It is observed that the pH before and after autoclaving is different. It generally falls by 0.3 to 0.5 units after autoclaving. If the pH falls appreciably during plant tissue culture (the medium becomes liquid), then a fresh medium should be prepared. It should be known that a starting pH of 6.0 could often fall to 5.5 or even lower during growth. pH higher than 6.0 give a fairly hard medium and a pH below 5.0 does not allow satisfactory gelling of the agar.

26.2.14 Controlled Environment:

Temperature: $25 \pm 2^{\circ} \text{C}$; Humidity: 20 – 98 % RH; Light: 16 h light + 8 h dark are the most usual conditions for plant growth in the laboratory.

26.3 TISSUE CULTURE TECHNIQUES

26.3.1 For Micropropagation

- Cell culture and Callus culture
- Meristem culture
- Shoot tip culture
- Node culture / Axillary bud culture
- Organ culture

26.3.2 For Crop Improvement

- Anther and microspore culture
- Somaclonal variation

- Embryo / ovule culture
- Somatic hybridization (Protoplast isolation and fusion)

26.4 APPLICATION OF PLANT TISSUE CULTURE:

Since the plant tissue culture work requires costly instruments, technical expertise, and involves a huge capital cost (especially for commercial setup), therefore, it is usually done for a **Specific Purpose**, which is described as follows :

26.4.1 Crop Improvement / Plant Breeding

- Haploid production : For producing homozygous plants, reduction of time involved in conventional breeding. (e.g. Anther / ovule / pollen culture)
- Triploid production : For production of seedless fruits (e.g. Endosperm culture)
- In vitro pollination and fertilization : To overcome the barrier of sexual incompatibility between different species or genus of plants in development of distant hybrids.
- Zygotic embryo culture : To rescue the embryo after fertilization from abortion
- Somatic hybridization and cybridization : To develop inter-generic hybrids, or to develop hybrids between plants that are not crossable with each other
- In vitro mutagenesis : Mutagen is applied at cell-level usually with an objective to develop new varieties of crops, with novel traits, through mutagenesis.
- Somaclonal and Gametoclonal variant selection : Selection pressure is applied at cell or tissue level and tolerant/ resistant cell types are selected for regeneration. The regenerated plants are expected to be tolerant / resistant to the selection pressure applied. (e.g. resistance to diseases/toxins, higher amino acid content, etc.)
- Genetic Transformation: Genes from other organism are used for development of transgenic plants using this technique.

26.4.2 Horticulture / Forestry

- Production of disease free plants: For production of disease free plants/ trees. e.g. Virus free plant production (Meristem culture).

1. micropropagation : For mass scale propagation of large number of plants in very short time. Production is independent of season and can continue throughout the year.

26.4.3 General

- Cryo-preservation: Long and medium term storage of germ plans
- Secondary metabolite production : Production of highly valuable secondary metabolites through *in vitro* techniques

26.5 BASIC LABORATORY FACILITY AND INFRASTRUCTURE REQUIRED FOR PLAN TISSUE CULTURE WORK:

The following basic laboratory facilities are required for plant tissue culture work

Sr. No.	Infrastructure	Equipment / Instrumentation facility
i)	Washing Room	Washing room with wash basins, bottle washing machine, glassware drying racks.
ii)	Media Preparation Room	Stove, pH meter, Autodispenser, weighing scale, refrigerators
iii)	Sterilization Room	Autoclave
iv)	Media Storage Room	Racks / Shelves for keeping media
v)	Inoculation Room	Laminar air flow units, spirit lamps
vi)	Growth Room/ Culture Room	Illuminated culture racks, air conditioning system
vii)	Primary Hardening Facility	Microprocessor based fully automatic green house, with temperature and humidity control system.
viii)	Secondary Hardening Facility	Net House or poly house with fogging system



Module 18. Chemical growth regulation

Lesson 27 Chemical Growth regulation

27.1 INTRODUCTION

Floriculture is unlike other areas of agriculture in that the entire plant or at least a major portion of the plant is appraised according to its aesthetic value. While minor insect damage, leaf blemishes, or unusually tall height may not affect the yield or value of bean crop, it does reduce the value of potted plant. Several chemicals are used by greenhouse growers to control growth in one or another of its many forms to give desired aesthetic effect.

27.2 CLASSIFICATION

Chemicals used to control growth are either naturally occurring plant hormones or synthetically produced compounds.

27.2.1 Hormones

Hormones are compounds produced in the plant at one site and then transported to a different part of the plant at one site and then transported to a different part of the plant where they affect growth.

27.2.1.1 Auxins

Auxins promote growth primarily through cell enlargement. The major auxin produced in plants is indole-2-acetic acid (IAA). Synthetic auxins include indolebutyric acid (IBA), indolepropionic acid (IPA), and naphthalene acetic acid (NAA). Auxins play an important role in plant propagation.

Auxins are involved in tropistic growth movements. Such movements include the downward growth of roots, the upward growth of shoots, and the growth of shoots and leaves toward the light. It is believed that shoots grow toward the light source because auxin is inactivated by light. This occurs more on the bright side of the stem; thus, there is greater promotion of growth on the darker side.

Auxins also inhibit lateral shoot development. When the top of the main shoot of a plant is removed, the source of auxin is lost from that shoot, and lateral shoots are free to develop. This is why pinching (the removal of shoot tips) is practiced on some floral crops; multiple lateral shoots are promoted. A plant is said to display apical dominance when only one shoot predominates. When apical dominance is lost, several lateral shoots usually develop simultaneously.

Auxins are effectively used for promoting root formation on cuttings. Many types of cuttings benefit from the use of rooting substances. Root formation occurs faster, and in the end the root system is usually more extensive. The benefit is least on plant species that normally root quickly, and there are a few species where no benefit is seen.

Rooting compounds are very concentrated and so are always diluted. Talc powder is a customary diluent. Active-ingredient concentrations of 0.1 to 1.0 percent are used — the lower concentrations for easy-to-root soft cuttings and the higher concentrations for slower-to-root woody cuttings. The base of the cutting is dipped into the powder and then tapped to remove all but a thin film of powder. To reduce the possibility of disease transfer, a duster is often used.

Rooting compounds can be diluted by another method for use on woody cuttings where penetration is difficult. A concentrated stock solution of the rooting compound is made by dissolving it in alcohol. The stock solution is further diluted with water to a final concentration in the range of 500 to 5,000 ppm (0.05 to 0.5 percent). The cut end of cuttings is dipped in this solution for a short time and then “stuck” into propagation substrate in a propagation bed. The concentration of the solution and the length of dipping time (five seconds to a few minutes) are determined by the ease of rooting and the penetrability into the woody stem of the cutting.

Rooting compounds are a very common and valuable aid to the propagators of greenhouse crops, since so many crops are propagated by cuttings. African violet, azalea, begonia, carnation, chrysanthemum, geranium, hydrangea, kalanchoe, poinsettia, and many green plants are examples of plants that benefit from rooting compounds.

27.2.1.2 Gibberellic acid (GA)

GA promotes growth through cell enlargement. Various gibberellins have been isolated from species of the fungus *Gibberella*. It promotes growth, but unlike that of Auxins, the promotion is uniform throughout the plant tissue.

GA inhibits root formation on leaves and stems; thus, it is not found in root-promoting products. It is used by gardeners for enlarging the size of camellia blooms. Also, GA sprayed on geranium flowers at the time of first colour appearance (at a concentration of 5 ppm) stimulates a 25 to 50 percent increase in flower size. The number of petals remains constant, but each petal is larger. When greater concentrations are applied, however, increased responses carry an adverse effect. Stems and flower stalks elongate and become thinner. Stems may become adversely weak; flowers that are normally flat may become undesirably spikelike.

Flowering of cyclamen can be accelerated by four to five weeks with a single spray of 50 ppm GA 60 to 75 days prior to the anticipated flower date (Widmer, Stephens, and Angell, 1974). Higher concentrations result in adversely tall and weak flower stems. Lyons and Widmer (1983) suggest applying 0.25 ounce (8 mL) of 15 ppm GA₃ solution to the crown of the plant below the leaves 150 days after seed is sown.

Researchers have used gibberellins to replace the cold treatment of azalea. In the cold treatment, when the plant has reached sufficient size, it is pinched for the last time. New shoots are allowed to develop for about six weeks, and then flower-bud initiation is induced by about six weeks of long-night treatment. Once flower buds are established, a period of six weeks at a temperature of 45°F (7°C) or lower is required for development of flower buds.

After this treatment, the plants are moved to the greenhouse and forced into bloom in four to six weeks.

The cold treatment is expensive, requiring costly moving of plants and also cooler facilities. Considerable efforts have been made to reduce or eliminate the cold treatment (Boodley and Mastalerz, 1959). Five weekly sprays of a combination of gibberellins 4 and 7 (GA_{4+7}) or gibberlin 3 (GA_3) at a concentration of 1,000 ppm have proven effective (Figure 13-2) (Larson and Sydnor, 1971; Nell and Larson, 1974). The five consecutive weekly sprays begin when flower buds are well developed after the short day treatment. Plants treated in this manner usually flower earlier and have larger blossoms than plants given the cold treatment. Most cultivars respond well; however, there can be some variation. For instance, flower pedicels (flower stems) may become too long, causing flowers to droop.

There have also been studies on partial replacement of the cold treatment. In one such study, after three weeks of cold treatment, plants were moved to the greenhouse for forcing, and three weekly sprays of GA_3 at 250 ppm were made. Half of the cold treatment was eliminated, thereby permitting twice the volume of plants to be moved through the cooler facilities.

Hydrangea is also subjected to a period of cold storage. On occasion, the plants are removed prematurely, and slow development, small flowers, and short stems ensue. Research studies show promise of eliminating this situation by a spray of GA at a concentration of 5 to 50 ppm.

A 250-ppm GA spray applied to fuchsia four times at weekly intervals temporarily prevents flowering and stimulates rapid growth (Heins, Widmer, and Wilkins, 1979). This could lend itself well to production of tree-type fuchsia. Tree-type geraniums can likewise be produced (Carlson, 1982) by applying GA_3 as a spray to plants two weeks after potting. A total of five weekly applications of 250 ppm must be applied. A tolerable delay in flowering occurs. Excessive GA application results in distorted growth and poor plant quality.

27.2.1.3 Ethylene

It is naturally produced in fruits, seeds, flowers, stems, leaves and roots and controls a multitude of processes. Ethylene lends itself to numerous commercial applications.

27.2.1.4 Absciscic acid (ABA)

ABA promotes abscission of leaves and petals as well as a number of other processes. It is not a major hormone in the vegetative stages of growth but comes into play in the later stages of maturity and senescence. ABA is not commercially important in greenhouse crop production.

27.3 SYNTHETIC COMPOUNDS

A number of synthetic compounds also exist for control of greenhouse plant growth. These include the height retarding chemicals A-rest®, B-Nine®, and Cycocel®, the chemical pinching agents Atrinal® and Off-Shoot-O® and ethylene producer ethephon.

27.3.1 Florel®

Ethephon is the common name for the commercial product Florel (produced by Rhone-Poulenc Ag. Co., Research Triangle Park, NC 27709). It is a 3.9 percent liquid concentrate of the chemical [(2-chloroethyl) phosphonic acid]. Ethephon undergoes a chemical conversion that releases ethylene to the plant. Depending on the plant type and stage of growth, one or more of the following desirable responses can be induced: flowering, increased branching, height retardation, and leaf drop.

The commercial appeal of bromeliads is enhanced by the presence of a flower stalk. Flowering can be induced in two months' time by pouring 1/3 ounce (10 mL) of a diluted solution of ethephon (1.54 oz ethephon/gal water; 12 mL/L) into the vase of plants at least 18 to 24 months old (Heins, Widmer, and Wilkins, 1979). Flowering of Dutch iris bulbs is likewise affected by ethephon. A number of bulbs, particularly smaller bulbs, fail to bloom when they are greenhouse forced. A spray of 156 ppm (4 mL ethephon/L water) applied to green plants in the Dutch bulb-production fields just prior to bulb harvest led to earlier flowering, less bud abortion, and fewer leaves during greenhouse forcing (Kamerbeek, Durieux, and Schipper, 1980). British work showed that the reduction in leaf number permitted increased plant density from 14 to 30 bulbs/ft² (150 to 320 bulbs/m²) (Krause, 1984). Many Dutch iris bulbs are now treated by the producer in the storage area after harvest with 500 ppm ethylene gas for 24 hours to promote earlier and more extensive flowering on higher-quality plants.

As might be expected, ethylene plays a role in fruit maturation. Ethylene gas, or the ethylene-producing compound ethephon, is used to ripen apples, bananas, coffee, grapefruit, oranges, peppers, tobacco, and other fruit. Ethephon spray is applied to processing tomatoes in the field to hasten maturity. Fresh-use field tomatoes are treated after harvest in the mature-green stage with 200 ppm ethylene gas. This enhances color formation and hastens ripening by about two days (Lutz and Hardenburg, 1968).

Leaf abscission, like flower and fruit formation, is part of the maturation process. It is likewise enhanced by ethephon. This has a commercial advantage in hydrangea production, where it is desirable to remove the leaves for the six-week cold treatment that occurs after flower-bud initiation and just prior to greenhouse forcing. An application of 1,000 to 5,000 ppm ethephon two weeks prior to the start of cold treatment has been shown to result in the defoliation of the cultivars "Merville" and "Rose Supreme" (Tjia and Buxton, 1976).

Light intensity at the crown of rose bushes diminishes as the canopy grows larger over the years. This discourages the development of new canes from the base of the plant. Renewal of the plant is dependent in great part on the large, floriferous shoots that come from these basal breaks. The best hope for encouraging such breaks has come from scoring lower canes with a saw blade dipped in 7,500 ppm ethephon (Zeislin et al., 1972). Ethephon sprays have, in fact, been used commercially in Israel to stimulate basal branching of "Baccara" rose.

Surprisingly, ethephon is used as a height retardant as well. Drenches or sprays serve well to control the height of narcissus. Ethephon sprays prior to floret color result in shorter hyacinths and prevent stem topple, which is a problem with some cultivars (DeHertogh, 1989).

27.3.2 Cycocel®

Potted plants must be grown to a height compatible with the environment in which they will be used. Many plants grow too tall if not checked. In past years, water and nutrients were withheld to reduce height, resulting in bad side effects in the appearance of the foliage and size of the bloom. Poinsettia stems were sometimes folded to reduce height, which was an effective but time-consuming process. Cycocel is used today.

Height retardants, in general, result in shorter stem internodes but do not affect the number of leaves formed. Stems are thicker, and leaves are deeper green because chlorophyll is more dense in the smaller cells. As a result, plants have a very pleasing appearance.

Cycocel [(2-chloroethyl) trimethylammonium chloride] is available in a liquid formulation containing 11.8 percent active ingredient. The common name of the chemical is chlormequat. (Cycocel is produced by American Cyanamid Company, P.O. Box 400, Princeton, NJ 08540.) Since Cycocel is considerably cheaper to apply as a spray than a drench, it is generally sprayed on crops.

Cycocel is applied as a spray to azaleas when about 1 inch (2.5 cm) of new growth occurs after the plants have been pinched for the last time. This checks growth and prompts early flower-bud initiation. Quite often, a larger number of flower buds develop. The retardant helps further by reducing the formation of vegetative shoots at the time of flower-bud development. These undesirable side shoots give the plant an unbalanced appearance.

Cycocel is recommended as a drench or a spray for poinsettia height retardation. Sprays can result in blotchy yellowing of foliage about 24 hours after application. This is a temporary situation and is not noticed at flowering time. Combinations of Cycocel plus B-Nine have proven more effective than either alone on poinsettia. Cycocel is also labeled for height control of geranium, hibiscus, Jerusalem cherry, and many bedding plants and green plants.

27.3.3 B-Nine WSG

B-Nine WSG (N-dimethyl amino succinamic acid) is known under the common name daminozide. (B-Nine WSG is produced by Uniroyal Chemical Company, Inc., Crop Protection Div., Specialty Products Group, World Headquarters, Middlebury, CT 06749 <www.uniroyalchemical.com>.) It is an effective height retardant labelled for use on azalea, begonia, browallia, caladium, pot chrysanthemum, cut chrysanthemum, crossandra, exacum, gardenia, gerbera, gloxinia, hydrangea, hibiscus, kalanchoe, liatris, poinsettia, and many plug seedlings, bedding plants, perennials, and green plants. B-Nine WSG is sold as a water-soluble granule containing 85 percent active ingredient plus a wetting agent. It is not used as a drench but rather as a foliar spray to the upper leaf surfaces. It is slowly absorbed, thus foliage should not be wetted for 24 hours after application.

Azalea is treated with B-Nine WSG for the same reason that Cycocel is used – to promote early and more extensive flower-bud set and to retard vegetative shoot development. Some cultivars of standard chrysanthemum develop a long pedicel, which is unattractive. A compact flower with a short pedicel can be produced by spraying the upper third of the foliage to the point of runoff two days after disbudding with a 0.25 percent concentration of B-Nine WSG. Pot mums are most often sprayed when new shoots are 1.5 inches (4 cm) long,

about two weeks after the pinch. No delay in flowering occurs. B-Nine WSG is particularly useful in producing compact bedding plants but is not effective on coleus, French-type marigold, pansy, or snapdragon.

27.3.4 A-Rest

The chemical A-Rest [a-cyclopropyl-a-(p-methoxyphenyl)-5-pyrimidinemethanol] (produced by SePRO, 11550 N. Meridian St., Suite 200, Carmel, IN 46032) takes the common name ancymidol. A-Rest effectively controls the height of and is labeled for azalea, pot chrysanthemum, gardenia, geranium, gerbera, hydrangea, liatris, lilies (including Easter lily), poinsettia, tulip, several green (foliage) plants, and numerous annual and perennial plants. It is purchased as a solution containing 250 mg of active ingredients per quart (264 ppm). A-Rest can be applied as a spray or as a drench, depending on the crop.

A-Rest loses activity at low pH levels. Consequently, the effectiveness of A-Rest drenches in pine-bark substrates has been found to be poor (Larson, Love, and Bonaminio, 1974; Tschabold et al., 1975). A solution to the problem was found by Simmonds and Cumming (1977) by dipping hybrid lily bulbs in A-Rest solution. This procedure worked well for Easter lily as a dip prior to cold-storage treatment (Lewis and Lewis, 1982). Larson (1985) refined the procedure, calling for a dip in 24-ppm A-Rest for 30 minutes after cold-storage treatment.

Another interesting function of A-Rest has been seen in research, where it was used to induce flowering of *Clerodendron* (Koranski, Struckmeyer, and Beck, 1978). Retardation of vegetative growth prompts flowering in this plant. Cycocel has a similar effect in *Clerodendron* (Hildrum, 1973).

27.3.5 Bonzi

Bonzi is a more recent height retardant. This product contains 0.4 percent of the active ingredient [(±)-(R*,R*)-b ((4-chlorophenyl)methyl)-a-(1,1,-dimethylethyl) -1 H-1,2,4-triazole-1-ethanol]. This ingredient is a member of the triazine group of compounds; its common name is paclobutrazol. (Bonzi is distributed by Uniroyal Chemical Co., Inc., Crop Protection Div., Specialty Products Group, World Headquarters, Middlebury, CT 06749 <www.uniroyalchemical.com>.)

Bonzi can be absorbed by the roots from a soil drench or through the shoots from a spray. In either event, it is translocated to the upper portion of each shoot, where it reduces internode elongation by inhibiting gibberellin biosynthesis. If a spray is used, it is very important that the spray coat all the stems of the plant; otherwise, some shoots will grow longer than others. Bonzi is primarily absorbed by stems as opposed to leaf blades and moves upward in the plant via the xylem. As in the case of A-Rest, this material is less effective in pine bark-based root substrates. Higher rates must be used if it is applied as a drench to these root substrates. Higher rates are also needed when it is applied to very vigorous-growing varieties compared to those that are naturally shorter, and when it is applied during high-temperature periods.

Bonzi is labeled for application on ornamental crops including plug seedlings, bedding plants, flowering pot plants, green plants, and bulb crops. Instructions for specific crops are

presented on the label. Other crops should be trialed first to determine safety, effectiveness, and required rates.

27.3.6 Sumagic

Sumagic is the most recent height retardant to be introduced. The common name for this chemical is uniconazole. Uniconazole is produced by Sumitomo Chemical Co., Ltd.; in the United States, it is distributed as Sumagic for greenhouse use by Valent USA Corp., P.O. Box 8025, Walnut Creek, CA 94596-8025 <www.valentpro.com>.

It has chemical properties closer to Bonzi than to the other height retardants and is also a member of the triazine chemical group. The active ingredient is (E)-(+)-(S)-1-(4-chlorophenyl)-4, 4-dimethyl-2-(1,2,4-triazol-1-yl)-pent-1-ene-3-ol. Like Bonzi, it is effective at very low rates.

Sumagic can be applied as foliar spray, drench, bulb or cutting dip or to the surface of substrate prior to planting. It can be used on the whole range of ornamental plants. However, when used on crops for which specific instructions are not given on the label it should first be tried for safety, effectiveness, and required rate. As in the cases of A-Rest, and Bonzi, Sumagic drenches are less effective in root substrates containing pine bark, thus higher rates are required in these substrates.

27.3.7 Off-Shoot-O

Off-Shoot-O is composed of methyl esters of C₆ to C₁₂ fatty acids, primarily methyl octanoate and methyl decanoate, in combination with an emulsifying agent. It is a product of the Cochran Corporation, P.O. Box 14603, Memphis, TN 38114. Off-Shoot-O is termed a chemical pinching agent because it causes death of the terminal bud on shoots, which in turn results in the development of side shoots (Figure 13-5). Often, more side shoots are produced from a chemical pinch than from a manual pinch. Off-Shoot-O is applied in a very fine spray to wet the shoot tips. The remainder of the plant need not be treated, and spraying is stopped before the point of runoff. Runoff increases the possibility of injury to lateral buds and leaves.

Azaleas are effectively pinched with this chemical. Considerable labor is saved, since azaleas must be pinched many times in order to produce a large plant with numerous shoots. Concentrations of 2 to 5 ounces of product per quart (63 to 155 mL/L) are used, depending upon the cultivar. A concentration of 3.2 ounces per quart (100 mL/L) is common. Several species of woody ornamentals can also be chemically pinched, including Cotoneaster, Juniperus, Ligustrum, Rhamnus, and Taxus.

27.3.8 Atrimmec

Atrimmec [sodium salt of 2,3,4,6-bis-O-(1-methylethylidene)-α-L-xylo-2-hexulofuranosonic acid] is known by the common name dikegulac. (Atrimmec is produced by PBI/Gordon Corp., P.O. Box 014090, Kansas City, MO 64101-0090.) The predecessor to this product was Atrinal.

Atrimmec temporarily stops shoot elongation, thereby promoting lateral branching. It is thus a pinching agent for greenhouse crops, including azalea, Elatior begonia, bougainvillea,

clerodendron, fuchsia, gardenia, grape ivy, ivy geranium, kalanchoe, lantana, lipstick vine, Pachystachys lutea (shrimp plant), Schefflera arboricola, and verbena. Branching can also be enhanced in 41 species of landscape ornamentals. Atrimmec is used to prevent flowering, and ultimately fruiting, in glossy privet, Japanese holly, multiflora rose, and ornamental olive.

27.4 COST OF MATERIALS

It is difficult to make cost comparisons for height retardants and pinching agents. Not all are effective on each crop. Some are applied as a drench, while others are applied as a spray. The number of pots that can be sprayed with a gallon depends upon the density of pots in the bench and the spray equipment; a high-pressure, fine-droplet spray covers more area. The concentration of growth regulator required varies according to the crop, its stage of growth, and the weather conditions.



Module 19. Disease control, integrated pest management,

Lesson 28 Disease Control, Integrated Pest Management

28.1 INTRODUCTION

In protected cultivation, pests and diseases find more favourable conditions for their development than in open field cultivation. The mortality of insects due to abiotic factors (rain, wind, cold temperatures) is enormously decreased and the climatic conditions (high humidity, higher temperatures) favour the development of diseases (Elad, 1999).

This chapter discusses disease control and integrated pest management.

28.2 INTEGRATED PEST MANAGEMENT

Integrated pest management (IPM) is a holistic approach to managing diseases, insects, and mites in the greenhouse, using the best tools, tactics, and strategies to control pests with the least disruption to the environment. IPM can decrease pesticide exposure of workers and the environment, and can decrease pest control costs while still maintaining high-quality, pest-free plants.

Appropriate use and timing of pesticides and the use of non-pesticide methods is essential, particularly given increasing regulations on pesticide use, decreasing numbers of registered pesticides, and increasing resistance of pests to pesticides. The most important aspect of IPM is prevention of epidemics, as many pest management decisions cannot be made in hindsight. As a consequence, most of this fact sheet is devoted to the prevention of pest problems, such as maintenance of a healthy crop, exclusion of pest access to the facility, close monitoring of plant health, prompt remedial action when pests are detected and careful documentation of monitoring, pests found, treatments employed, and treatment efficacy.

“Integrated” is an essential word in IPM. It means combining a variety of pest management techniques and strategies that can either reduce pest populations or lessen their economic impact while maintaining plant quality. An IPM program is built on several basic components, many of which are already needed to grow a healthy crop. While components may be modified to customize IPM programs for different operations, most components below should be included for a successful IPM program.

28.2.1 Sanitation

A basic component of IPM is sanitation. Infestations are easier to prevent than to cure. Start with a clean greenhouse. Walkways should be free of soil, organic matter, weeds, and algae. Benches should be disinfected and pots, flats, and trays must be new or disinfected. Water sources should be pathogen-free and hose ends kept off the floor. Note any drainage problems and take corrective action. Growing media should be clean, preferably pasteurized, and kept covered.

No plant material should be held in the media mixing area. Do not accumulate contaminated pots or media near the growing area, and systematically remove unhealthy plants and plant parts from the greenhouse. A weed-free zone should be maintained outside the greenhouse.

Insects and diseases are a major challenge to greenhouse production. IPM is an important tool in the management of these pests. The primary goal of IPM is to optimize pest control in an economically and ecologically sound way. IPM involves the integration of cultural, physical, biological, and chemical practices to grow crops with minimal use of pesticides. Monitoring, sampling, and record keeping are used to determine when control options are needed to keep pests below an economically damaging threshold. Pest management, not eradication, is the goal of IPM. IPM is a simple, practical, and, most important, flexible way to manage insects, mites, diseases, weeds and vertebrates.

28.2.2 Techniques used to manage pests

- Monitoring or scouting program
- Individual plant inspection
- Yellow, blue, and hot pink sticky cards
- Indicator plants
- Pest identification and life stages
- Record keeping to identify trends and direction for your pest management program
- Exclusion techniques to prevent pests from entering the production area
- Insect screens to exclude aphids, whiteflies, and thrips from entering through doors and ventilating systems
- Cultural practices to prevent problems
 - Soil testing
 - Sanitation
- Biological controls, living organisms used to reduce the incidence of pest organisms
- Insect growth regulators, insecticides that interfere with normal insect development or the molting process
- Chemical controls
- Proper choice of pesticides
- Proper timing of pesticide application
- Proper application procedure

28.2.3 Several practices that increases the success of an IPM program:

- Cover all soil floor surfaces with concrete, black plastic or weed barrier.
- Use resistant varieties of plants.
- Keep people and “pet plants” out of crop areas as much as possible.
- Pasteurize growing medium.
- Keep doors closed.

28.3 GREENHOUSE DISEASE CONTROL

The greenhouse climate is ideal for the development of plant diseases. An integration of cultural practices, environmental control, biological control, and natural control products will be needed to prevent widespread outbreak. Many fungicides are also toxic to beneficial organisms, and should be avoided if possible. Alternative disease control techniques include the use of disease resistant varieties, disease-free seeds and plants, well-drained soil, air circulation, weed eradication, humidity control, sanitation, disease-suppressive composts, compost watery extracts, and microbial antagonists.

Disease control may be classified into two approaches:

- 1) those aimed at the root environment, and
- 2) those aimed at the aerial environment

28.3.1 Cultural Practices

A healthy crop is less susceptible to most diseases. As a general rule, pathogens do not thrive under good cultural conditions but take advantage of cultural errors and stressful conditions encountered by a crop. Maintaining the proper environment for the crop being grown is the first step to eliminating problems.

28.3.1.1 Fertilization

Soluble salt levels and the pH of growing media should be tested periodically. Fertilization schedules for each crop should be implemented. Nitrogen should be applied only as needed for optimal growth. Periodic heavy applications will set up nitrogen surpluses that cause excessive growth, which enhance the population growth of aphids, pathogens, and other pests. Excess nitrogen will also leach from pots and contaminate the environment. Slow-release fertilizers are ideal to use when possible.

28.3.1.2 Irrigation

Watering is another cultural practice that can be manipulated to slow the increase of pest populations. Plants should be watered only as needed, reduced on cloudy days, and avoided late in the day. Wetting the foliage should be avoided because moist leaves provide ideal conditions for pathogens. Plants should be watered thoroughly and then allowed a dry-

down period. The length of the dry-down period will vary with the species. Proper spacing of plants to allow air circulation and drying will also decrease the incidence of moisture-loving pathogens.

28.3.1.3 Media

Always grow crops in pasteurized media. Disease-suppressive mixes are available. These mixes either naturally suppress soil borne pests or contain beneficial organisms (biological control agents). Beneficial fungi are now available commercially and can be added to the media by the grower. Beneficial fungi compete with disease-causing fungi by competing for food, by parasitism, or by producing antibiotics, which kill the disease-causing fungi. Using disease-suppressive mixes and biological control fungi can reduce the number of fungicide applications for root diseases on a crop.

28.3.1.4 Scouting and Monitoring

Monitoring is one of the most important principles of IPM. Pest management systems cannot be implemented if a grower does not know which pests exist and whether populations are significant. Therefore, a scouting and monitoring plan must be devised for each greenhouse. Correct pest identification is essential, and employees must be trained to monitor pests correctly.

Scouting and monitoring should be performed weekly or, preferably, twice weekly during the entire production season. Scouting procedures should be performed as routinely as any other greenhouse operation. Maps should be made of the greenhouse and scouting should follow the same method in the same manner every time. Scouting must be intensive; the more plants monitored the better. Scouting should always start at a major doorway, which is usually an entry point of pests. Special attention should be paid to plants around any openings in the greenhouse, especially those on outside rows of benches.

Scouts should walk every aisle and move from bench to bench in a snake-like manner. At least 10 minutes should be spent inspecting 20 or more plants for every 1,000 square feet of production area. Three or more randomly chosen plants on every bench should be inspected. Inspection starts at the bottom of the plant by checking the soil for insect, mite, or disease pests and proceeds upwards, looking at older leaves, younger leaves, and new growth. Pots should be tipped sideways for inspection of the underside of the leaves. Hanging pots and baskets should also be inspected.

A daily inspection of indicator plants and yellow sticky cards is recommended. The first plant showing symptoms on a bench becomes an indicator plant. This plant is marked with a stake or in some manner that allows the scout to check the same plant daily. Pests on this plant are monitored for population increases. A plant more susceptible to a certain pest(s) may be placed among the crop being produced to act as an indicator plant. Flagging indicator plants also can improve the time efficiency of daily monitoring.

Yellow sticky traps should be placed throughout the greenhouse. Many insects are attracted to the colour yellow (thrips are also attracted to the colour blue, and blue sticky traps are available), and insects caught on these traps will serve as an index of activity. The traps should be placed in a grid-like fashion, at least one card per 1,000 square feet of production

area. Increasing the number of cards per square foot of production area may be beneficial. Place the cards just above the plant canopy or up to 16 inches above the crop. The cards should be placed in the same position each time to allow a true picture of insect activity to emerge. Traps should be changed and insect counts recorded at least weekly, or more often depending upon the level of pest population.

28.3.2 Treatment equipment

Pesticide application methods have a great influence, both on their efficiency and on the labour costs. The application methods depend on the vehicle used to distribute the pesticide: (i) dust, when a solid is used (e.g. talc); (ii) spraying and fogging, when a liquid is used (usually in water); and (iii) fumigation when a gas is used.

The majority of horticultural treatments consist of spraying solutions or suspensions of the active materials. The most usual greenhouse sprayings are performed with a motor, provided with hoses and pistols to cover all areas of the greenhouse and direct the spray to the desired points. The service pressure must be sufficient to achieve a very small droplet size and to generate turbulence that helps the product cover the whole canopy (Aranda, 1994).

The ultra-low volume systems use a fan and a fog mechanical generator in association with each other, to obtain a very small droplet size and great canopy penetration, which allows for treating large areas from a fixed point. If located over a mobile trolley they can be operated in pre-fixed locations (as a semi-fixed system).

The thermo-foggers cause a very fine spray (of less than 100 µm diameter) by the explosion of a mix of fuel and air (Urban, 1997a).

Among the mobile automatic systems the most common is a treatment trolley that moves automatically along guiding pipes (also used for heating) between the crop rows.

28.3.3 Biological Control

Biological control is based on the use of natural enemies of the pests (parasitoids, predators and pathogens) to maintain their infestation below an economic damage threshold. Although biological control has been known about for more than half a century, its use had not expanded until a few decades ago (Blom, 2002).

The biological control of diseases is not widely used in practice. Techniques that may be highlighted include: (i) crossed protection techniques (where the organism that arrives first to an infection point acts against the pathogen that arrives later; this is used for the control of tobacco mosaic virus (TMV) by inoculating the plant with an innocuous form of the virus); (ii) induced resistance (the organism arriving first induces a defence reaction in the host); (iii) passive occupation (previous occupation of the infection point by an innocuous organism); and (iv) hyper-parasitism (*Trichoderma*). However, it should be pointed out that there are many other techniques (allelopathy, antibiosis) of possible use (Jarvis, 1997).

The use of biocontrol agents has been efficient against some diseases such as the use of *Trichoderma* against *Pythium*, *Fusarium* and *Rhizoctonia* (Elad, 1999).

The pest's natural enemies, besides not competing for the resources, carry out a predatory activity, feeding on the pest species. Parasitoid insects carry out a particular parasitic activity (external or internal oviposition of one egg on the host, from which a larva emerges that eats the animal as it develops). Parasitoids are more specific (monophagous in many cases), whereas predators are usually polyphagous (García, 1994).

The use of entomopathogens in biological control in the greenhouse, as an insulated enclosure, is of special interest. The massive use of *Bacillus thuringiensis* for the control of Lepidoptera has expanded, whereas the use of other pathogens, such as *Verticillium lecanii* (limited by the optimum temperatures range, Photo 28.3.1) or *Archensonia* (for white fly) and *Beauveria* or *Paecilomyces* (for white fly, aphids or thrips) is not so widespread (Parrella,1999).



Photo 28.3.1 Adult thrip covered with *Verticillium lecanii* hyphae

(Source: Nicolas Castilla, 2013)

The use of *Encarsia formosa*, for the control of white fly (photo 28.3.2) (*Trialeurodes*), as well as the use of *Phytoseiulus persimilis* for the red spider mite, are widespread in protected cultivation all over the world (Parrella, 1999). In Spain, the most common control for white fly is *Eretmocerus mundus* (J.V.D. Blom, 2007, personal communication).



Photo 28.3.2 White flies is one of the main pests of greenhouse vegetables.

(Source: Nicolas Castilla, 2013)

Module 20: Post Production Quality and Handling**Lesson 29 Post Production Handling of Greenhouse Production****29.1 INTRODUCTION**

Postharvest losses of fresh horticultural products usually exceed 25% of the total production and are caused by inappropriate control of the physical, physiological and microbiological conditions during storage and commercialization (Lioutas, 1998). The weight loss after harvest of fresh horticultural products is caused, mainly, by water loss through evaporation, which depends on the temperature and humidity of the surrounding environment and on the temperature of the product. The respiratory processes also contribute to the weight loss, but to a lesser extent, and are quite dependent on the temperature, increasing with it. Vegetable water loss causes a quality decrease in the form of product wilt, discoloration and loss of firmness. This water loss in some fruit vegetables, such as tomato, originates in the peduncles mainly, because the skin is practically impermeable, being possible to compare a tomato fruit to a container filled with water, because the water content may be as high as 95% (Scheer, 1994). Other vegetables such as cucumber, whose skin is much more permeable, are more sensitive to dehydration. Therefore, cucumbers are usually packed inside a plastic film to limit the postharvest water losses, as it is also common with leafy vegetables.

Whether you grow fresh product (fruits, vegetables or flowers) for the local farmers' market and retailers or have a large operation that sells truckloads to the national wholesale market, you need to move your product from the field to your consumers in a manner that ensures a high quality product. For this it need proper post-harvest management.

29.2 POSTHARVEST HANDLING**29.2.1 Postharvest Handling of Fruits and Vegetables**

The ideal management of vegetables starts with proper handling at harvest, an operation that should be done preferably in the morning, when the ambient temperature is lower. The harvested product must be protected from the sun, and whenever possible, to proceed immediately to their pre-cooling (fast cooling before processing) if such facilities are available. The most popular pre-cooling procedure is by forced air, which circulates air at low temperature (Tompson, 2003). Many vegetables are sensitive to cooling (chilling), that is they get damaged if exposed to low temperature (but above the freezing point) for a certain minimum period of time. Depending on their origin, tropical and subtropical fruits have their threshold for chilling at 10–15°C, whereas the threshold is lower for fruits that originate in temperate areas.

At 7°C chilling damage occurs in cucumber, aubergine, pepper, melon or ripened tomatoes, whereas for green tomatoes damage occurs at higher temperatures (Wang, 2003). Chilling damage can be very relevant if the low temperatures last a long time. If the duration of low temperatures is short, normal metabolic capacity in these plants is limited or

cancelled, affecting their shelf life, although the damage is only evident when the product goes back to normal temperatures.

In general, tomatoes can be conserved well with a RH of 90%, but the optimal thermal regime varies depending on the ripening stage, the recommendation being for less than 15°C for green and early pink-colour stage tomatoes, and less than 10°C for late pink-colour stage and ripened fruits (Chaux and Foury, 1994a, b). The storage temperature allows for regulating the ripening speed; for instance, for pink-colour stage tomatoes, a temperature of 10°C allows them to ripen in 10–20 days, whereas at 20°C ripening is shortened to 8–10 days (Chaux and Foury, 1994b).

The optimal storage temperature of greenhouse cucumbers is from 12 to 13°C, because lower temperatures cause the fruits to wilt and higher temperatures accelerate their respiration and dehydration (Chaux and Foury, 1994b). Covering them in a plastic film extends their shelf life.

The optimal storage temperature of leafy vegetables is lower than for fruit vegetables. In general, while temperatures of 0–2°C, with RH of 90–98%, are optimal for some (artichokes, asparagus, broccoli, cabbage, cauliflower, Chinese cabbage, endives, lettuce, carrots and cantaloupe melons), the fruit vegetables are better conserved at 7–10°C, with RH of 85–95% (Tompson and Kader, 2003). The usual greenhouse vegetables are all very sensitive to freezing (Wang, 2003). In fresh products, postharvest treatments with high temperatures can be of interest to control pests and insects and fungal diseases, before their storage or long-distance shipping. Washing the peppers with water at temperatures between 50 and 65°C, while simultaneously brushing them, has proved to be efficient for the control of postharvest diseases; the same is true for the treatment of tomatoes with hot water at 50°C for 2 min (Lurie and Klein, 2003).

A proper environmental humidity has a notable influence on maintaining the post-harvest quality of fruits and vegetables, especially during cold storage. An inappropriate humidity can increase the incidence of fungal diseases, alter the organoleptic characteristics and induce the cracking or cork-like texture of the fruits and vegetables (Scharz, 1994).

Storage in a controlled atmosphere involves the modification of the normal composition of the air (78% N₂, 21% O₂ and 0.03% CO₂), in order to have less than 8% of O₂ and more than 1% of CO₂, while keeping low temperature and adequate humidity according to the product being stored, which decreases the respiration rate of the product and the production of ethylene (Kader, 2003).

An optimum atmospheric composition delays: (i) the loss of chlorophyll (green colour); (ii) the biosynthesis of carotenoids (yellow and orange colours) and anthocyanins (red and blue colours); and (iii) the biosynthesis and oxidation of phenolic compounds (brown colour) (Kader, 2003). Low levels of O₂ and/or high concentrations of CO₂ in the air affect the flavour, decreasing the loss of acidity, the conversion of starch into sugar, the inter-conversions of sugars and the biosynthesis of volatiles that affect the flavour and aromas, resulting in an improvement of the nutritional flavour, as the ascorbic acid and other vitamins remain in the fruits (Kader, 2003).

In addition to a delay in senescence, storage under a controlled atmosphere decreases the sensitivity to ethylene (if the O₂ level is below 8%, and if the CO₂ level is above 1%), and can be useful to control pests and diseases.

Disadvantages of storage in a controlled atmosphere include: (i) irregular ripening in some cases; (ii) the modification of the organoleptic characteristics (as a result of anaerobic respiration); and (iii) the increase, sometimes, of physiological disorders and chilling damage (Mir and Beaudry, 2003).

When the aim is to accelerate the ripening of a product, such as tomato, ripening chambers may be used, adding ethylene and keeping a proper temperature. These chambers are often used in ripening citrus (degreening).

MAP (modified atmosphere packaging) of fresh vegetables allows for isolating fresh products, with active respiration, in plastic film packages to modify the O₂ and CO₂ levels in the atmosphere inside the package. At the time of packaging, levels of 2–3% of O₂ and 5% of CO₂ are usual (Kader *et al.*, 1989).

In addition, MAP decreases the dehydration of the product and insulates it from the external environment, limiting its exposure to pathogens and contaminants, which contributes to maintaining its quality. It is often used in fresh cut products.

The modification of the atmosphere in MAP requires active respiration of the plant tissues, on one side, and the existence of a barrier that prevents the gas exchange, on the other side. The creation of such barriers is achieved by using plastic films of a characteristic permeability (that controls the entrance and exit of O₂ and CO₂ into/from the package) and by means of micro-perforated plastic films (Mir and Beaudry, 2003).

In MAP, the control of temperature is essential. The decrease of water losses prevents the product becoming desiccated but in some cases may increase how much it wilts. Not all products are suitable for MAP.

A variant of MAP is partial vacuum packaging, which keeps the normal composition of the atmosphere, but at a lower than normal pressure in impermeable packages, at low temperature (Gorris *et al.*, 1994). This system stabilizes the quality, decreasing the metabolic activity of the products avoiding the increase of undesired microorganisms.

29.2.2 Post Harvest Handling of Cut Flowers

Once harvested, there are a series of steps or tasks done to prepare the flowers for market. These are collectively called handling. These handling steps include;



Not all of these steps are done to all flowers, and whether they are used or not depends on the market the flowers are going to be sold to. Where and how the steps are done depends on the market and the facilities of the operation. Flowers can have all the handling steps performed in the field, only some done in the field with the rest in the packing shed, or have all handling steps done in the packing shed.

Field handling usually is limited to leaf removal, grading, bunching, hydrating, and packing with immediate transport to market or cold storage for brief holding. Flowers for local retail markets often are packed this way since they are marketed immediately after harvest. Flowers also can have these steps performed in the field and then be transported to a packing shed where recutting, special treatments, precooling and dry packing can be performed.

All the handling steps can be done in a packing shed, too. It often makes for a better flow of activities if they are all done in the same place. Some of the steps can only be feasibly done in the packing shed, such as special treatments, precooling, cold storage and recutting. These extra steps usually are done for flowers going to wholesale markets.

Design and Maintenance of Green House

The packing shed may be an ultra-modern air conditioned building or an open air covered porch. The handling space should

- be shaded or covered to keep temperatures lower and prevent direct sunlight on the flowers.
- be well lit so you can see well when grading the flowers.
- have a clean water source for preparing harvest, treatment and holding solutions, and for use in cleaning the area.
- have ample space so all handling activities can be performed smoothly, such that workers are not crossing over each other.
- have a cold storage or at least a cooler, shaded place to store the flowers until they are ready for market.
- have a place to prepare for harvest activities.

Although not previously listed, the first step after cutting the stem, whether you are going to handle them in the field or in the packing shed, should be to place them in water or a harvest solution. This solution may be acidified (pH 3.5), tepid water, citric acid works well, or a floral preservative. The harvest containers should be clean and disinfected after each use. Flowers should never be laid on the bare ground. After the harvest container is full of flowers, place them in a cool place until they can be handled or taken to market. The cool place can be a shady area in the field or a refrigerated cold storage. Do not over fill the containers. This will bruise your flowers and cause some to tangle with each other.

Leaves should be stripped from the stem. If the flowers are being field handled this can be done before they are placed in the harvest containers or before they are bunched into marketable bouquets. Usually, leaves are stripped from the bottom one- third of the stem, or at least the ones that would be in any holding solution.

Grading starts with deciding which flowers to harvest. Only marketable flowers should be harvested. Marketable flowers are free of blemishes, including both leaves and petals. The flowers can be grouped or graded by stem length if there are differences and also by developmental stage. More mature ones should be sold as soon as possible, while others can be held in cold storage for later sales.

How the flowers are bunched and packaged depends on the market you are using. If you are selling in a local retail market you have a lot of flexibility, but your customers will let you know what sells the best. Mixed bunches and single type bunches are both popular. Larger flowers such as lilies, gladiolus and sunflowers often are sold as single stems. Sleeving or wrapping the bunches helps prevent the different bunches and flowers from becoming tangled. Columbine, larkspur, delphinium, baby primrose, forget-me-nots and buddleia are flowers that should be wrapped or sleeved prior to marketing to prevent tangling.

Wholesale markets have a set of guidelines for the methods of bunching and packaging flowers. Most are bunched by 10's or 5's . Some, like roses and carnations, are bunched by

25's. Lilies-of-the- Valley are bunched in 25's and Sweet Violets are bunched in 100's with a collar of leaves underneath the flowers. Large, expensive to grow flowers can be sold by single stems. As stated before, some should be wrapped to prevent tangling. Most are boxed and shipped dry.

Proper pre-shipping handling is important in order to get flowers to the market in good shape. The flowers should be well hydrated but not wet when packed. Most spike flowers like snapdragons and gladiolus need to be packed upright to prevent the tips from curving. Special boxes or hampers are made for these types of flowers.

Once bunched, flowers should be hydrated, placed in water for a while before they are packed dry. The hydrating step should include a step where, after the flowers are bunched, the stems are recut under water to eliminate any air bubbles in the xylem that can block the uptake of water. These air bubbles can occur when the flowers were harvested. Once recut, the flower can be placed in a general holding solution used to hydrate the flowers or receive a special treatment such as silver thiosulfate. Flowers usually are not packed dry into boxes in the field but are in the packing shed for distant wholesale markets. When flowers are packed into boxes, the bunches are sleeved or wrapped and then packed tightly so the bunches do not move or vibrate in transit (causes bruising). The standard flower box is 12×12×48 inches. There are smaller sizes, too, called half or quarter boxes that are 6×12×48 inches and 6×6×48 inches, respectively.

Precooling is a step that rapidly brings the temperature of the flowers down from the field temperature to a proper storage temperature. A low temperature slows the respiration rate of the flowers which in turn helps them last longer.

Forced-air cooling is the best method for flowers cool air is actively forced with fans through the bunched flower. This can be done when the flowers are in a bucket or when they are packed dry into boxes. The precooling of flowers is a very important step for individuals selling to a large wholesale market, distant markets and if their crop is to be stored for a long time such as peonies. Individuals who sell at a local retail market usually do not need to worry about this step since their flowers will be in the customer's home the day they are picked.

Cold storage is recommended for all flowers that will not be in the market immediately and any flowers sold wholesale. As stated before, low temperatures slow the respiration rate of the flowers and prolong the vase life of the flowers. In general, temperatures should be 32 to 40°F and have a relative humidity of 85 to 90 percent, for most flowers. Flowers should never be stored with fruits and vegetables. Some fruits and vegetables produce ethylene that can dramatically shorten the life of the flowers. Once flowers are bunched into marketable units they should be placed in cold storage. As a new grower using local retail markets, a refrigerated cold storage may not be available or affordable. Since most of their flowers will be sold within hours a cool place such as an air conditioned room, cellar or basement could be used.

Flower storage life and vase life are considered to be two different things. The customer wants to know the vase life i.e. how long would the flowers last in his home while the grower needs to know both: to determine how long flowers can be kept in cold storage and to be able

to tell customers how long the flowers will last. If flowers have to be stored before marketing, a cool place (preferably a refrigerated cold storage, especially for flowers) should be used.

There are many flowers that are not commonly found in the wholesale market because they do not store well, ship well or last long. These should only be used for local markets. These include foxglove, garden phlox, lupine, clarkia, stevia, common stocks, candytuft, cornflower, feverfew, blue lace flower, English daisy, calendula, pot marigold, sweet violets and gaillardia.



Lesson 30 Post -Harvest Quality of Greenhouse Produce

30.1 INTRODUCTION

The quality is the set of properties and characteristics of a product, process or service that grant its aptitude to satisfy established or implicit needs. The notion of a food product's quality is, simultaneously, complex and relative; it is complex because the quality of a product cannot be determined by a single property, but from the combination of all its physical, chemical and sensorial properties; and it is relative because this combination of factors that define it must be such that determines acceptance by the consumer. Fresh vegetable products maintain, after their harvest, a metabolic activity that is essential for the preservation of their quality.

30.2 QUALITY ATTRIBUTES

- The quality is a combination of attributes, properties or characteristics that provide the product value, depending on the destined use.
- The appearance, the texture, the firmness, the organoleptic characteristics and the nutritional value are components of the quality.
- The relative importance of each component of the quality depends on the product and how it is consumed, varying among growers, distributors and consumers.
- For the grower, a product must provide high yields and have a good appearance, be easy to grow and have a good resistance to transportation, whereas for the wholesaler the qualitative attributes of appearance, firmness and shelf life prevail.
- In addition, the consumer values the healthiness and the nutritional value. In general, consumers place a high value on fresh fruits and vegetables as a healthy and natural food.
- Many of the qualitative attributes of fresh horticultural products are subjective, which makes their evaluation even more complex.
- The consumer usually judges the quality of a product by its external appearance and, if there is no other information (different production methods, differentiating labels), will deduce that a product with a good appearance will have a good internal quality.
- The colour, the size, the uniformity and the absence of defects are basic aspects of the appearance, together with a good presentation, in proper packages that contain a standardized product.

- The food safety and hygiene in the production process demanded by the consumer have made necessary the establishment of rigorous production protocols (which specify growing methods, traceability, etc.) that guarantee the healthiness of the products.
- Transport over long distances in some cases means that some vegetables are harvested before the commercial ripening point; so that when they reach the consumer they are in a suboptimal organoleptic condition.
- The greenhouse growing conditions (light, temperature, irrigation, nutrition, salinity) affect the quality (Welles, 1999), so their management must be optimized.
- The qualitative attributes of vegetables vary with the species. In some products such as cucumber, whose shelf life is the main quality attribute, a qualitative evaluation is simple, whereas for others such as tomato, it is more complicated, especially regarding its organoleptic characteristics.
- In some cases, such as tomato, achieving a high quality may involve a decrease in the yield, so a compromise between quality and quantity in the production must be reached.
- The sensorial quality is dictated by a number of external and internal factors. The external factors include the attributes related to the appearance, such as colour, form, size and firmness, and are subject to physical and visual properties, being appreciated by the consumer through the senses of sight and touch, whereas the attributes related to flavour, aroma and texture, which are sensed by the taste and smell, are included among the internal factors of sensorial quality (Martínez-Madrid *et al.*, 2000).
- The essential criteria to evaluate the sensorial quality in fruits and vegetables are the colour, flavour, aroma and texture. The flavour and the aroma are the most subjective and difficult to evaluate qualitative aspects.
- The flavour can be evaluated by taste and smell, and is mainly composed of sweetness, acidity and aroma, that correspond to the sugars, acids and volatiles, respectively (Baldwin, 2003). Other components of the flavour are bitterness, salinity and astringency.
- The acidity and the aroma modify the perception of sweetness, one of the most important components of the flavour in fruits and vegetables. The perception of the non-volatile components of flavour (sweet, acid, salty and bitter) takes place on the tongue and the aromas are detected by the nose; both perceptions are integrated in the brain, being difficult to distinguish between them (Baldwin, 2003).
- The genetic characteristics are the main determinants of flavour and aroma of fresh horticultural products, although they are influenced, but to a lesser degree, by cultural practices and the pre-harvest conditions, as well as by the ripening stage at harvest and any subsequent handling.

- The organoleptic quality of non-climacteric fruits generally decreases after harvest, whereas climacteric fruits may reach their best quality after being harvested, if they are harvested after the beginning of the ripening process.
- The sensorial evaluation of flavour and aroma of a product is usually done by taster panels. Consumer preferences vary depending on socio-economic, ethnic and geographical conditions.
- The sugars that supply the sweet flavour are fructose (the sweetest), sucrose and glucose (the least sweet). Organic acids, such as citric acid in tomato, provide the acid taste.
- In the majority of melon cultivars the main sugar is sucrose and the most common acids are citric and malic acids, whereas in watermelon sucrose predominates and, in some cultivars, there are high levels of fructose, and malic acid is the only relevant acid (Baldwin, 2003).
- In tomato, the total content of soluble solids and the acidity determine its taste. The most abundant sugars are glucose and fructose, at approximately equal levels, with citric acid being present in greater quantities than malic acid. There is also the presence of a large number of volatile compounds (more than 400) from which 16 contribute more effectively to the taste and aroma (Baldwin, 2003).
- The texture is a qualitative attribute that is critical for the acceptance of fruits and vegetables, that is, for the perception that the consumer has of the qualitative characteristics. The texture involves the structural and mechanical properties of an edible product and its sensorial perception in the hand or in the mouth (Abbot and Harker, 2003).
- The texture is related to a series of chemical compounds responsible for the perception of the structure, such as pectin, cellulose, hemi-celluloses and proteins (Martínez-Madrid *et al.*, 2000).
- Sometimes, the term texture includes some mechanical properties, which cannot be of interest to the consumer, such as resistance to mechanical damage or transport. The texture is altered throughout the shelf life of the product, so it can only be referred to at the time of evaluation.
- Measurements of texture, nowadays, are considered critical indicators of the non-visual aspects of quality. The complexity of the texture allows for its complete measurement only by means of sensorial evaluation (valuation panels), although instrumental measurements are preferable, whenever possible. There are many measurements that relate to textural attributes, normally the more precise ones being those that use destructive methods (Abbot and Harker, 2003).
- Obtaining a high quality product depends on the expression of the genetic characteristics of the chosen cultivar under the ecological conditions in which it is cultivated.

- The study of the nutritional value and the beneficial effects of fruits and vegetables on human health has become increasingly relevant in recent years (Desjardins and Patil, 2007; Patil *et al.*, 2009).
- The control of the pre-harvest conditions, of an environmental nature (temperature, humidity, radiation, soil, rain) and cultural nature (nutrition, irrigation, pruning), is not enough to achieve a good quality product, as the ripening stage of the fruits at the time of harvesting is the factor that plays an essential role in the sensorial qualitative characteristics. This is because the production of compounds such as the aromas that contribute to the flavour take place, mainly, in the advanced stages of the ripening process (Martínez- Madrid *et al.*, 2000).
- An early harvest has advantages for distribution of the product, as the texture is maintained for a longer period extending the shelf life, but this is to the detriment of its sensorial quality, at least in non- climacteric fruits.

It is evident that the future relies on the quality, but it must be economically feasible quality. The fixing of integral quality systems is a clear priority in the production of greenhouse vegetables.

30.3 QUALITY CONTROL AND ASSURANCE

Quality control (QC) is the process of maintaining an acceptable quality level to the consumer. Quality assurance (QA) is the system whose purpose is to assure that the overall QC job is being done effectively (Hubbard, 1999). QA and QC are often used interchangeably to cover the planning, development, and implementation of inspection and testing techniques; they take time and a lot of training. A successful QA/QC system cannot be flexible, but it must be subject to constant review and improvement as conditions change (Hubbard, 1999).

Many attempts are currently being made to automate the separation of a given commodity into various grades and the elimination of defective units. The availability of low-cost microcomputers and solid-state imaging systems has made computer-aided video inspection on the packing line a practical reality. Solid-state video camera or light reflectance systems are used for detection of external defects, and x-ray or light transmittance systems are used for detecting internal defects (Abbott *et al.*, 1997; NRAES, 1997). Further development of these and other systems to provide greater reliability and efficiency will be very helpful in quality control efforts.

An effective quality control and assurance system throughout the handling steps between harvest and retail display (Table 30.1) is required to provide a consistently good- quality supply of fresh horticultural crops to the consumers and to protect the reputation of a given marketing label. Quality control starts in the field with the selection of the proper time to harvest for maximum quality. Careful harvesting is essential to minimize physical injuries and maintain quality. Each subsequent step after harvest has the potential to either maintain or reduce quality; few postharvest procedures can improve the quality of individual units of the commodity (Cavalieri, 1999; Kader, 1988; Kader, 1992; Shewfelt *et al.*, 1993).

Exposure of a commodity to temperatures, relative humidity, and/or concentrations of oxygen, carbon dioxide, and ethylene outside its optimum ranges will accelerate loss of all quality attributes. The loss of flavor and nutritional quality of fresh intact or cut fruits and vegetables occurs at a faster rate than the loss of textural and appearance quality. Thus, QC/QA programs should be based on all quality attributes and not only on appearance factors as often is the case. More research is needed to identify the reasons for the faster loss of flavor than appearance quality and to develop new strategies for extending postharvest-life based on flavor to match that based on appearance.

Table 30.1 Quality assurance procedures during handling of horticultural perishables.

Handling steps	Quality Assurance Procedure
Harvesting	Training workers on proper maturity and quality selection, careful handling, and protecting produce from sun exposure.
Packing house operations	Checking product maturity, quality, and temperature upon arrival. Implementing an effective sanitation program to reduce microbial load. Checking packaging materials and shipping containers to ensure they meet specifications. Training workers on proper grading by quality (defects, colour, and size), packing, and other packinghouse operations. Inspecting a random sample of the packed product to ensure that it meets grade specification. Monitoring product temperature to assure completion of the cooling process. Maintaining effective communications with quality inspectors and receivers to correct any deficiencies as soon as they are identified.
Transportation	Inspecting all transport vehicles before loading for functionality and cleanliness. Training workers on proper loading and placement of temperature-recording devices in each load. Keeping records of all shipments as part of the “trace- back” system
Handling at destination	Checking product quality upon receipt and moving it quickly to the appropriate storage area. Shipping product from distribution center to retail markets without delay and on a first in/first out basis unless its condition necessitates a different order.

30.4 STANDARDIZATION AND INSPECTION OF FRESH PRODUCE

Grade standards identify the degrees of quality in a commodity that are the basis of its usability and value. Such standards, if enforced properly, are essential tools of quality assurance during marketing and provide a common language for trade among growers, handlers, processors, and receivers at terminal markets. Some production areas like California, USA enforce minimum standards concerning produce quality, maturity, container, marking, size and packing requirements. This provides orderly marketing and equity in the marketplace and protects consumers from inedible and poor quality produce.

Inspection is done either on a continuous basis (where one or more inspectors are assigned to a packing house to make frequent quality checks of the commodity along the packing lines), or on a sample basis (where representative samples of a prescribed number of boxes out of a

given lot are randomly selected and inspected to determine whether the product meets the grade specification for which it is packed). When inspection is completed, certificates are issued by the inspector on the basis of applicable official standards.

To ensure uniformity of inspection: 1) inspectors are trained to apply the standards, (2) visual aids (color charts, models, diagrams, photographs and the like) are used whenever possible, (3) objective methods for determining quality and maturity are used whenever feasible and practical, and (4) good working environments with proper lighting are provided.

International standards for fruits and vegetables were introduced by the Organization for Economic Cooperation and Development beginning in 1961, and now there are standards for about 40 commodities. Each includes three quality classes with appropriate tolerances: Extra class = superior quality (equivalent to "U.S. Fancy"); Class I = good quality (equivalent to "U.S. No. 1"); and Class II = marketable quality (equivalent to "U.S. No. 2"). Class I covers the bulk of produce entering into international trade. These standards or their equivalents are mandatory in the European Union countries for imported and exported fruits and vegetables.



Module 21: Cost analysis of greenhouse Production

Lesson 31 Cost Analysis of Greenhouse Production

31.1 INTRODUCTION

Growing crops in a greenhouse environment requires a substantial investment in capital and management resources. The two financial considerations regarding any such enterprise are profitability and cash flow. Profitability potential can be addressed through an enterprise budget, which is an itemization of costs incurred over a typical or average production cycle. The second consideration is addressed by analyzing cash flows in and out of the enterprise for a fixed interval of time, that is, through a cash flow budget.

Greenhouse enterprise budgets contain two types of costs, variable and fixed. Variable costs are those costs incurred only if the production cycle is started. Seeds, fertilizer and perlite bags are examples of such costs. Fixed costs occur whether or not there is production. Property taxes, insurance, depreciation and interest on investment such as buildings and equipment are examples of fixed costs and must be accounted for even if there is no production. An enterprise budget can be used to estimate the profitability of an enterprise by including sales revenue and net returns. Net returns will be expressed as gross margin and net income. Gross margin is expressed as revenue minus variable cost and net income is revenue minus all costs. Enterprise budgets do not address whether the enterprise can produce a sufficient flow of funds to meet the cash obligations of the enterprise.

Cash flow analysis is used to determine whether the cash generated from operations (cash inflow) will be adequate to meet the cash outlays required to operate the enterprise (cash outflow) over a given time interval. Unpaid family labor is charged to the enterprise as an expense because it represents the loss of opportunity for the family member to work elsewhere and earn income. Consequently, while not a cash outlay, it should be charged as an opportunity cost to the enterprise. Both enterprise and cash flow budgets for greenhouse tomato production for one greenhouse are presented as an example in the following tables and discussed and analyzed. While this discussion uses tomato as a crop example, the principles discussed are applicable to other crops such as pepper, cucumber and eggplant. This particular example was chosen to illustrate several important aspects of greenhouse production and marketing that affect profitability such as market price, yield and labor.

31.2 GREENHOUSE PRODUCTION COSTS AND RETURNS

31.2.1 Computation of Individual Cost Components

31.2.1.1 Interest on Investment:

Interest is defined as a sum paid or calculated for the use of capital. The sum is usually expressed in terms of a rate or percentage of the capital involved, called the interest rate. Interest is charged for the use of investment capital. Had the capital not been invested to buy a specific asset, it could have been used elsewhere, either within or outside the firm and

would have brought some additional return to the firm. However, for the purposes of the study, use actual paid capital interest to arrive at capital costs.

31.2.1.2 Depreciation:

Depreciation is defined as the loss in value of an asset over time, mainly as a result of obsolescence. In the case of buildings and equipment, it is that portion of the decrease in value resulting from the passage of time. Obviously, part of the reduced value of the buildings and equipment is the result of usage and is considered a variable cost. The entire depreciation is considered a fixed cost.

For computing depreciation, a 10 percent allowance or salvage value is generally taken from the purchase price of the buildings and equipment. The following formula is used in arriving at depreciation for buildings and equipment.

$$\text{Depreciation} = \frac{\text{purchase price} - \text{Salvage value}}{\text{Number of Years of life}}$$

31.2.1.3 Land Value

Land associated with each greenhouse operation is valued as per local market condition. This value is determined through real estate values for good farmland suitable for a greenhouse operation. It can be argued that allocation of such a value distorts cost of land in and around urban areas relative to farmland. However, for uniformity and reasonable cost estimates, the land value should be standardized regardless of its location. Researchers are aware that land values in cities or towns are much higher than decided standardized value, but if market values are used for land acquired ten years ago, it would lead to artificially high fixed costs that would greatly inflate overall production costs.

31.2.1.4 Property and Business Taxes

Taxes on real estate include payments made on the assessed value of the greenhouse operation less any assessment for the greenhouse operator's residence or operations other than the greenhouse. There is a business tax on greenhouses located in urban municipalities. Exact amounts of property and business taxes are included in the costs.

31.2.1.5. Labour Costs:

Hired labour costs include the amount of wages and any benefits received by the hired workers, such as contributions to Workers' Compensation. The hours spent by the operator and his/her families in greenhouse production needs to be estimated.

31.2.1.6 Production Materials and Supplies:

Production materials and supplies include the purchase of cuttings, seed plants, fertilizers, chemicals, soils, vermiculite, perlite, peat moss, straw, peat pots and plastic.

31.2.1.7 Heating Cost:

Almost all greenhouse operators have reasonably accurate costs for heating the greenhouses with natural gas. Monthly bills are helpful in arriving at the total heating costs.

31.2.1.8 Utility Costs

Utility costs include electricity, telephone and water. If utility bill is combined with the greenhouse operator's residence, the operator is asked to apportion the bill to arrive at total utility costs for the greenhouse operation.

31.2.1.9 Transportation Expenses:

Expenses for trucks or other vehicles owned by greenhouse operators are apportioned according to their use in the greenhouse operation, personal and leisure driving. Freight charges paid to commercial or private carriers for hauling greenhouse produce or supplies should be included in the transportation expenses

31.2.1.10 Repairs and Maintenance Cost

Maintenance costs include repairs to greenhouse structures, boilers, heating equipment, tractors and all other machinery and equipment associated with the greenhouse operation.

31.2.1.11 Marketing Charges:

These charges cover grading, packaging, marketing and administrative fees.

31.2.1.12 Miscellaneous costs:

These costs include legal and accounting fees, office supplies, bad debts, donations, membership fees, insurance costs and other costs incurred in a greenhouse operation, but not reported under any other heading.

31.2.2 Components of Cost Analysis

31.2.2.1 Net Present Worth:

The NPW is defined as the difference between present worth of savings and cost of investment. The mathematical statement for net present worth can be written as:

$$NPW = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t}$$

.....(Kothari *et.al.* 2001)

Where,

C_t = cost of each year

B_t = Benefit in each year

$t = 1, 2, 3, \dots, n$

i = discount rate

31.2.2.2 Internal Rate of Return:

The internal rate of return is threshold rate at which the NPW is zero. Internal rate of return is the discount rate (i) such that

$$\sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} = 0$$

..... (Jain *et.al.*2004)

31.2.2.3 Benefit Cost Ratio

This ratio was obtained when the present worth of the benefit stream was divided by the present worth of the cost stream. The mathematical benefit-cost ratio (Kothari *et. al.*, 2006) can be expressed as:

$$\text{Benefit-cost ratio} = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}}$$

31.2.2.4 Payback Period

The payback period is the length of time from the beginning of the project until the net value of the incremental production stream reaches the total amount of the capital investment. It shows the length of time between cumulative net cash outflow recovered in the form of yearly net cash inflows.

$$PP = \frac{IC}{ANI}$$

..... Chito F.Sace, (2007)

Where,

PP= Payback Period

IC= Investment Cost

ANC= Annual Net Income

31.2.2.5 Break- Even Analysis (Chito F. Sace, 2007)

Break-even analysis presents the point where there is just sufficient revenue to cover the costs. It is the point at which the total cost and the total gross revenue intersect. It is a method used more frequently to demonstrate the probable effects of change than to determine what those changes should be.

$$BEP = \frac{TFC}{S_p - u_p}$$

Where,

BEP= Break- Even Point; the volume where $T_r = T_c$

TFC= total fixed Cost Per Year

S_p = selling price per Kg

u_p = Cost per Kg

= $TVC / (\text{Total wt.}/\text{year})$



Module 22. Application of greenhouse & its repair & maintenance

Lesson 32 Repair and Maintenance of Greenhouse

32.1 INTRODUCTION

Greenhouses, and their environmental control systems, are susceptible to many destructive forces. Of these, the most common are lack of preventive and corrective maintenance. A good greenhouse manager should observe potential problem areas in the facilities, equipment and grounds. Records should be kept on when routine maintenance checks were made and what corrective measures, if any, were taken. The records should include such entries as evaporative cooling pad replacement, fan belt replacement, boiler compound addition, fertilizer injector maintenance, fumigation equipment inspection, and bearings and motor lubrication. Of course corrective maintenance should be done when the need is discovered, but a good preventive maintenance program will reduce the number of corrective maintenance actions necessary and could save many dollars in equipment down time and labour saved. This lesson will emphasize corrective and preventive maintenance procedures for ventilation, evaporative cooling and heating systems.

32.2 VENTILATION SYSTEM

The operating efficiency of a ventilation fan can be reduced 30-50% by the build- up of dust on fan blades or by shutters that do not operate freely. Regardless of how well a ventilation system has been designed and installed, the system will not function properly without maintenance and care. When a ventilation system is not operating properly, the results can be pockets of stagnant air, inadequate cooling from evaporative cooling pads, high heating expenses, heavy condensation in winter, reduced life and reliability of ventilation equipment, and high repair bills.

The major points to consider in any maintenance program for fans and their components are:

- Be sure the fan blades, fan housing, and shutters are clean. The accumulation of only ounces of dust on fan blades can create enough imbalances in the fan to reduce operating efficiency by 30%. Clean the fans and components as often as necessary to prevent dust accumulations.
- Whenever cleaning the fans, lubricate the fan bearings, motor, and shutters. Any parts that do not move freely should be replaced.
- Check the fan belts for proper tension to prevent slippage. If the belts are cracking, splitting, or fraying, replace immediately. Otherwise, the belt may fail when no one is available to install a new belt.
- Inspect the electrical supply cords to fans from the receptacle and from the thermostat. Whenever the insulation begins to crack or split, replace with UL, approved insulated wire.

- Check fan wheel for proper rotation. Fan rotation is sometimes reversed when fans are installed, repaired, or when the polarity of wiring circuits is alternated. Since fans move a fraction of their rated capacity when running backwards, reversed direction often goes unnoticed in spite of much less efficient performance. Proper direction of rotation is generally marked on the fan housing.
- Remove weeds and shrubs growing outside greenhouses close to each fan. Nothing should obstruct the flow of air from the fan within a distance of two blade diameters of the fan. Any weeds or shrubs would make it harder for the fan to exhaust the air; hence, the fan would operate with lower efficiency.
- Never allow any obstructions that would limit the flow of air into a fan within a distance of one blade diameter of a fan. Any obstructions to the flow of air would also make the fan operate with less efficiency.
- If it is necessary to replace any fans, always replace with fans rated according to AMCA (Air Moving and Conditioning Association) standards. Such fans will carry an AMCA seal on the fan housing and in the sales literature.
- When it is necessary to replace the fan motor, always replace it with a totally enclosed motor having sealed bearings. This type motor is required to protect the motor windings from the corrosive effects of high humidity and dust accumulations that would otherwise shorten the service life of the motor.
- Check for openings around fan housings that permit air flow to bypass the desired air inlet pattern. Close all other openings in the house such as laps or unions between sections of glazing materials, service utility entrances, cracks around evaporative cooling pads and frames, voids in evaporative cooling pads, and doors where outside air can enter. Efficiencies of heating, cooling, and ventilation systems can be drastically reduced by the presence of such openings.
- Calibrate thermostats and humidistats to insure that fans operate according to the prescribed environmental conditions. Be sure to carefully wipe any accumulated dust from the sensing elements of the controls before calibrating. Aspirated sensing units are preferred because of faster response to changes in greenhouse environments. Thermostats and humidistats should be placed at or near crop level, rather than human level, to insure most accurate environmental control for the plants.

32.3 EVAPORATIVE COOLING SYSTEM

The efficiency of evaporative cooling can be greatly reduced by compacting of cooling pads, improper operation of fans, greenhouse doors remaining open and insufficient water supply to cooling pads. Whenever the efficiency of evaporative cooling is reduced, the air temperature inside the greenhouse increases. Major factors to consider in any maintenance and care program for evaporative cooling are difficult to generalize because several different types of cooling pads are now available. The major factors are:

- Be certain that the rated air flow passes through the cooling pad, not through open doors, cracks, or other openings in the greenhouse. Check pads and supporting frames

to insure tightness of fit and good condition of pads. Cracks around pads should be sealed and pads with holes exceeding $\frac{1}{4}$ inch diameter should be repaired or replaced. Only air that passes through the cooling pad is cooled; air entering through other openings is not cooled. Furthermore, if any openings exist because of open doors, cracks, etc., virtually all the air will enter through these openings rather than through the cooling pads. If pads are covered with algae, which increase resistance to air flow, they should be cleaned or replaced.

- Check the fan ratings to be certain the proper volume of air is drawn through the cooling pads at the required static pressure resistance. Air volumes may range from 150 to 400 cubic feet of air per minute (cfm) per square foot of pad area at static pressures ranging from about 0.05 to 0.30 inches of water. Be sure to follow the manufacturers' specifications. Fans must be properly maintained to perform at rated capacities.
- Use water meters, rota-meters, or bucket and stopwatch to check the rate of water supply to the cooling pads. The specified rate of water supply differs for various types of cooling pads; therefore, follow the manufacturers'
- Recommendations. For aspen pads, the recommended water rate is $\frac{1}{3}$ to $\frac{1}{2}$ gallon per minute per lineal foot of pad. A check of the water supply should be performed at the beginning of each cooling season.
- Use fungicides in the water supply system to retard the growth and build-up of algae in the cooling pads. Algae and other bacteria will hasten the deterioration of the pads and also increase resistance to air flow.
- If using aspen cooling pads, replace with new pads whenever the void area in the pads is 10% or greater of the original total pad area. Replacement is necessary because cooling efficiency is reduced as an increasing volume of air enters the greenhouse through the void space rather than through the cooling pads.
- If replacing cooling pads, seriously consider replacing with the newer types of pads such as concrete coated cooling pads or corrugated cellulose cool pads. Research has shown the cooling efficiencies of these newer pads to be as high as or higher than new aspen pads and much higher than rubberized hog hair pads and aging aspen pads. Life expectancy of these new pads is longer than that of aspen pads.

32.4 HEATING SYSTEMS

There are three basic types of heating systems commonly used. They are:

- Unit space heaters,
- Hot water heaters, and
- Steam heaters.

The latter two require a boiler to produce the hot water or steam. There are a number of ways that these systems can be applied. Normally, unit space heaters are either oil or gas fired although space heaters utilizing hot water from a boiler are used in some instances. A fan is used to distribute the heat uniformly throughout the house. Unit heaters should be spaced in such a way and have sufficient fan capacity to provide uniform heat distribution and good air circulation (a speed of 40 feet per minute is considered minimum). In an enclosed greenhouse, all fossil fuelled heating units should be vented to the outside. By-products of combustion are injurious to many kinds of plants and it is possible to have as much or more plant damage from combustion by-products of unvented heaters as from the low temperatures which would result if no heat were supplied.

- Vent all fossil-fuelled unit heaters to the outside in any enclosed house. The vent stack should extend a minimum of four feet above the house ridge or any nearby building or other obstruction.
- Make sure you have good air circulation. Auxiliary fans may sometimes be a good investment.
- Locate thermostats which control the system near plant bed level.
- Do not expose the thermostat to a nearby heat source or draft. It may be necessary to use a protective shield and a small fan to move air across the thermostat in order to obtain proper temperature conditions at the bed level.
- Check all burner nozzles, clean fan blades, and oil fan motor as recommended by manufacturer prior to initial operation.
- Check all flues for leaks and make sure the stack extends the proper height as described earlier.
- Check all pipes in a hot water or steam system for leaks.
- Where unit hot water systems are used, check to be sure fan blades are clean, fan motors properly oiled (if recommended by manufacturer) and that orientation of each unit is proper to give optimum heat and air distribution at plant level. If fans are belt driven, check all belts and pulleys to be sure they are in good condition.
- Do not increase number of hot water unit heaters or, if bench hot water lines are used, extend their length, without making sure the boiler or furnace has sufficient capacity to handle the added load.
- Keep pipes in a hot water system clean. Accumulation of dust can decrease efficiency significantly. The same is true for registers or finned pipes which are used in a steam system. Allow for heat losses in the transport pipe from the boiler to the house when calculating the heating requirements for a house heated with hot water or steam. Normally, 15-25% should be added to take care of this loss. An experienced heating contractor or engineer should probably be retained to design and supervise installation of these type heating systems. Make sure all boiler components are in proper working condition well ahead of the heating season.

Design and Maintenance of Green House

- If a polytube heat distribution system is used, be sure length of tube, size, spacing and location of openings in tube are properly matched to the heating unit(s) and house configuration for good heat and air distribution. Normally the manufacturer will provide dependable instructions for installation and operation.
- Do not use unvented fossil fuel heaters. If, however, you feel this is necessary to save your plants from freezing, provide as much ventilation (either natural or mechanical) as practical to reduce damage from the by-products of combustion. Some plants are more tolerant than others. Determine degree of tolerance prior to the heating season if it is anticipated that unvented heaters may have to be used.
- Contact your fuel dealer well in advance of the heating season to be sure of an adequate fuel supply in the event a fuel shortage should develop.
- When building new houses, consider the efficiencies of alternative systems and local availability of different types of fuel.

32.5 GREENHOUSE SANITATION

Greenhouse sanitation involves cleaning in and outside of the greenhouse.

- Weeds should be controlled around the greenhouse.
- Inside the greenhouse you should prevent weeds, insects, rodents, and diseases

32.6 UTILITY REPAIRS

Utility repairs involve:

- Water
- Electricity
- Gas or Fuel Oil
- Waste and Trash Disposal

32.7 STRUCTURAL REPAIRS

A greenhouse is like any other building in that it requires structural repairs.

Check for and repair any:

- Loose, torn or cut plastic covers
- Broken glass or fiberglass
- Door locks and fasteners
- Air leaks

- Damaged framework or foundation

32.8 SHADE CLOTH MAINTENANCE

- Shade cloths help regulate greenhouse temperature by diffusing the sunlight before it enters the greenhouse.
- Shade cloths also regulate light intensity in the greenhouse.
- Shade cloth maintenance involves:
 - Being attached properly
 - Being applied or removed as needed



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