



Greenhouse Structures

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Glass Greenhouses

- Glass was the only choice until the 1950s
- Advantages
 - Greater light intensity over plastic panels and film plastic
 - More air exchanges with glass
 - Lower relative humidity
 - Less disease
 - Greater evapotranspiration



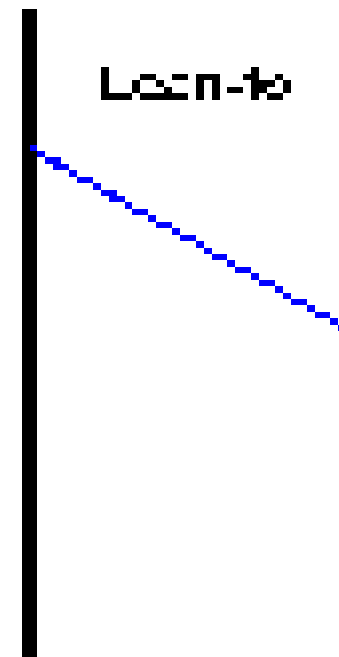
Glass Greenhouses

- Disadvantages
 - More “leaks” – greater heat input
 - Higher initial cost compared to plastic
 - Initial cost vs. long-term
 - Maintenance
 - Plastics require recovering



Glass Greenhouses

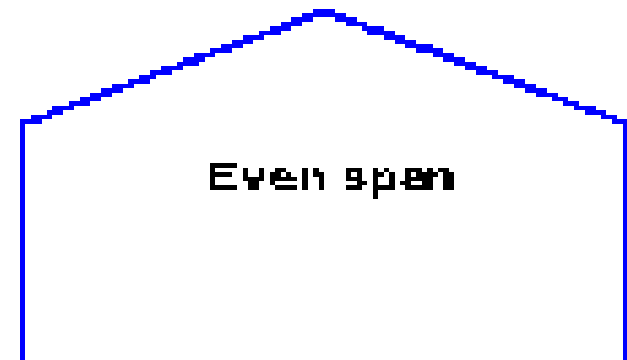
- Lean-to
 - Placed against an existing wall
 - Typically facing south
 - Common for institutional or hobby greenhouses





Glass Greenhouses

- Even-span
 - Two slopes of equal pitch and width
 - Most common configuration





Glass Greenhouses

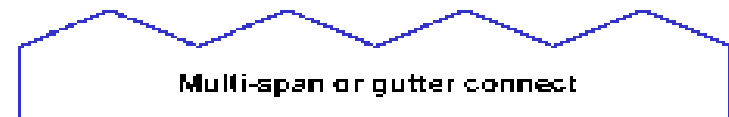
- Uneven-span
 - Roofs of unequal width and pitch
 - Adaptable to slopes
 - Good for high latitude sites





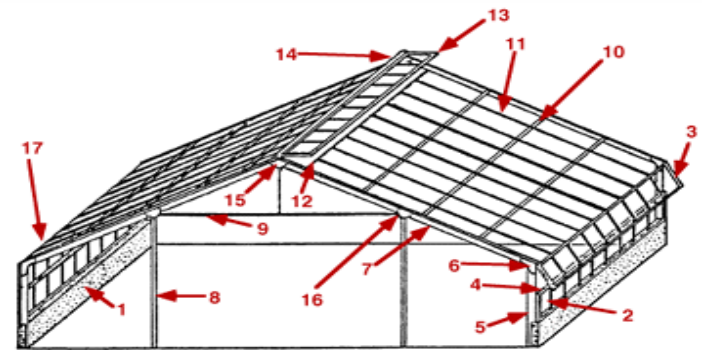
Glass Greenhouses

- Ridge and Furrow
 - Multiple A-frame spans connected along the eaves
 - Gutters placed at junction of eaves
 - Also termed gutter connect

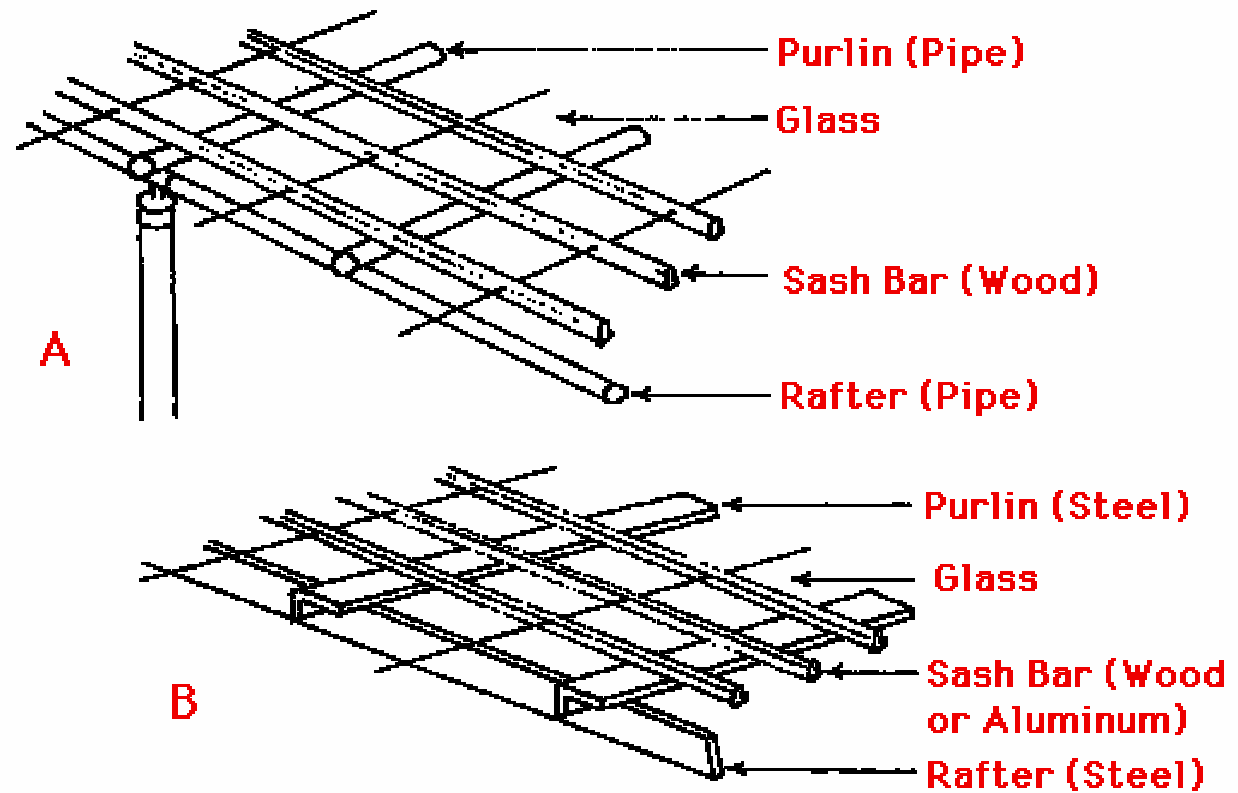


Glass Greenhouses

- Frame types
 - Wood frames
 - < 20 ft. wide
 - Pipe Frames
 - Up to 40 ft. wide
 - Side posts, columns, cross ties, and purlins from pipe



Pipe Frame Greenhouses





Glass Greenhouses

- Truss frames
 - Flat steel, tubular steel, or angle iron used to form truss
 - Most glass houses use truss frames

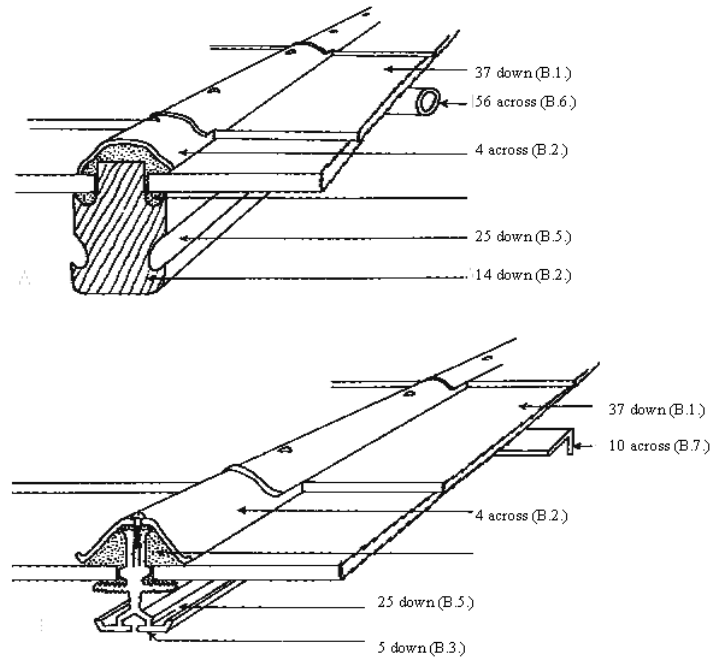




Glass Greenhouses

- Glass attachment
 - Placed upon sash bars with putty
 - Most sash bars are aluminum
 - Stronger = less superstructure per unit of glass
 - Reflective = more light than painted wood
 - Less maintenance than wood

Sash Bars





Glass Greenhouses

- Glass types
 - 16-inch up to 39-inch pane widths
 - Wider panes = more light
 - Mainly double strength
 - Float glass is mainly used in U.S.
 - 88% light transmission
 - Low iron glass
 - 90-92% light transmission
 - More expensive



Glass Greenhouses





Glass Greenhouses

- Tempered glass allows wider panes
 - Up to 6 by 13 feet
 - Bent to a curve
 - Fewer seals between eaves and ridges
 - Can be bent to a curve



Glass Greenhouses





Tempered Glass





Glass Greenhouses

- Roof styles
 - Low profile roof
 - Venlo
 - Single panes from eaves to ridge
 - Smaller pitch angle
 - Less roof area
 - Less heating cost

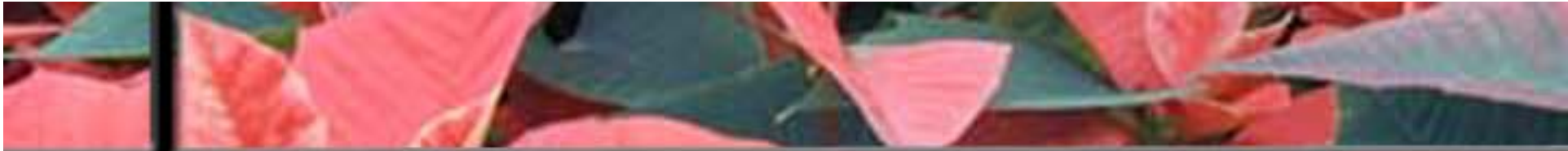




Glass Greenhouses

- Roof styles
 - High profile
 - Large pitch angle
 - 6 x 12
 - Large roof area
 - Greater heating costs





Hail Damage



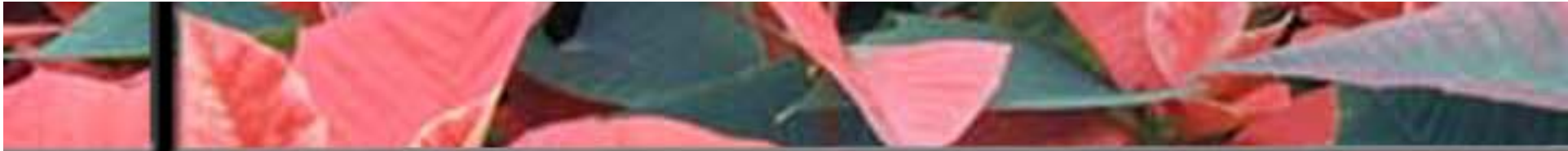


Hail Damage



Snow Damage





Film Plastic Greenhouses





Film Plastic Greenhouses

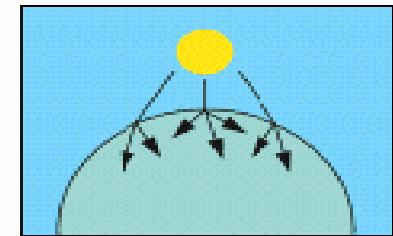
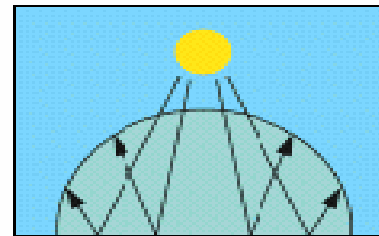
Polyethylene

- Major film used in U.S.
- 6-mil exterior
 - 4-mil interior
 - Double layer for insulation
- UV inhibitors to increase life span
 - 3-5 year life
 - Anti-fog materials to prevent condensation
 - IR blockers = less heat loss



Film Plastic Greenhouses

- IR blockers to prevent heat loss
 - Short wave energy into greenhouse
 - Surfaces radiate IR radiation
 - Films block re-radiation





Film Plastic Greenhouses

Polyester

- Mylar
- Too expensive for glazing, but is used for shade cloth materials
- Retractable roof material





Film Plastic Greenhouses

Frame Types

- A-frame not the best (hard to cover)





Film Plastic Greenhouses

Frame Types

- Quonset
 - Bent bows using steel pipe or square steel tubing
 - 20-30 ft. width
 - Ground to ground





Film Plastic Greenhouses

Frame Types

- Gutter-connected
- Sidewalls of 8-14 feet
- Can be roll-up
- Usually rigid plastic
- Quonset-arch
- Gutters
 - 6-inch/100-ft slope





Film Plastic Greenhouses

Frame Types

- Gutter-connected venting





Film Plastic Greenhouses

Frame Types

- Saw tooth venting

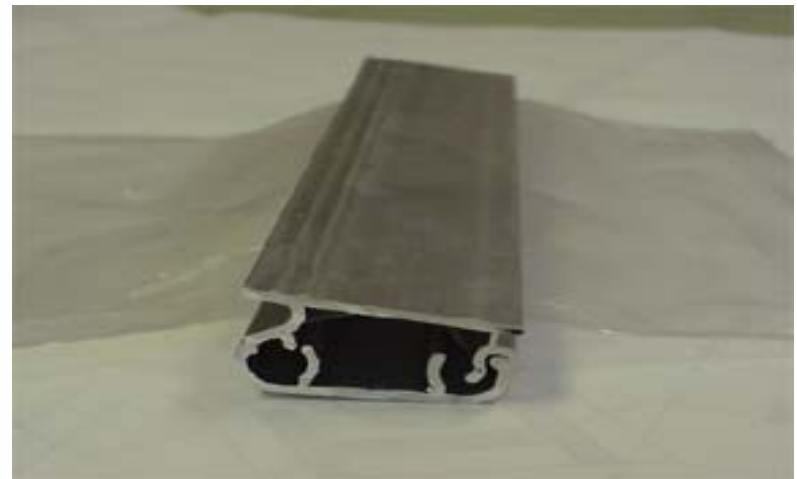




Film Plastic Greenhouses

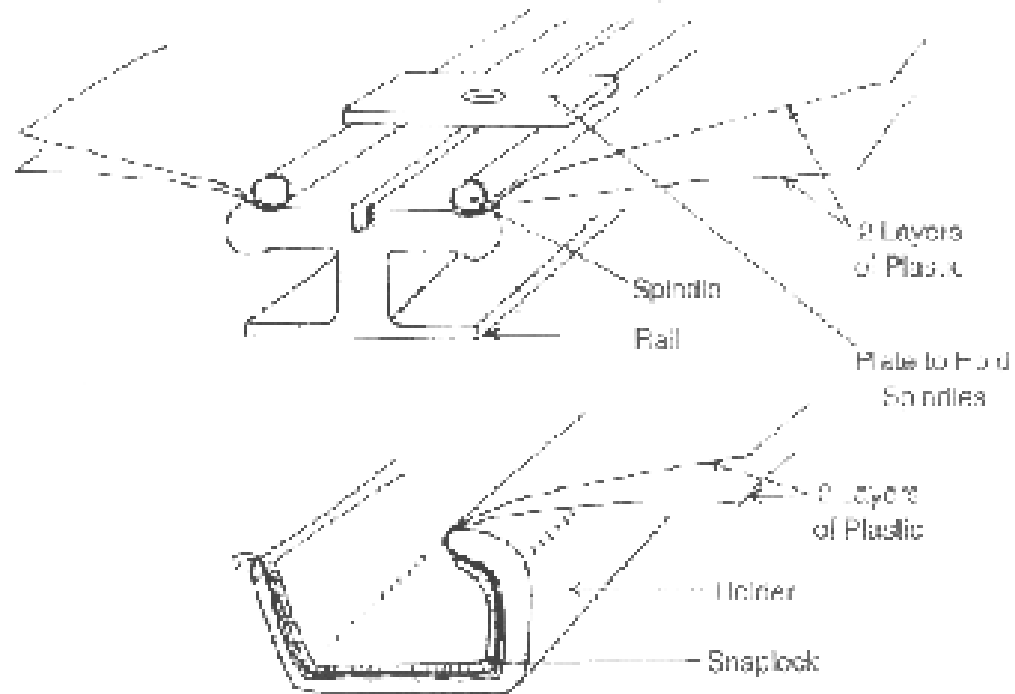
Double-layer Covering

- Two layers with air pocket in between
- Attached with clamping channel or batten strips



Polylock

Plastic Film Attachment Systems





Film Plastic Greenhouses



Reinforced
polyethylene



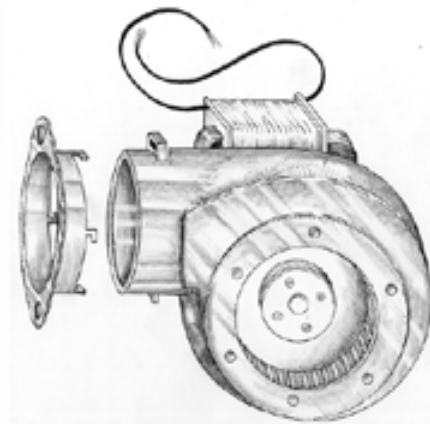


Film Plastic Greenhouses

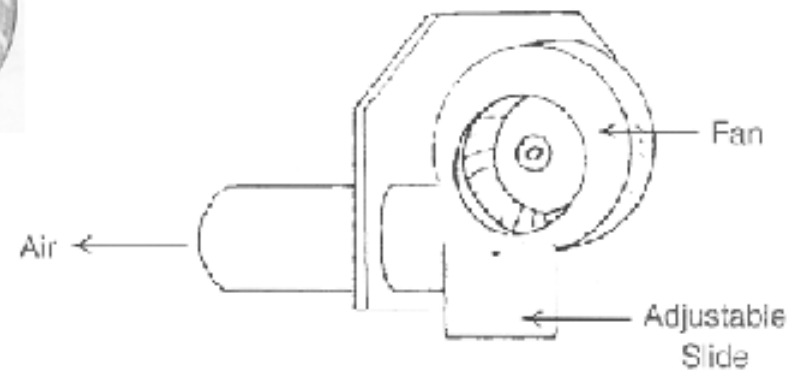
Double-layer Covering

- Plastic expands and contracts with temperature changes
 - Leave 2-3 inches or more when warm
 - Pull plastic tight when cold
- Air space (inflated)
 - 4-inches
 - Not too much – Not too little

Inflation Fan



Squirrel Cage Fan for Film Inflation





Rigid-Plastic Greenhouses

Fiberglass Reinforced Plastic (FRP)

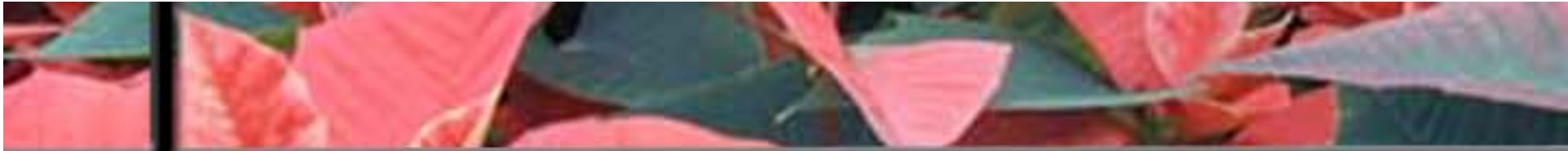
- Less popular in the past
- Flexible and can be bent over a Quonset frame
- More resistant to glass to breakage
- More light diffusion than glass



Rigid-Plastic Greenhouses

Fiberglass Reinforced Plastic (FRP)

- Surface easily abraded
 - Results in a pitted surface
 - Frayed fibers “bloom”
 - Gather dirt and debris
- Transmits 88% PAR
- Light – less structure



Rigid-Plastic Greenhouses

Fiberglass Reinforced Plastic (FRP)





Rigid-Plastic Greenhouses

Fiberglass Reinforced Plastic (FRP)





Rigid-Plastic Greenhouses

Fiberglass Reinforced Plastic (FRP)

- Bows / trusses / rafters placed 8 to 10 feet apart
- Distance between purlins is dependent on:
 - Weight of FRP used
 - Live load
- FRP is very flammable



Rigid-Plastic Greenhouses

Polycarbonate

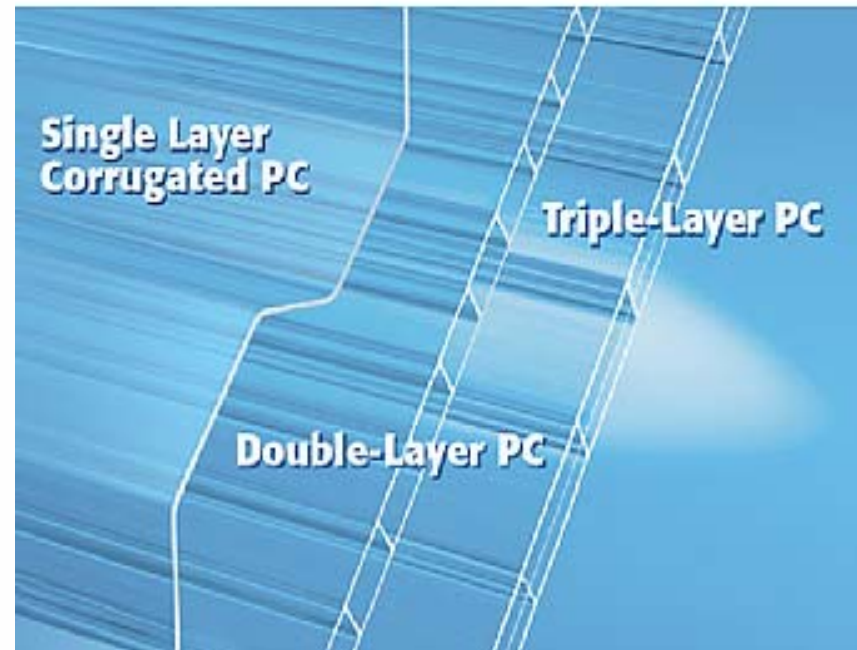
- Considered relatively new
- 10-year life span guarantee
- Widely used to glaze end walls and gables of Quonset houses
- Easily retrofitted to glass houses
- High impact resistance
- UV protectant added to most products



Rigid-Plastic Greenhouses

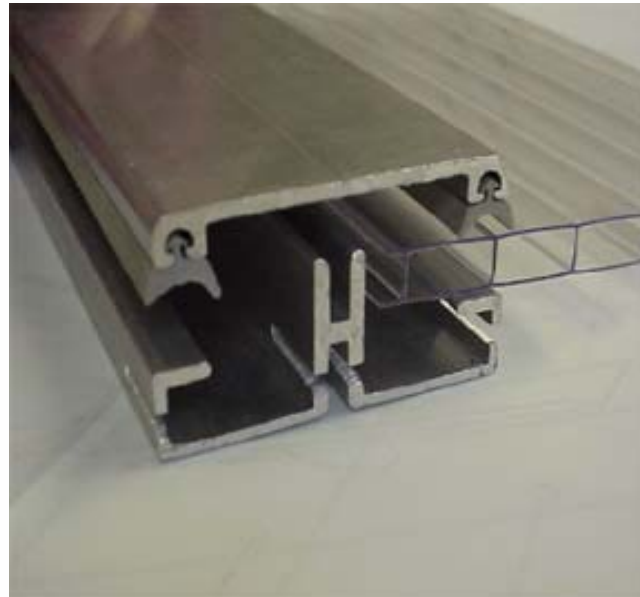
Polycarbonate

- Available as:
 - Corrugated
 - Double wall
 - Triple wall
- PAR light transmission about 79%
- Not considered flammable

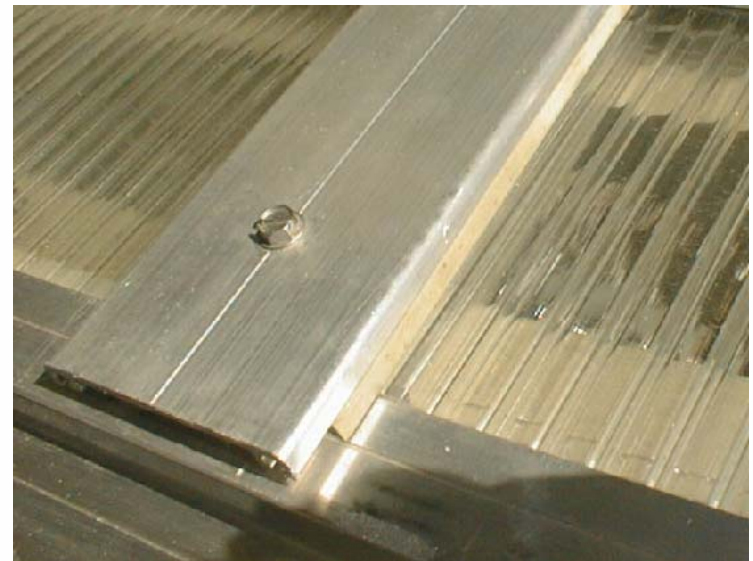




Rigid-Plastic Greenhouses



Extruded aluminum
locks and seals





Rigid-Plastic Greenhouses

Acrylic

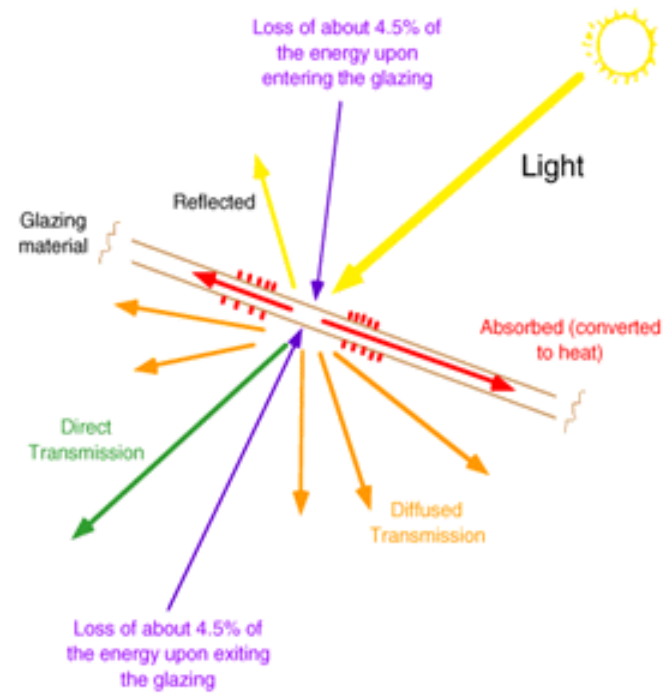
- Good PAR transmission – 83%
- Very flammable
- Guaranteed for 10 years
- More resistant to breakage than glass, but less than polycarbonate
- Attachment similar to polycarbonate



Orienting a Greenhouse

- Want to maximize light (and uniformity of light)
 - Percent light entering a greenhouse depends on “angle of incidence”
 - Angle that a light ray striking a surface makes with a line perpendicular to the surface
 - An angle of incidence= 0° allows the most light to enter the surface
 - Reflective loss increases as AOI increases (up to 90°)

Reflection



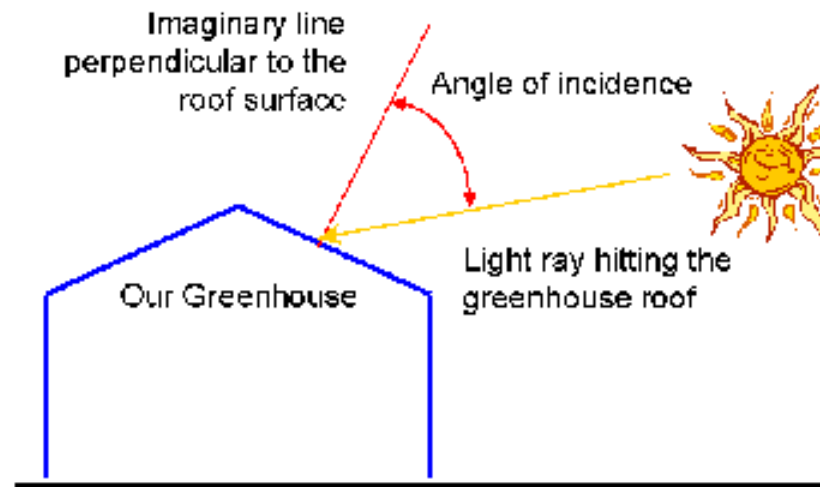


Orienting a Greenhouse

- Above 40° latitude:
 - Run ridges of single-span houses E-W to maximize light intensity
 - Run ridges of multi-span houses N-S for light distribution
 - Must accept lower winter light transmission to avoid shadow pockets
 - N-S ridge and gutter shadows “move” but E-W shadows do not

Angle of Incidence

Angle of Incidence during winter at a high latitude



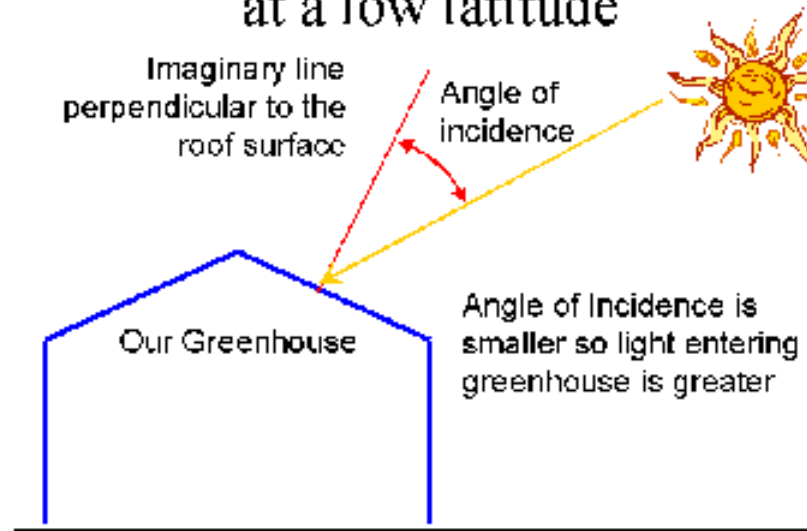


Orienting a Greenhouse

- Below 40° latitude:
 - Run ridges of all houses N-S
 - Better light distribution (moving shadows) is more important than light transmission optimization
 - Remember: **WINTER** light is the factor

Angle of Incidence

Angle of Incidence during winter at a low latitude





Greenhouse Floor Plans

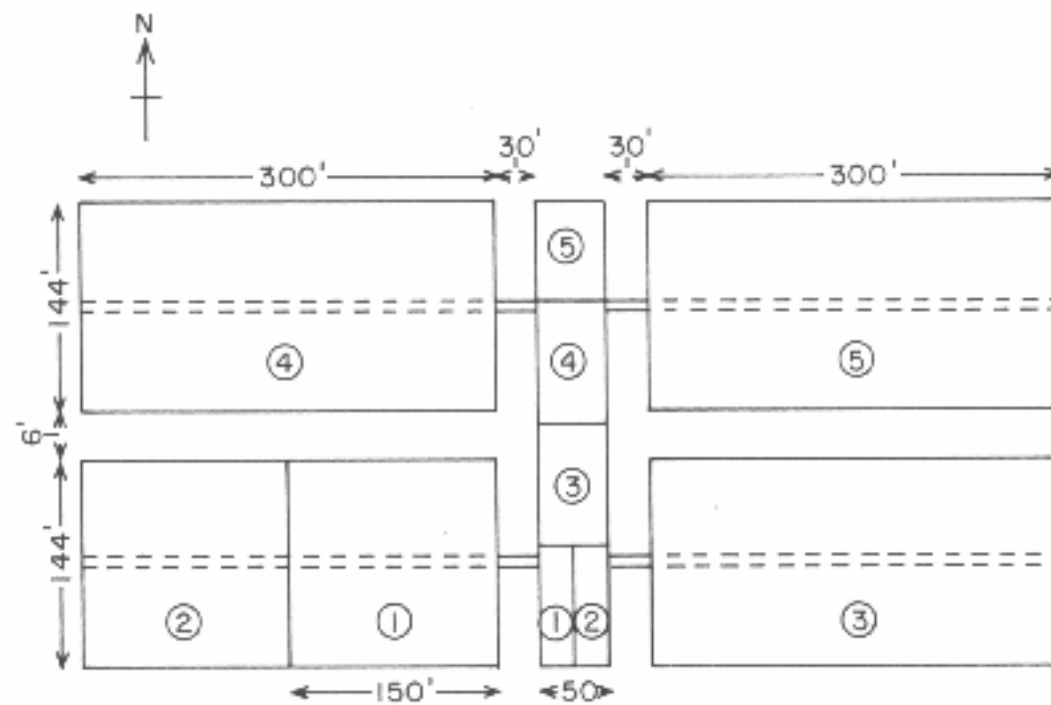
- Plan for “ultimate size”
- Plan for materials and product movement
 - Height of carts
 - Width for passing carts
 - Paved aisles / monorails



Carts



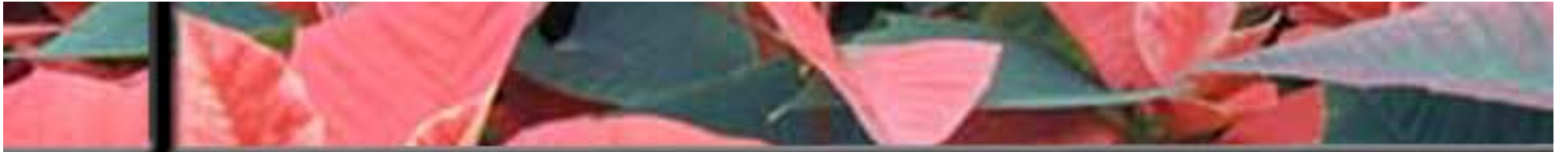
Layout





Monorails



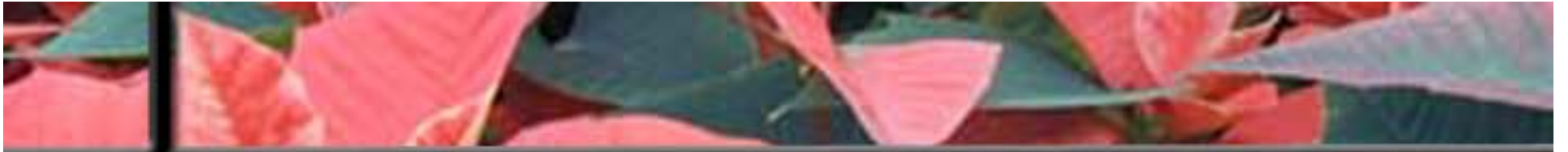


Conveyer



Conveyers





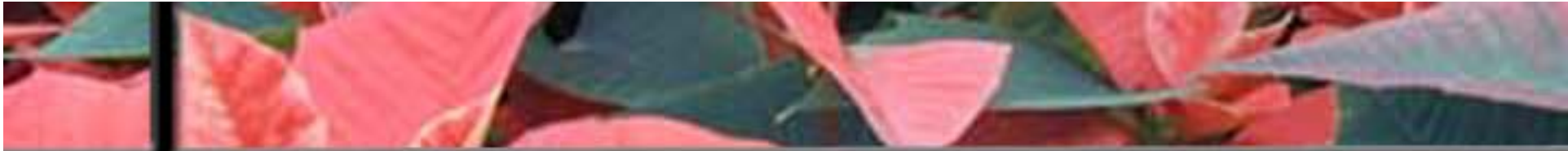
Conveyer





Basket Lines





Moving Tables





Cut Flower Beds

Height dependent

- Tall crops
 - Typically grown on or in the ground
 - Roses, carnation, tomatoes, and peppers





Cut Flower Beds

Height dependent

- Medium height crops
- May be grown in raised benches
- Consider harvest techniques
- Chrysanthemums, snapdragons, and lilies





Cut Flower Beds

Height dependent

- Some crops require trellising
 - Tall crops require wire supports to prevent crooked stems
 - Select material allowing easy handling and convenient access
 - Roses and carnations





Cut Flower Beds

Height dependent

- Trellises require bracing to support weight
 - Greenhouse structure not the best choice
 - Adds to the dead load of the structure





Cut Flower Beds

Height dependent

- Climbing or vine crops use vertical netting or frames
 - Sweet peas
 - Tomatoes
 - *Stephanotis*





Cut Flower Beds

Width dependent

- Consider the length of a worker's reach
- Accessible from both sides - 42 in.
- Accessible from one side - 18-20 in.





Construction - Cut Flower Beds

Growing directly in the ground

Advantages

- Cheapest construction
- Long term installation
- Easily modified for organic production
- Easily modified for other crops

Disadvantages

- Requires soil amendment
- Root spread not contained
- Exposure to potential pathogens in soil
- Drainage tiles may be required
- May result in non-point source pollution

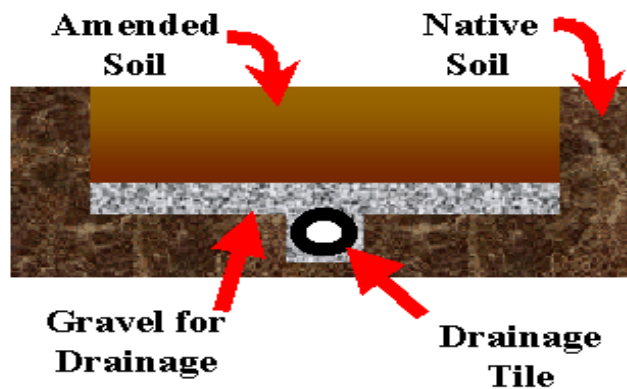


Construction - Cut Flower Beds

- Isolate from native soil
 - Prevent root spread
 - Prevent pathogen exposure
 - Prevent co-mingling of roots

Construction - Cut Flower Beds

Typical ground bed



- Amended soil
- Native soil
- Gravel drainage
- Drainage tile

Construction - Cut Flower Beds

Perched water table

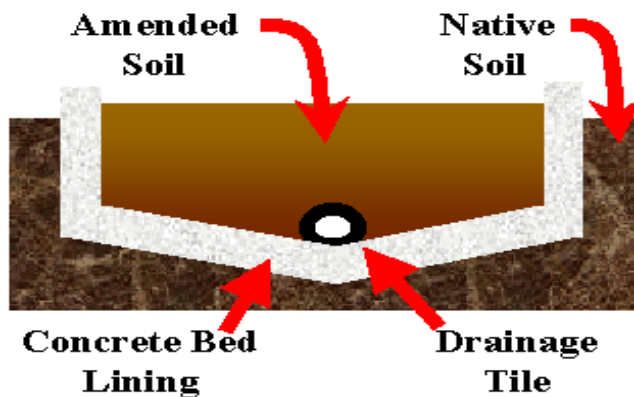
- Amended soil
- Perched water table
- Interface must be at saturation in order for profile to drain



**Requires saturation before
leaching to next layer**

Construction - Cut Flower Beds

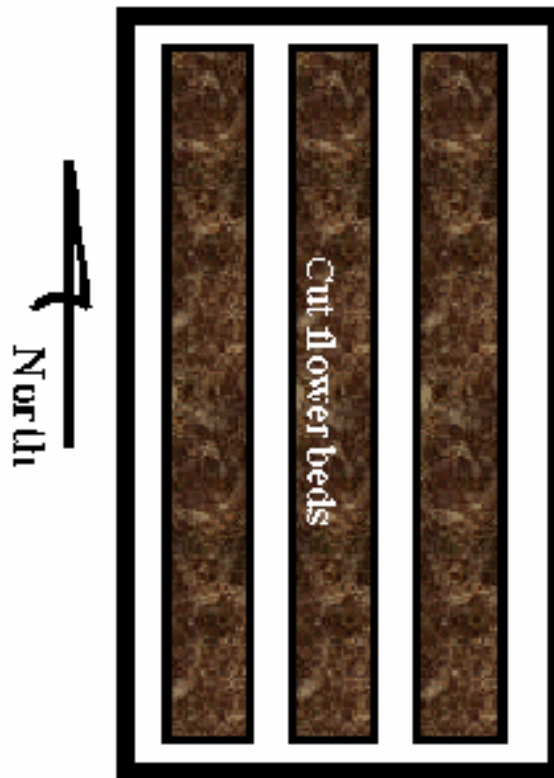
Concrete ground bed



- Soil-borne disease
- Concrete prevents root egress
- Drain tile to remove excess water
- Pasteurization
- Raised edge to prevent debris

Construction - Cut Flower Beds

Cut flower beds



- Run beds the length of the greenhouse
- Narrow walks (18") allows for 67% space use
- Orient north to south to maximize light penetration



Benches, Beds and Floors

Function Defines Structure

- Potted Crops and Bedding Plants
 - Raised benches
 - Ebb and Flood (flow) tables
 - Trough systems
 - Flood floor systems



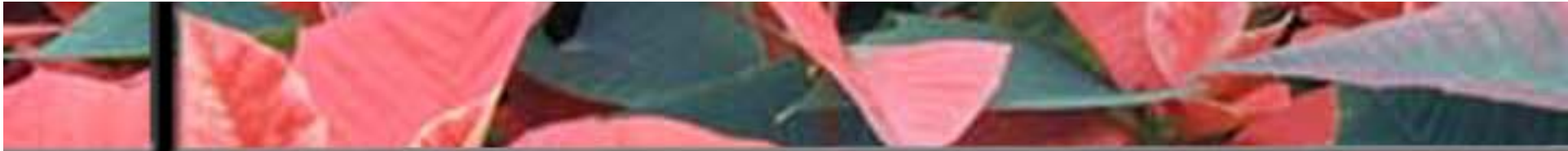
Benches - Potted Crops

- Raised benches
- Height should be adapted to worker height – 32 to 36 inches high
 - Width
 - One side - do not exceed 3 feet
 - Two sides - do not exceed 6 feet
 - Wider widths reduce labor efficiency



Benches - Potted Crops

- Air circulation
 - Bench top material must allow for air circulation
 - Bench top material must allow for water drainage
 - No sides
 - Reduces labor efficiency forcing a worker to lift a pot or tray over an edge
 - Reduces air circulation



Benches - Potted Crops

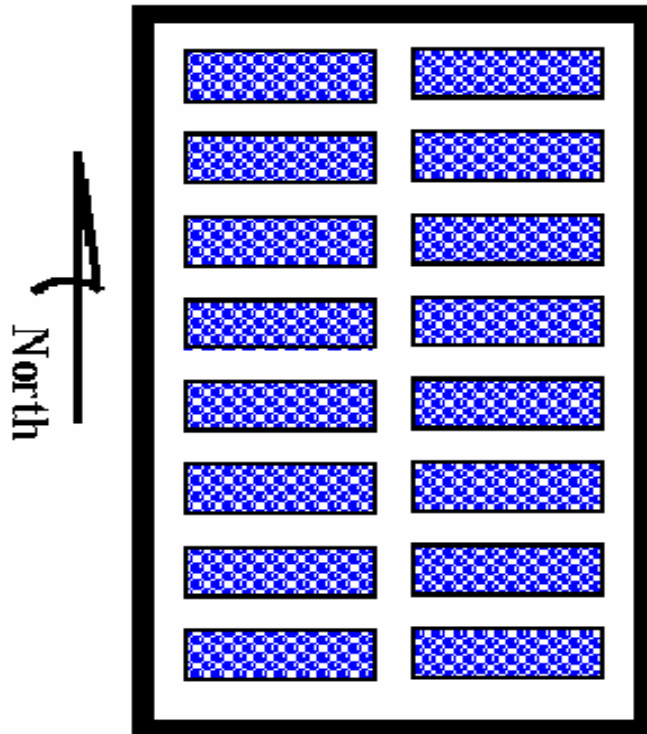




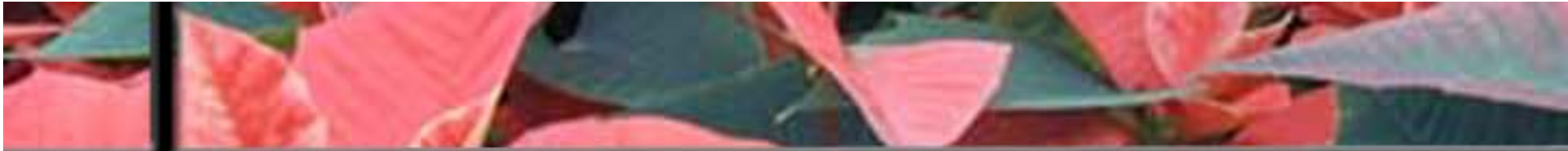
Benches - Potted Crops

- Construction Materials
 - Wire mesh or expanded steel (galvanized)
 - Redwood lath
 - Bench tops may be supported by concrete blocks, wood framing or steel framing
 - Provide support to prevent sagging

Benches - Potted Crops



- Peninsular layout
 - 80% of space use
- Benches typically run across width of greenhouse
- Aisles 18 in. wide
- Center aisle
 - 3-4 feet for carts
 - 8 foot for vehicles or larger transport systems



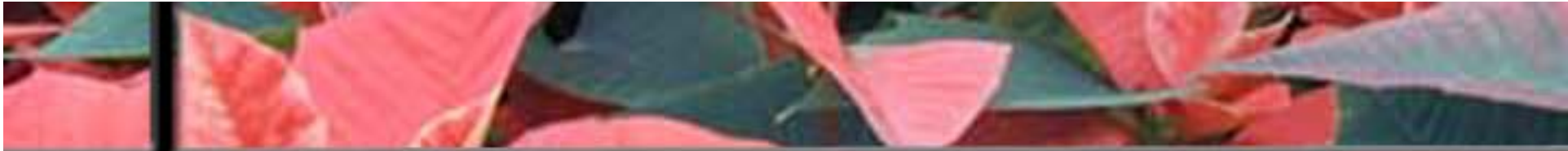
Fixed Bench Tops





Fixed Bench Tops

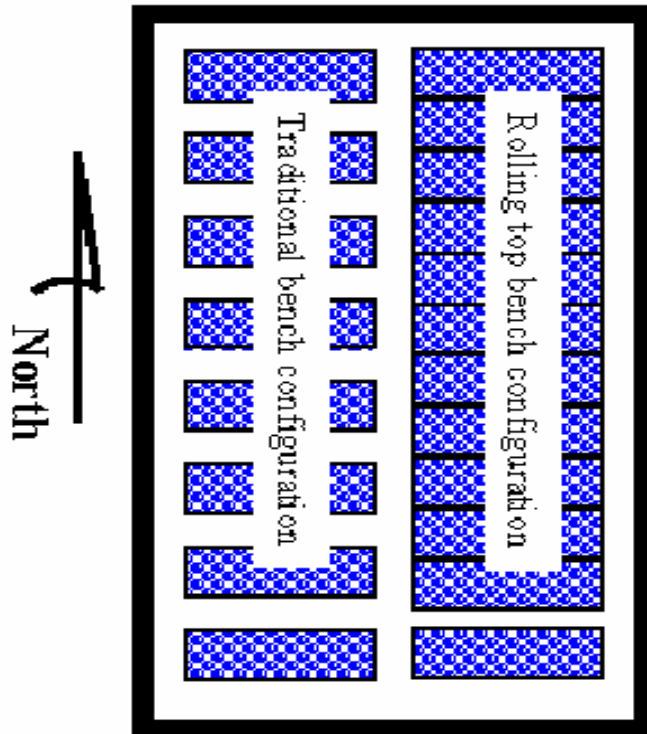




Under Bench Area Important



Benches - Potted Crops



- Moveable benches
 - 90% or more space use
 - One aisle, several benches
 - Each bench allowed to move opening a space



Rolling Top Benches



Rolling Top Benches



Rolling Top Benches





Moving Benches

- Bench moves on trolley
- Bench moves in and out of greenhouse
- Benches moved to worker for plant handling
- Adaptable to high degrees of automation
 - High initial investment
 - low labor input



Moving Benches



Moving Benches



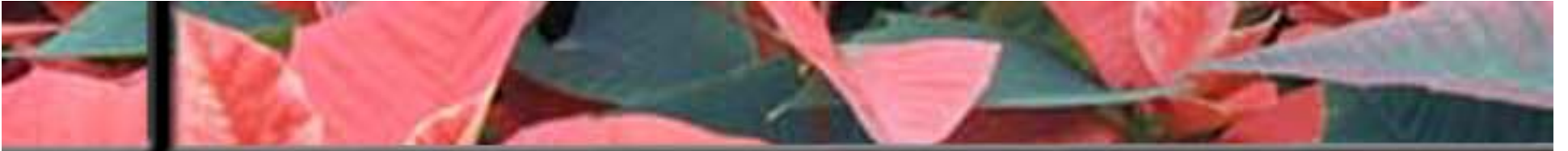


Ebb and Flood Tables and Floors

- Water tight benches allowing periodic flooding with water and fertilizer
- Trough systems
 - a modification of water tight benches where narrow troughs are used to hold plants for periodic flooding with water and fertilizer, allowing air circulation

Ebb and Flood Tables





Ebb and Flood Tables





Ebb and Flood Tables and Floors

- Flood floor systems
 - Floors designed for periodic flooding with water and fertilizer
 - Closed system preventing waste and point source pollution
 - Water
 - Nutrients
 - Pesticides

Capillary Mat Tables





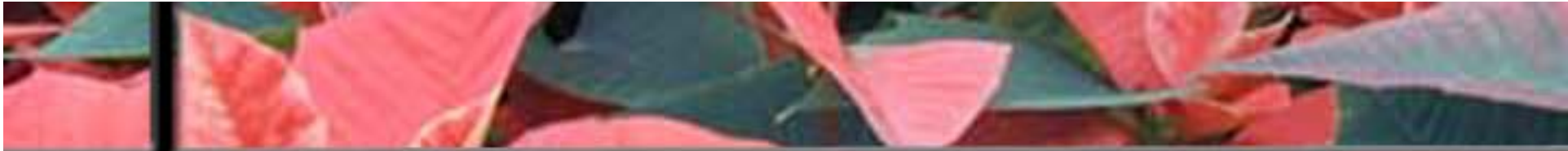
Flood Floors





Floor Production





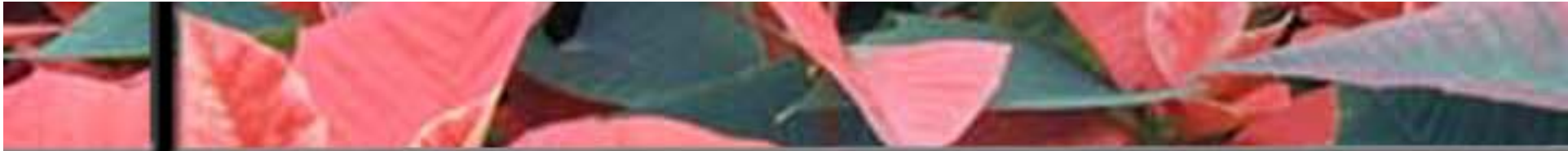
Floor Production





Hanging Basket Lines





Hanging Basket Lines

