International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
www.chemijournal.com
IJCS 2021; SP-9(1): 40-45

Received: 19-11-2020
Accepted: 28-12-2020

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Greenhouse structures, construction and design

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DOI: https://doi.org/10.22271/chemi.2021.v9.i1a.11417

Abstract
Greenhouse is a frame structure that covers transparent materials such as glass, polyethylene and polycarbonate, etc. It consists of two parts frame and covering material. The greenhouse covering material acts as a barrier to the passage of air and traps energy inside the greenhouse, which heats both the plants and the soil within it. This wall, like the air near the ground, raises the temperature within the greenhouse. Greenhouses may be used for the cultivation of high-quality fruits, flowers, various crop nurseries, ornamental and medicinal plants. The benefits of greenhouses are high production per unit area because the genetic potential of the crop can be completely exploited, vegetables and nurseries can be grown off-season that obtain high market prices, good quality products and it is easy to protect the crops from pests, diseases and extreme climatic conditions. Greenhouse farming is a highly intensive industry that needs considerable labour and capital inputs. Because of this, all factors important for a successful enterprisers should be carefully considered by potential growers. Greenhouse vegetable processing is a 24-hour commitment in several respects. Constant vigilance is required for the maintenance, crop production and handling of emergencies.

Keywords: Crop production factors, greenhouse, loads, orientation, site selection, and shapes

Introduction
The existence of root media can only be regulated by traditional agricultural practices by tillage, manure, fertilizer application, irrigation etc. In open field cultivation, there is no influence over sun, temperature, air composition, humidity, etc. (Tiwari, 2003) [1]. However, greenhouse cultivation can be used as one of the solutions for these parameters. Some of the benefits of greenhouse cultivation are efficient use of agro-chemicals by minimizing emission of waste and recycling, efficient use of solar, wind and thermal energy, off season cultivation, better insect and disease control, reduced use of pesticides, protect plants from environmental hazards such as heavy rain, strong wind, excess solar radiation and extremes of temperature and humidity, better quality of produce, higher productivity, high-income generation for small land holdings (Fernández *et al.*, 2018) [2].

Greenhouse Classifications
The greenhouses can be classified on the bases of cost, shape, size and environment control. On the basis of cost the greenhouses can be classified as:

Low Cost
The low-cost greenhouses are constructed from locally available materials i.e. bamboo, wood etc. is used for construction of frame and glazed with stabilized polyethylene sheet. There is no environmental control in this type of greenhouses. The cost varies from Rs 250 to 300 per square meter.

Medium Cost
In case of medium cost greenhouses the frame may be made from Galvanized Iron/Mild steel pipes. But the problem associated with MS pipes is rusting after some time, which also damages the covering sheet. These greenhouses are also glazed with UV stabilized polyethylene sheet. The cost varies from Rs.800 to 1000 per square meter.

High Cost
The high- cost greenhouses are made from aluminum/GI pipes, glazed with double layer poly ethylene sheet or poly carbonate. The environment inside the greenhouses is fully controlled and operation is also automated. There are sensors and controllers for temperature, humidity and soil moisture. The cost of this type of greenhouses is more than Rs 2000 per square meter.
On the basis of shape the greenhouses may be classified as Quonset, modified Quonset, gable/standard peak free standing (even and uneven span), multi span gutter connected and lean to type figure 1.

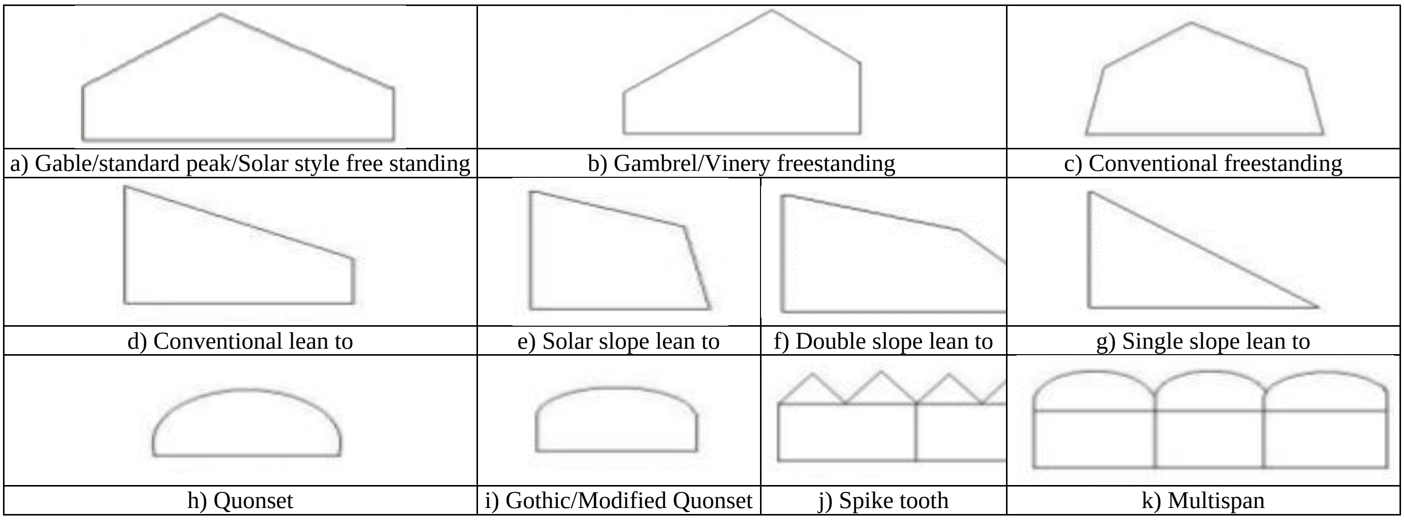


Fig 1: Various shapes of greenhouses

Indian standards for greenhouse
The BIS has formulated following standards with respect to greenhouse technology (Waaijenberg, 2006) [3].

- IS14462:1997-Recommended for layout, design and construction of greenhouse structures.
- IS14485:1998 – Recommendation for heating, cooling and ventilation of greenhouse.

On the bases of height of greenhouses these may be classified as portable low tunnels and high tunnels. The portable low tunnels are of height 1 m and used to raise the seedlings of various crops.
On the basis of cooling system the greenhouses may be classified as

1. Without cooling system
2. Passive cooing system
   a. Natural ventilation
   b. Shading type
3. Active cooling system
   a. Forced ventilation and
   b. Evaporative cooling

The natural ventilated and use of shade nets for reducing inside temperature is the most preferred energy saving way of reducing greenhouse temperature.

Crop Production Factors
The crop production inside the greenhouse is affected by micro climate, fertilizers, quality of seeds, seed treatment, pest control, field preparation and irrigation. The plant growth also depends on other factors that are well within one's reach and control (Pritam and Yadav, 2015) [4]. The key environmental factors affecting plant growth are light intensity, temperature, humidity, carbon-dioxide concentration, airflow etc.

a) Light intensity
Visible light constitutes a source of energy for plants. Light energy, carbon dioxide, water all enter into the process of photosynthesis through which carbohydrates are formed. Considerable energy is required to reduce carbon that is combined with oxygen in carbon dioxide to reach the state in which it exists in carbohydrate (José *et al.*, 2020) [5]. The light energy thus utilized is trapped in the carbohydrate. Later, the carbohydrate can be moved from the green stem and leaf cells where photosynthesis occurs to the other parts of the plant. The carbohydrate can be converted into all other compounds needed in the plant. Energy from the sun is utilized in all of these compounds. These processes result in plant growth. Respiration occurs in all living organisms at all time. In fact, most living organisms are ultimately dependent on light energy. The day length (i.e. photoperiod) also affects the plant growth. The relative day-night lengths may affect the rooting of cuttings, initiation of flowers and fruits, bulb and tubes formation, advent and cessation of dormancy, etc.
The intensity of incoming solar radiation is an important parameter for influencing the photosynthetic activity of plants. The light intensity varies from place to place but it generally varies from zero at the beginning of the day to about 100,000 to 150,000 lux (lumen/m^2) around noontime. Light intensity on cloudy days is quite low which leads to poor photosynthetic process. Light intensity below 3200 lux and above 129,000 lux is not ideal for plant growth since the optimum light intensity for plant is 32,000 lux. In this case, solar radiation transmittance needs utmost attention while considering controlled environment agriculture obtained in greenhouse. It is also influenced by the orientation of structure (greenhouse) and the sun elevation.

b) Temperature
All crops have certain temperature range in which they grow better. Below this range, the process necessary for growth stops. Under very high or extreme temperatures, enzymes become inactive, causing necessary processes for plant's development to stop. Thus, the temperature may affect the movement of minerals, water and food in roots, stems and leaves. This can affect the photosynthesis process significantly. Prolonged low temperature will result in loss of

flowers and fruits; slowing their growth. On the other hand, prolonged high temperature will result in loss of flowers, fruits, burning of leaves and lowering in plant growth. Soil temperature also affects the plant growth because it affects the absorption of water from the soil by the plant.

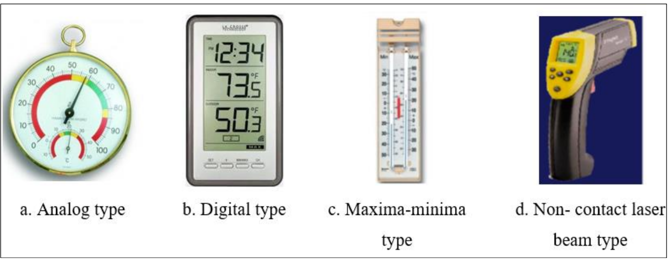


Fig 2: Temperature measuring instruments

c) Humidity

Humidity in the atmosphere has its own importance as it governs most of the metabolic and photosynthesis activities of the plants. It has been observed that a relative humidity between 20 and 70 per cent is ideal for plant growth. This is so because, very high relative humidity will provide better environment for pathogenic organisms making the plant susceptible to diseases. Low humidity is also harmful for plants since it increases the evaporation rate, and at the same time, enhances the water requirement. In environmentally controlled chambers, relative humidity between 55 to 65 per cent and temperature between 20 to 25 °C is maintained.

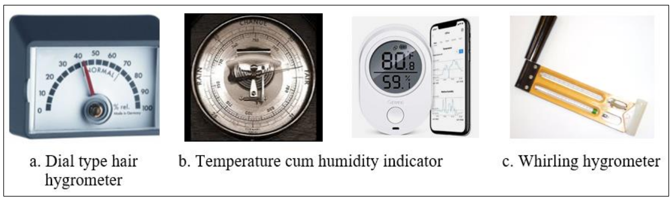


Fig 3: Relative Humidity measuring instruments

d) Carbon dioxide (CO_2)

The amount of CO_2 present in the plant environment affects the plant growth considerably because it is essential for photosynthesis. The amount of CO_2 required for optimum plant growth depends on the plant type, state of development, temperature, light intensity, leaf area, air, velocity, humidity, water stress etc. But the CO_2 requirement differs for various plants. Research has shown that controlled environments, such as closed greenhouse system, offers ample opportunity to improve production through the elevation of CO_2 levels. Carbon dioxide, which comprises about 0.03 percent (300 ppm) of ambient air, is essential for plant growth. This level of carbon dioxide in atmospheric air is sufficient to meet the photosynthetic requirement of open field crops. In closed conditions, the level of carbon dioxide rises to nearly 1000 ppm, because respired carbon dioxide remains trapped overnight. As sunlight becomes available, photosynthesis process begins and carbon dioxide from greenhouse air gets depleted. As a result, the CO_2 level in the greenhouse even goes below 300 ppm before noontime. If the greenhouse air does not receive additional carbon dioxide from any other source, the plant would be deficient of carbon dioxide resulting in poor growth. Reports have shown that crop yield increased by 20-30 per cent when carbon dioxide level was maintained from 1000-1500 ppm inside the greenhouse. The most common method of CO_2 supplementation is through burning of carbon fuels.

e) Air Movement

Although air movement affects the plant growth, through its effect on transpiration, evaporation of water from soil, CO_2 availability, tearing of leaves, cooling effect, etc. The air velocity affects the boundary layer thickness of the plant's leaves through which the plant transpires and water vapour diffuses into the outside air while the atmospheric. CO_2 required for photosynthesis enters into the plant.

Procedure for Greenhouse Construction Site Selection

- The greenhouse should be so located that it is well connected to market for getting input supplies as well as for marketing its produce.
- The soil should be of good quality and well drained.
- There should be permanent source of water near greenhouse, this is most important for meeting out water requirements of greenhouse crops.
- There must be no obstructions (shadow), which will restrict the supply of sunlight to greenhouse Locate the greenhouse at -a distance of 2 times the height of any object that might cast a shadow on the greenhouse.
- The availability of uninterruptable electricity supply must be ensured.

Greenhouse Orientation

The most important and complicated decision that what should be the orientation of greenhouse. The greenhouse orientation should be such that: it receives maximum sunlight in winter and prevailing winds should have the minimum effect on greenhouse structure and other operations. The maximum sunlight will be received in the winter if the long side of the greenhouse is oriented from east to west as compared to north south (Figure 4). However in case of the multi-span greenhouse the gutter should be oriented east-west to avoid the shadow of structural components. The long side of the greenhouse should be so oriented that the wind exert minimum pressure on the greenhouse. It should be parallel to wind direction.

Size of Greenhouse

The size of greenhouse depends upon: production required from greenhouse, land available and the capital investment.

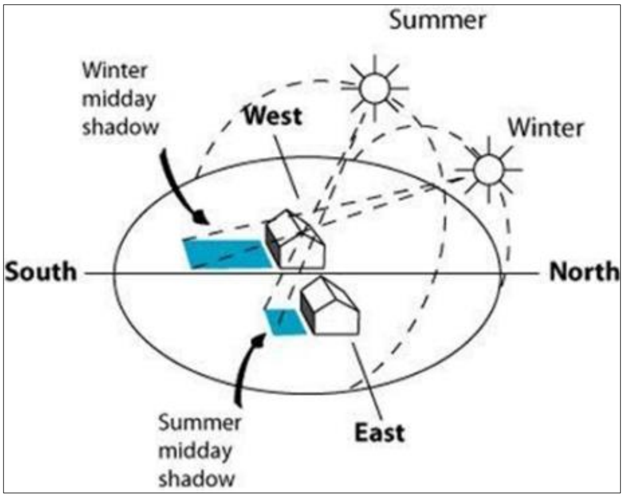


Fig 4: Greenhouse Orientation

Greenhouse Frameworks

The greenhouse frame can be constructed from different types of material. The selection of right framing material will depend upon capital investment, size of greenhouse, height of greenhouse and availability of material. The most common materials for greenhouse frameworks are bamboo, wood, mild steel (MS) pipes, galvanized pipe and aluminium. The framework should be strong enough to bear wind, snow and dead load including the load required for training of plants as well as for hanging of plant pots. It should allow the maximum amount of light to reach the plants. It should require little maintenance. Avoid the use of MS pipes as it will require frequent painting and its rusting will damage the greenhouse cover (Lilly Cao, 2020) [6].

Greenhouse frame material

Wood, Bamboo, Steel, Galvanized iron pipe, Aluminum and Reinforced concrete (RCC), Glass, Polyethylene film, PVC film, TefzelT[2], Polyvinyl chloride rigid panel, FRP rigid panel, Acrylic and polycarbonate rigid panel

Greenhouse glazing

The covering of the greenhouse is referred to as the *glazing.* The considerations in choosing a glazing material include durability, light transmission, cost, and heating and cooling costs. The solar radiation spectrum can be divided in several specific wavebands, which are defined by their range of wavelengths or energy content (e.g., radio and TV radiation, microwave radiation, visible light, etc.). The higher the wavelength, the smaller the energy content. Typically, the wavelength of light used by plants is expressed in the units of nanometer (rim). Not all components of sunlight are useful for plant growth and development. In general, ultraviolet (UV; less than 380 nm) and excessive infrared (IR; above 770 nm) or heat radiation can be harmful to plants and should be avoided. Plants use Photosynthetically Active Radiation (PAR; 400-700 nm), as their energy source for the process of photosynthesis. Therefore, greenhouse structures and especially the glazing material should have a high transmittance of PAR radiation (John W. Bartok, 2013) [7].

The common materials for greenhouse glazing (covering) are: glass, plastic films and rigid plastics (poly carbonate and acrylic).

Glass

Glass has the highest light transmission, lasts the longest and is the most expensive. However the single layer glass covering have relatively high heat transfer coefficient.

Plastic films

The use of plastic films as greenhouse glazing is very popular across the globe. The advantages offered by them such as lightweight, translucency, flexibility, toughness, hydrophobic nature and durability, make plastics films the most preferred material for cladding of greenhouses. Different types of plastic materials such as Poly Vinyl Chloride (PVC), Poly Carbonate (PC) and Low Density Polyethylene (LDPE) are commonly used for cladding of greenhouse structures. LDPE remains the most popular of all plastic material because of its features, ease in availability and economics.

Polyethylene films when exposed to outdoor environment for longer duration are prone to degradation as a combined effect of sunlight, heat and oxidation. Interaction with the Sulphur or Halogen based Crop Protection Chemicals (CPC), further accelerates this degradation process. Special chemical additives are incorporated into the polymer matrix to provide a longer lifetime in case of greenhouse films. These additives are known as U.V. Stabilizers, when used along with anti-oxidants, protect the poly film from photo as well as thermal degradation. The main types of LDPE films used for greenhouse covering are: cross laminated, clear, multi-layered (different layers having different properties). The different variant of multi-layered sheets are available such as: anti-dip, anti-dust, diffused, thermic, anti sulphur, UV blocking, thermic etc.

Different types of chemicals are blended into the material when manufacturing these films. The two main types of U.V. Stabilizer systems being used are: HALS (Hindered Amine Light Stabilizer) + UV absorber Films based on the above package are colorless / translucent in appearance, stabilizes the harmful U.V. radiation form entering in to the Greenhouse and allow maximum transmission of light. For chemical resistance against halogens or Sulphur, it is necessary to include a co-stabilizer in this system. Nickel-quencher + UV absorber Films stabilized with above package are greenish / yellowish in appearance. This shade gives a slightly hazy effect thus reducing the intensity of direct light transmission. This stabilization system gives excellent U.V. Stabilization also provides good protection against action of CPC's. This property is also sometimes termed as Anti-Sulphur.

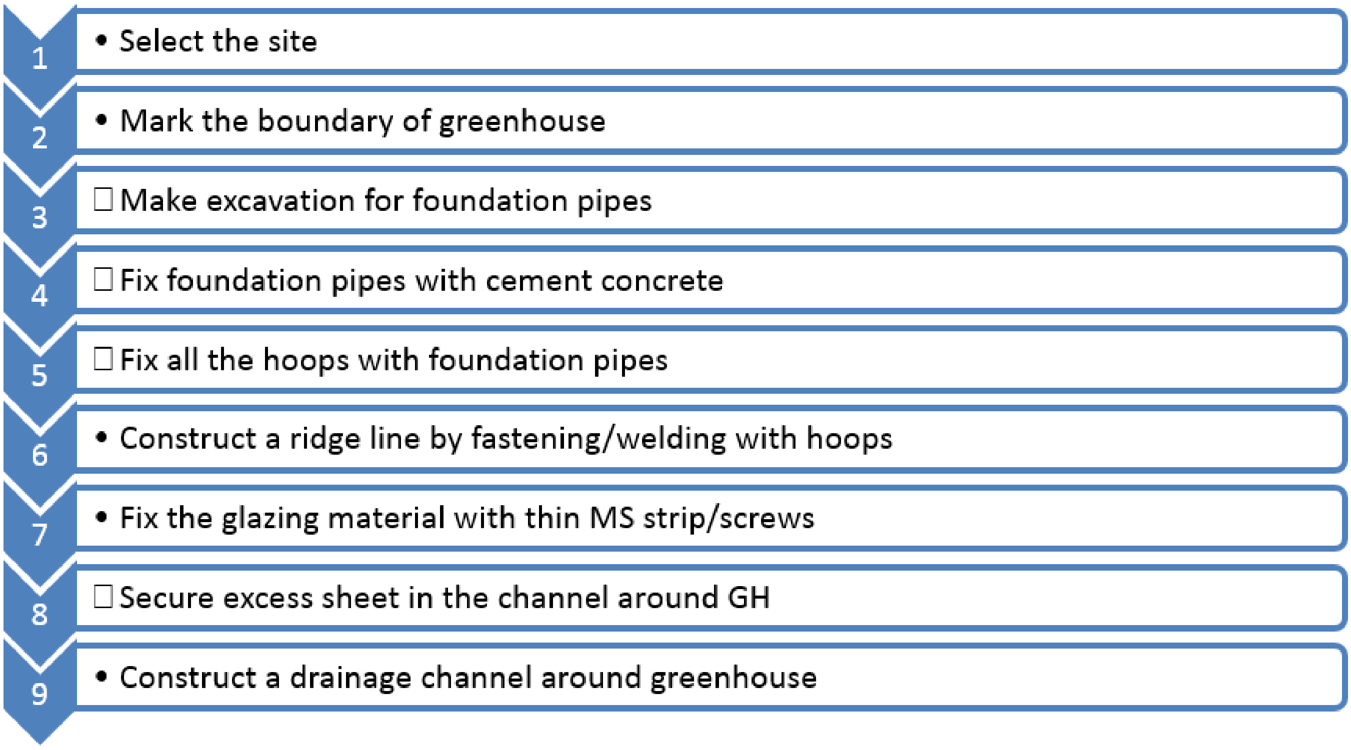
Proper light transmission filtering, out the harmful Ultra Violet (U.V.) radiation is very essential for optimized growth of the crops inside the Greenhouse. The photosynthesis activity in plants is directly proportional to the amount of light. Higher light transmission enhances the growth of plants. Therefore it is crucial to select the right combination of polymer and specialty additives, to get maximum light transmission. This is more significant for greenhouses located in colder climates where availability of daylight is limited. The ultra violet radiation is harmful for the plants growth. As well as when the protective polyethylene films are exposed to outdoors environment for longer duration are prone to, degradation as a combined effect of sunlight, heat and oxidation. Interaction with the Sulphur or halogen based crop protection chemicals (cpc), further accelerates this degradation process.

Special chemical additives are incorporated into the polymer matrix to provide a longer lifetime in case of greenhouse films. These additives are known as U.V. stabilizers, when used along with anti-oxidants, protect the film from photo as well as thermal degradation. At the same time helps in proper and maximum light transmission. The selection of film will depend upon the type plants grown inside the greenhouse and properties of glazing cover required. The film thickness is specified in microns or weight density, 200 microns thick or 120-150 GSM (grams per square meter, weight density) sheets are uses for greenhouse covering.

Rigid plastics

The rigid plastics (e.g., polycarbonate and acrylic) are less expensive than glass and last seven to 20 years. They are usually manufactured as twin-walled sheets. The air space between the two walls acts as an insulator. Light transmission through rigid plastics is very good, although it usually decreases over time as the plastics age and turn yellow due to the amount of UV radiation contained in sunlight. The large sheets are much lighter than glass and require fewer support bars to attach them to the greenhouse frame. However, these rigid panels are not so easy to install on curved roofs.

Procedure for construction



The greenhouse glazing should properly secure with greenhouse for its long-life. The properly constructed greenhouse with quality construction material will last many years (Montero *et al*., 2009) [8].

a. Dead load: Weight of all permanent construction, cladding, heating and cooling equipment, water pipes and all fixed service equipments to the frame.

b. Live load: Weights super imposed by use (include hanging baskets, shelves and persons working on roof). The green house has to be designed for a maximum of 15 kg per square meter live load. Each member of roof should be capable of supporting 45 kg of concentrated load when applied at its centre.

c. Wind load: It depends on wind action and creates upward thrust. ANSI code a 25 year of mean recurrence interval is taken. It depends upon the height of the building and location of the structure like urban, rural, open area etc.

Calculation of wind load

Effective pressure of wind (q) = $2.37 (v^2/10^5)$

where,
q = wind pressure (pa)
v = wind velocity (m/s).
Load factor (W) = $q*q_p$
q_p= external pressure acting at the level area

Table 1: Minimum values of GH design loads

Load	Minimum load (kg/cm^2)
1. Dead Load	
i. Pipe frames	10
ii. Cladding materials	25
iii. Crops (Tomato, Cucumber, Capsicum etc.)	20 – 25
2.Live Load	15 -25
3.Snow load	75
4.Wind load	Site Specific

Site layout

Facilities master plan

A master plan provides a framework for orderly construction of the buildings and should be based on a sound business plan. The plan starts with a survey of any existing facilities, evaluates the benefits and constraints of the site and establishes where new facilities should be built. A good arrangement is to plan a core area which contains the propagation and production greenhouses, head house, storage and parking. Outdoor production areas should be located nearby for efficient plant movement and shipping. Expansion space should be planned for all areas. It is best to do the planning on paper so that several alternatives can be evaluated.

Parking and Access

Good, all weather vehicular access to the buildings and growing areas should be provided. Parking for employees and customers, convenient to the core area is desirable. An adequate number of parking spaces for retail sales may be needed to meet the zoning code. A paved surface is usually required. Other areas and driveways can be unpaved. Surface can be bank-run gravel, pea stone, crushed stone or trap rock. Driveways and parking areas should slope to provide drainage. Swales or underground piping is necessary to carry the water away from the area. Swales should be grassed and slope at least ¼"/ft.

Storage

An area for storage of materials including soil mix, containers, chemicals and equipment is needed. Indoor storage for some items is desirable for easy access and protection from weather. This can be in a head house or separate building. An outdoor area is usually provided for growing mix. Space for an equipment storage shed with a shop for maintenance should be planned. A clear span pole building is a low-cost alternative.

Outdoor Production Areas

Prime space should be allocated to plant production including growing beds, shade houses and overwintering structures. Good light, drainage and proximity to water are needed. Production areas should be laid out in rectangular blocks of 1000 to 2000sq ft. Within the blocks, 6' to 8' wide beds are placed adjacent to 2' wide walkways. Generally an arrangement with shorter length walkways across the block is preferred over ones with walkways that run the length of the block. Roadways are placed between blocks to transport and maintain plants. These should be 15' to 20' wide to allow movement of trucks or tractors. Gravel or stone on the surface requires a minimum of maintenance.

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