Presentation to the
ANNUAL MEETING OF THE AMERICAN SOCIETY FOR HORTICULTURAL SCIENCES
Working Group Commercial Horticultural Extension CHEX

Colloquium:
High Tunnels-Season Extension Technology for Production of Horticultural Crops
Scottsdale, Arizona

"Engineering Principles Impacting High Tunnel Environments"

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Thursday, July 19, 2007
Engineering Principles Impacting High Tunnel Environments

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High tunnels, a special type of greenhouse, have operational goals of season extension, crop quality improvement and new crop production opportunities to reach unique markets. From an engineering viewpoint, high tunnels have many of the same design concerns as the larger more complex greenhouse, and they capitalize on the greenhouse effect as all enclosed plant growth structures. However, fewer and less automated environmental control systems are required for adequate crop production. Tunnel designs are less complex and less expensive than the large greenhouse ranges but they should be designed and constructed with fundamental assurance of structural stability, safety, efficient layout, appropriate environmental control, and effective crop management in mind.
Introduction

Tunnels are good use of Greenhouse Effect with specific goals.

Respect their capabilities, realistic expectations. They have an important place in USA food production industry.

Benefits of quality product, improved timing, greater yields, better market for the grower to make profit.

Locally grown, less pesticides, reduced transport, specialty products.

Labor intensive.

Do not compare to High Tech Greenhouse.
High Tunnels are not simply field production with a cover!
    ....even though grown in the soil

High Tunnel environmental control is
    better than open field,
    better than field with Plasticulture techniques
    not better than environmentally controlled
greenhouse because there is limited control of aerial
    and root zone of the plants

Aerial protection -- rain shelter, wind break, insect exclusion(?), limited temperature control

Rhyzosphere control - moisture/nutrients by fertigation, passive soil temperature enhancement
What is CEA and Protected Agriculture?

Controlled Environment Agriculture (CEA) also known as Protected Agriculture is defined as an integrated science and engineering-based approach to establish the most favorable environmental conditions for plant productivity while optimizing resources including water, energy, space, capital, and labor, and thereby to provide the desired plant product or biological processes under controlled conditions.
Why CEA?

(Why Tunnels?)

- Production Quality/Consistency
- Water use efficiency
- Nutrient capture & recycling
- Energy efficiency
- IPM for Biological Control
- Transportable System
- Urban/Suburban Green Space
- Functional on poor lands
- Complements field production
- Captures Imagination of Young People
- Supports Local Markets
- Transportation Energy Reduced
- Community Supported Agriculture
High Technology Commercial CEA
Agricultural Fresh Food Factory

350 ton/acre/year  500,000 lb per day  320 acres

75 kg/m²/year  220,000 kg per day

EuroFresh Farms,
Willcox, AZ
Strength of Current CEA Food Production Industry

**Greenhouse production of tomatoes** is the leading crop in high market value and the fastest growing demand in North America.

Tomato greenhouse production can gross $600,000 per acre (compared to $4300 for field vegetable crops), representing nearly $900 million per year to the USA fresh market produce industry.

Since 1998, the U.S.A. greenhouse tomato production area has been increased approximately 28% (257 to 330 ha) providing 160,000 metric tons in 2003.

Arizona has the largest greenhouse vegetable production area (130 ha, 330 A) in USA.
Glass covered structures use natural ventilation and fan & pad evaporative cooling, and heating and CO2 enrichment with natural gas for environmental control. (16 hectare; 40 acre)

It’s Greenhouse Environmental Control at the highest level!
and at the greatest investment and resource expense!
130 – 150 $/m² (12 – 14 $/ft²)

EuroFresh Farms, Willecox, AZ
High Tunnel Technology

32 $/m² ($3.00 per ft²) for materials
9.2 x 29 m (30 x 96 ft) structure
(Lamont)

47 $/m² (4.39 $/ft²) for materials and installation
of 5.2 x 11 m (17 x 36 ft) structure
(Reiss et al, 2004)
Price doubled with motorized side vents
Define High Tunnel Physical Components

Structure with glazing, without heating system or electric power, with passive ventilation for air exchange, soil fertigation system, input/output location, and (row crops)

Seasonal use
Modular
Temporary
Structure

Single-span
Steel tube (pipe) frame
Access doors (equipment)
Side-wall ventilation
Limited footings
Accessible by tractors for tillage

Height - 5 m (at center) (16 ft)
Clear span - 5.5 to 8.5 m (18 to 28 ft)
Side-wall - 1.5 to 2m (5 to 6.5 ft)

Photo source ttp://plasticulture.cas.psu.edu/
Structure

Roof shape considerations

Slope and curvature for strength & light transmission
- Avoid small radius bends
- Weak point
- Avoid small roof slope (less than 10%)
- Snow removal
- Sun angle
- Condensation dripping

Condensation ‘dripping’ at ‘leg’ row [post support row]

Photo source http://plasticulture.cas.psu.edu/
Structure

Roof Slope
20 - 30°

'Vetse Line

Radius of curvature

Wind brace for 3-D stability

Photo source [http://plasticulture.cas.psu.edu/](http://plasticulture.cas.psu.edu/)
Structure

Footings

Resistance to ‘uplift’ provided by soil 25 – 50 mm diameter pipe (1 – 2 inch) 0.4 – 0.6 m deep (18 – 24 inches) Attach pipe frame to soil pipe don’t just insert it, bolt it.
Footings – Wind Resistance

- High velocity at a surface = low pressure (airplane wing)
- 80 MPH wind = 16 lb/ft² or 220 lb/ft uplift
- Therefore each footing holds 880 lbs (at 4 ft spacing)

Photo source ttp://plasticulture.cas.psu.edu/
Structure

Hinged Equipment Door

Side-Wall Ventilation

Photo source http://plasticulture.cas.psu.edu/
Without Solar Energy there is nothing

Why do these appear differently than these?

Reflection due to angle of the sun relative to GH and angle of GH relative to the camera [or your eye]

More reflection means less sunlight entering GH

Almeria, Pennsylvania 1999
Wisely choose location
Orient the structure
E to W for Oct – May for most ‘winter’ season light
N to S for year round production; most yearly light
Solar angle more critical than type of glazing for sunlight

Almeria, Pennsylvania 1999

Without Solar Energy there is nothing
East-West Oriented Ridge

large south-facing wall and roof area

good for low sun angle winter sunlight provides most total daily light during the winter season however, distribution not uniform within greenhouse causes variable plant growth especially for tall crops, if rows aligned with east-west ridge
East – West Ridge Orientation

South facing wall & roof

Shadow October 29th

Shadow from adjacent High Tunnel

Photo source http://plasticulture.cas.psu.edu/
Glazing

PE (polyethylene) film; others?
Single layer
Single bay; narrow span; without gutters
simple
less costly
less shading

Photo source http://plasticulture.cas.psu.edu/
Glazing PE (polyethylene) film

PE film most common
Reliable, low initial cost
Low air-infiltration rates
continuous film offers energy savings
High greenhouse air humidity
Moisture condensation/dripping
avoid flattened, arch-shaped roofs
74% average PAR light transmission
(Reiss, et al, 2004)

Photo source http://plasticulture.cas.psu.edu/
Glazing PE (polyethylene) film

Factors Affecting Film Useful Life

Ultra-violet (UV) radiation
Temperature extremes and their duration
Film contact on metal greenhouse structure
Air pollutants
Chemicals for pest control

Photo source http://plasticulture.cas.psu.edu/
Enhancements include:

Ultra-violet radiation (UV) inhibitors  
3 - 4 year life
Infrared radiation (IR) absorbency  
night heat saving
Anti-drip surfaces  
less dripping from condensation
Selective radiation transmission properties  
 improve plant growth (morphology)
Environmental Control

Side-Wall Ventilation

Manual control provides poor air temperature control

Automation increases cost & need for electric power

Photo source http://plasticulture.cas.psu.edu/
Environmental Control

Daytime (cooling with side vent only)
Inside air temperature always greater than outside

Nighttime (no heater)
Inside air temperature approximately equal to outside

Thus, what are day/night air temperatures for your location during the season?

Photo source http://plasticulture.cas.psu.edu/
Environmental Control

From Both, et al

**Nighttime Air Temperature in Tunnel**

(April/May in New Jersey)

0.9°C (1.6°F) greater than outside
2.3°C (4.1°F) greater than outside w/energy curtain

Photo source http://plasticulture.cas.psu.edu/
Energy curtain was XLS10 (Ludwig Svensson, Inc) with properties of 15-20% shading, and 50% energy savings. It was mounted horizontally above the crop, and moved manually to cover or uncover the crop.

Glazing was 4-year, single-layer, no-drip, infrared-blocking 6 mil polyethylene film.
Environmental Control

From Both, et al

Nighttime Soil Temperature in Tunnel
(April/May in New Jersey)

6.7°C (12°F) greater than outside
7.2°C (13°F) greater than outside w/energy curtain

Photo source http://plasticulture.cas.psu.edu/
Environmental Control

From Both, et al

**Nighttime Air Relative humidity in Tunnel**
(April/May in New Jersey)

12% points greater than outside
15% points greater than outside w/energy curtain

Photo source http://plasticulture.cas.psu.edu/
Environmental Control

From Both, et al

Accumulated Solar Radiation (PAR) in Tunnel
(April/May in New Jersey)

24% less than outside
29% less than outside w/energy curtain*

*depends on management [time of daily open/close]

Photo source http://plasticulture.cas.psu.edu/
Cheap labor, that you can trust, is hard to find these days!
Acknowledge Plasticulture Center at Penn State for their passion and persistence in getting the message out about the next generation of modern high tunnels for use in 21\textsuperscript{st} Century (October 1999)

Pete Feretti, Mike Orzalek, Bill Lamont (October 1999)
Fertilizer Injector

Inlet Water

Chemical Solution

Outlet
Labor and Mechanization

Good Luck!

Lots of hand labor

Harvest aids - trays, carts, etc

Logistics
The University of Arizona
CEA Program
Education – Research – Outreach –
Economic Development