Presentation to the

ANNUAL MEETING OF THE AMERICAN SOCIETY FOR HORTICULUTRAL 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”

Presented by

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ASHS 2007 Colloquium Abstract

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 environment control

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


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High Technology Commercial CEA
Agricultural Fresh Food Factory
350 ton/acre/year
500,000 lb per day
320 acres
EuroFresh Farms,
Willcox, AZ
75 kg/m²/year
220,000 kg per day
CE AC CONTROLLED ENVIRONMENT AGRICULTURE CENTER

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 CO_2 enrichment with natural gas for environmental control. (16 hectare; 40 acre)

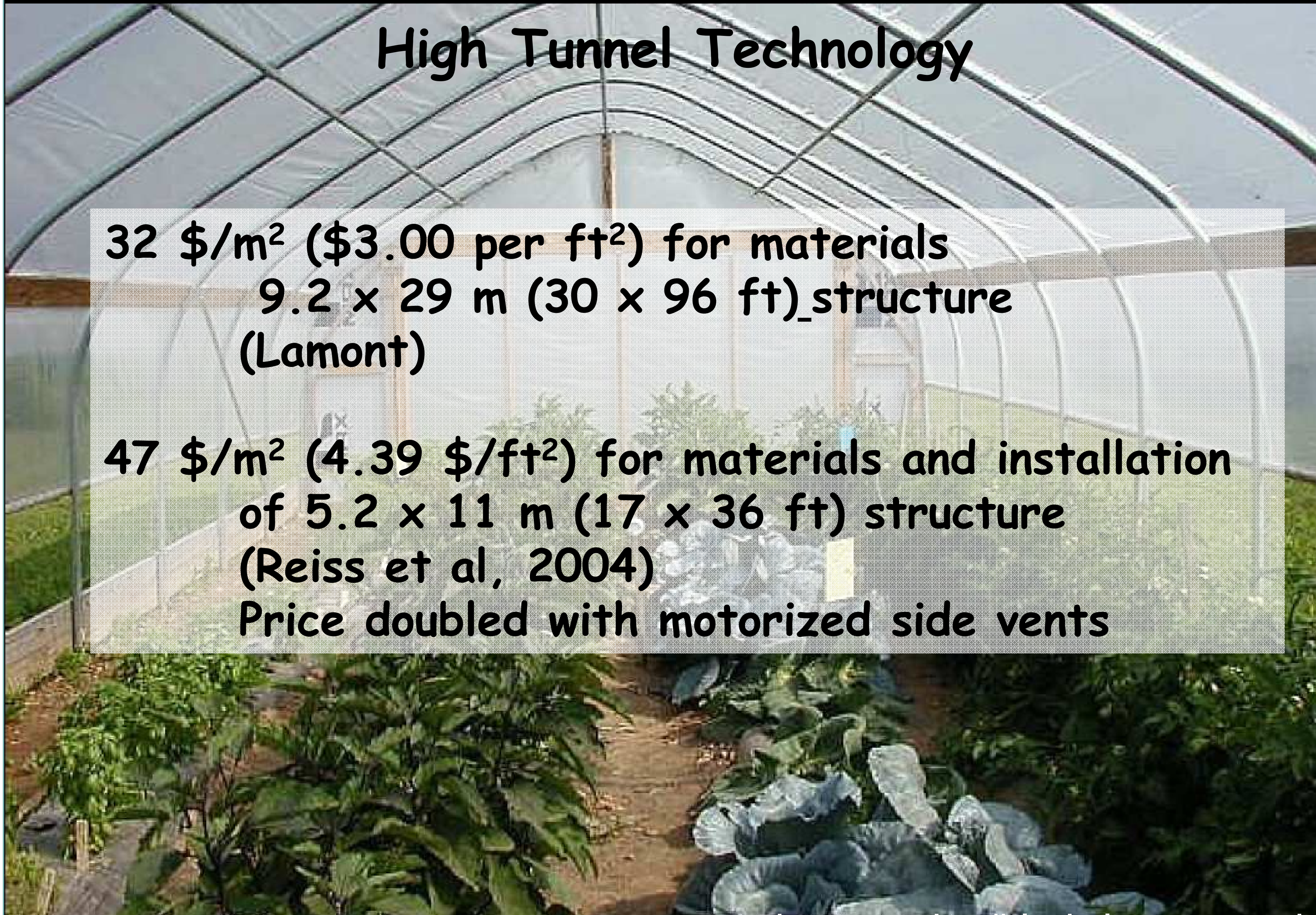
It's Greenhouse Environmental Control at the highest level!

and at the greatest investment and resource expense!

130 – 150 $\$/m^2$ (12 – 14 $\$/ft^2$)

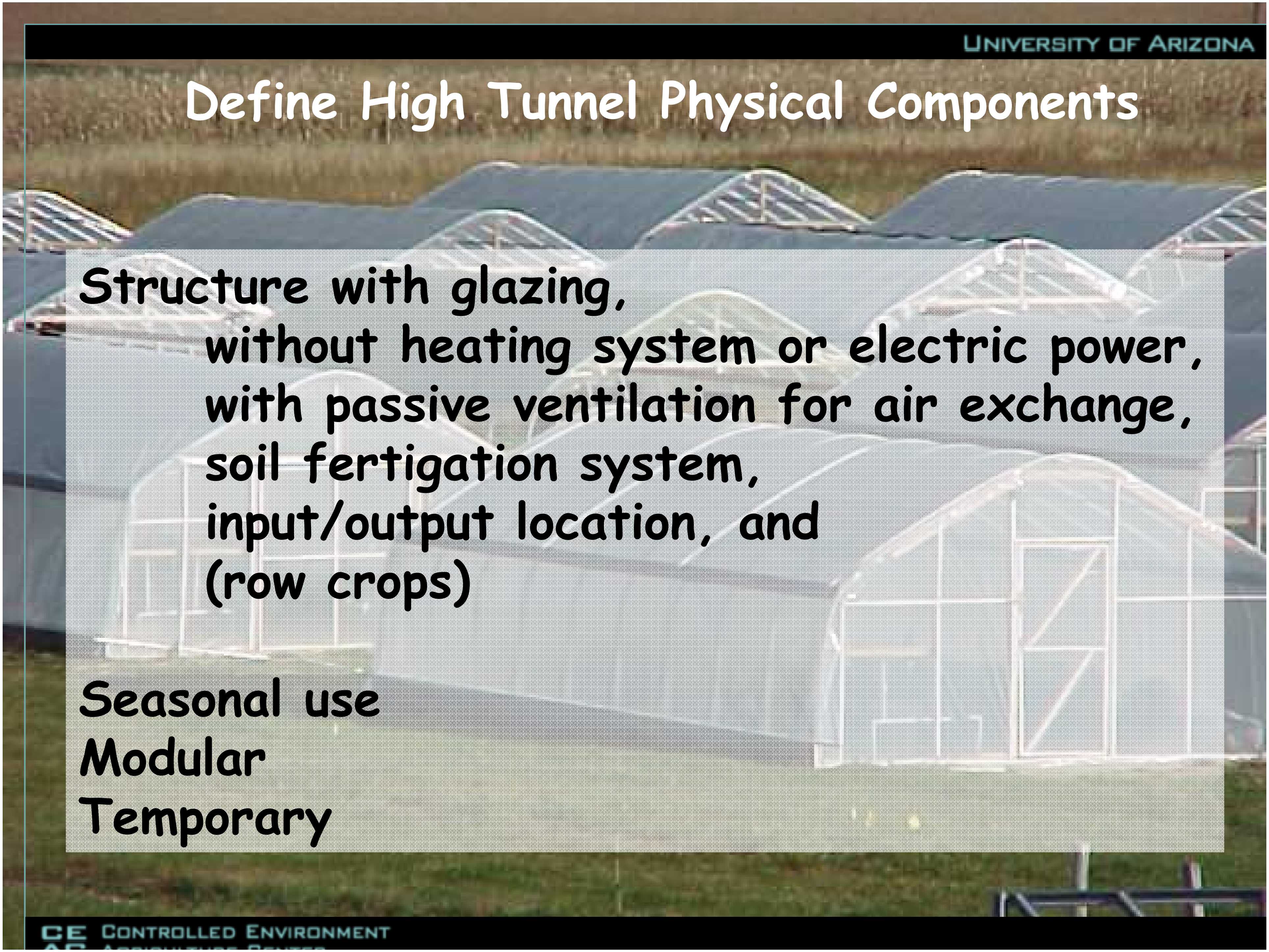
EuroFresh Farms, Willcox, AZ

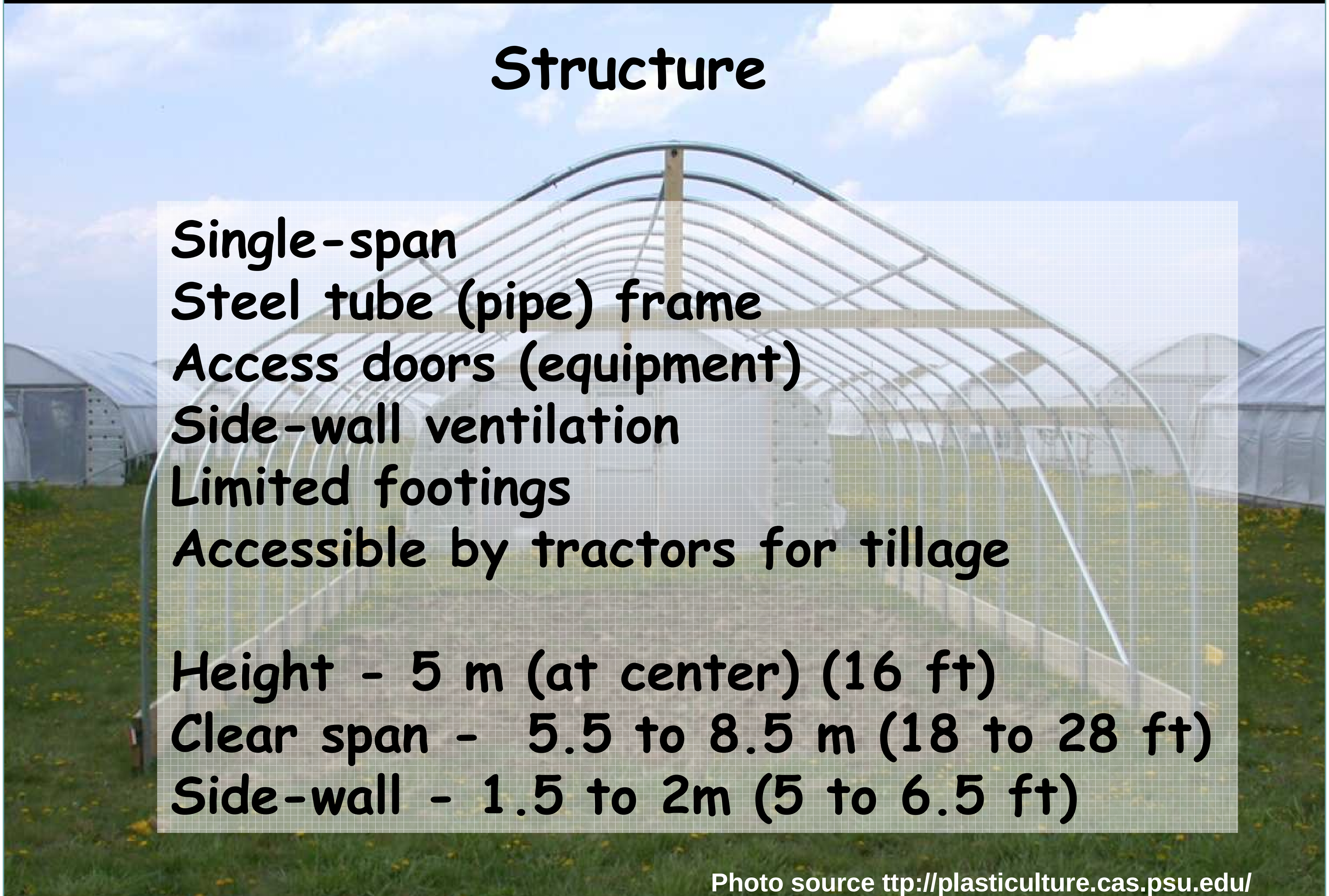
High Tunnel Technology



32 $/m^2 ($3.00 per ft^2) for materials
9.2 x 29 m (30 x 96 ft) structure
(Lamont)

47 $/m^2 (4.39 $/ft^2) 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


University of Arizona
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
CE Controlled Environment



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

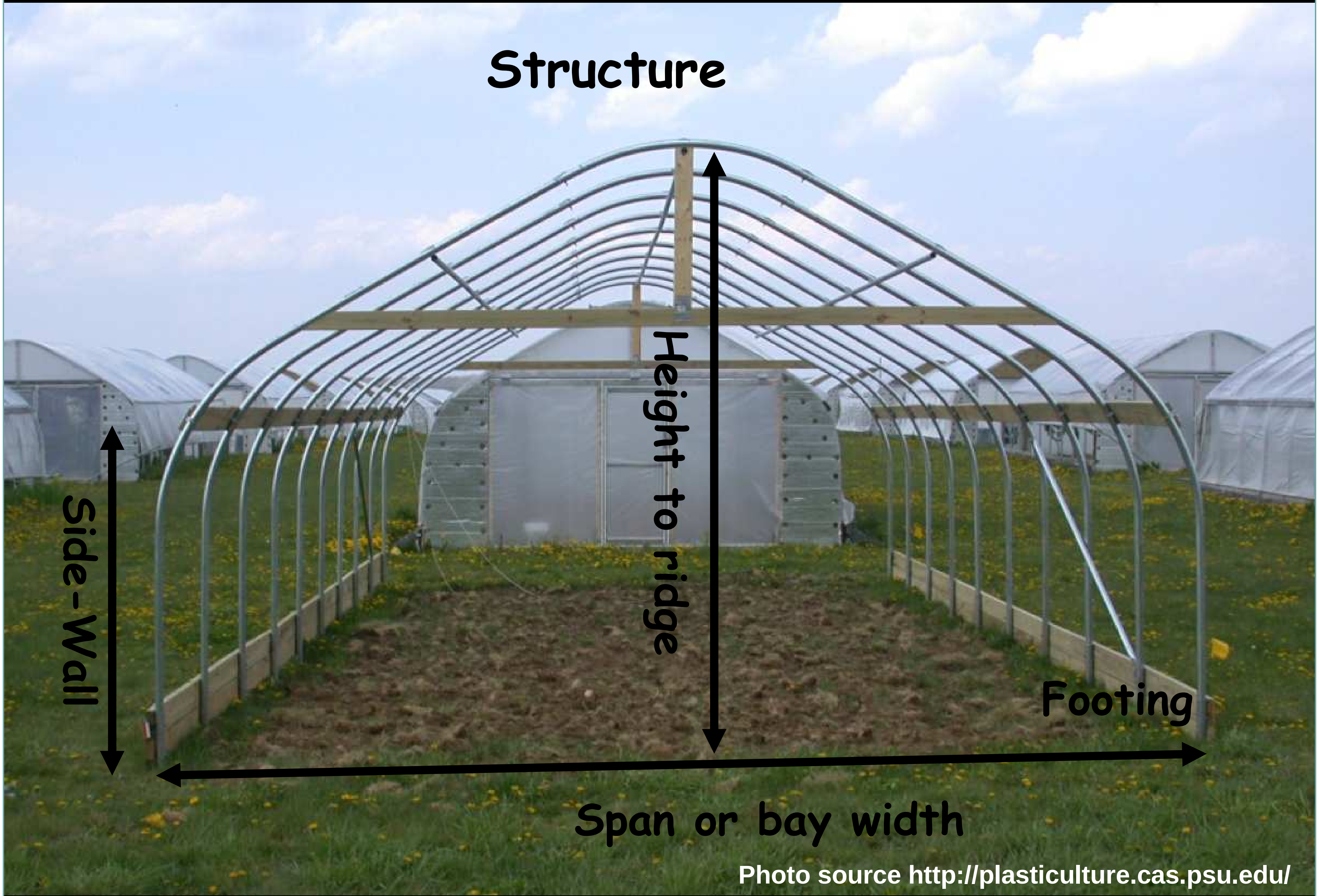
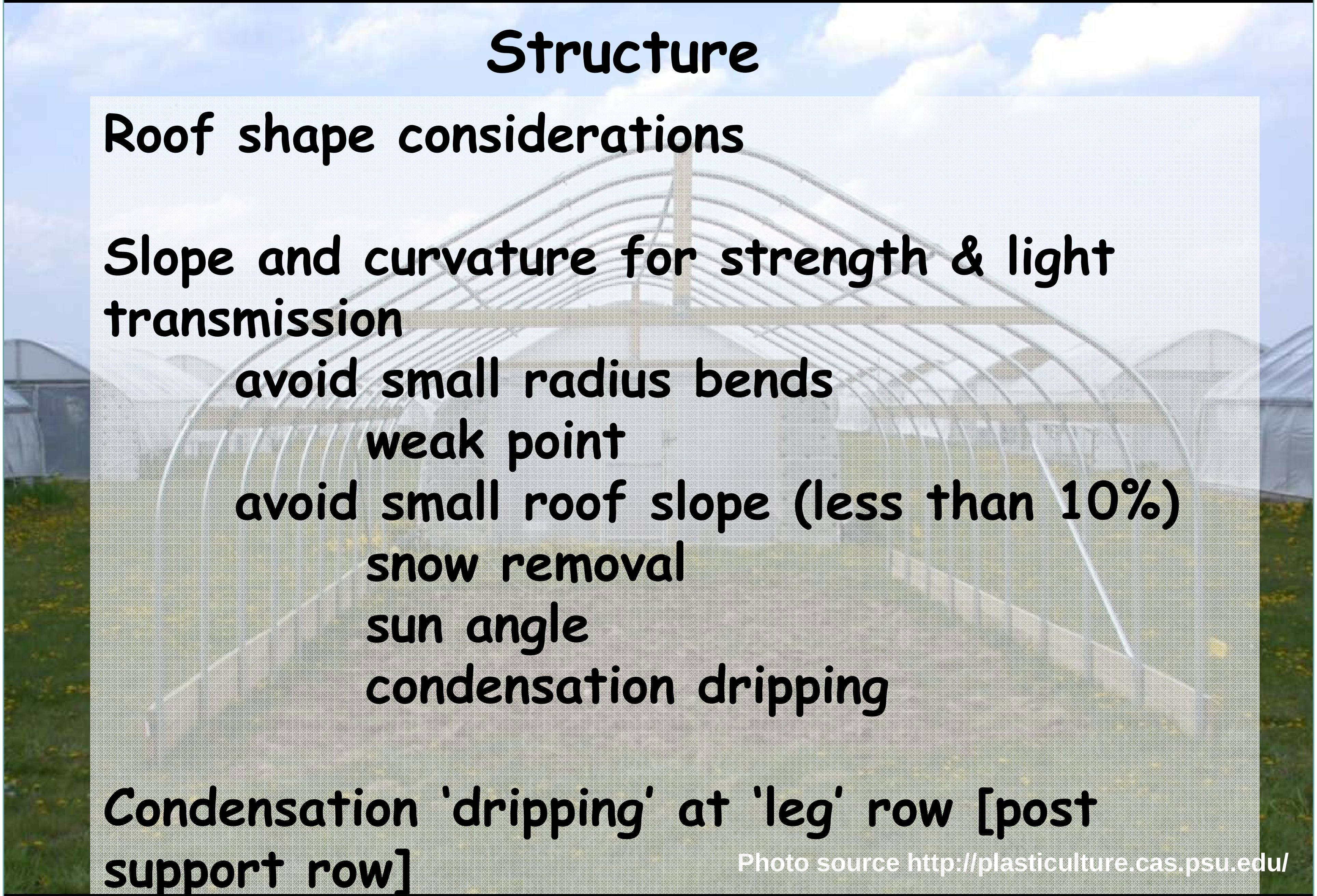


Photo source http://plasticulture.cas.psu.edu/

Structure



Roof shape considerations

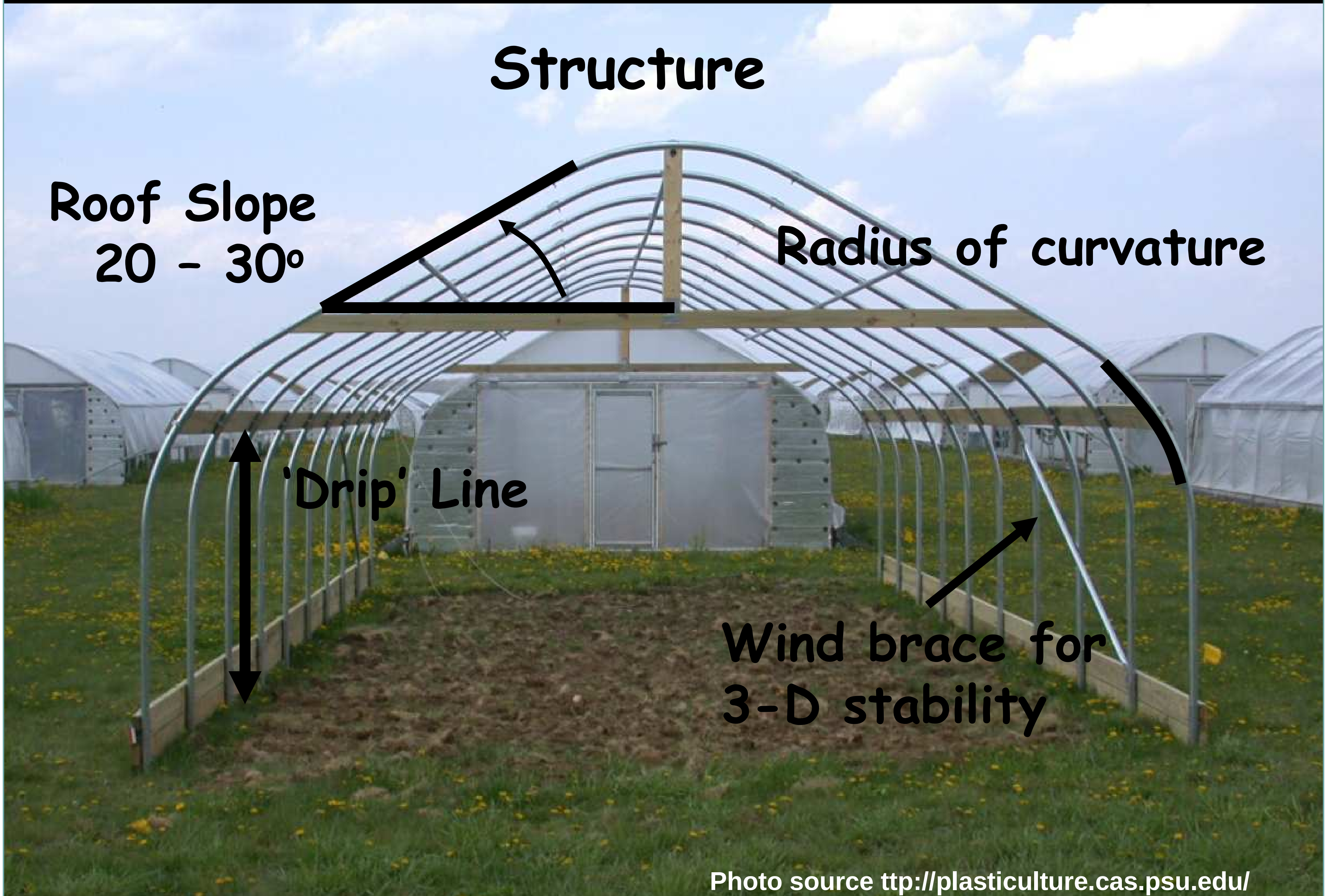
Slope and curvature for strength & light transmission

- avoid small radius bends
  - weak point
- avoid small roof slope (less than 10%)
  - snow removal
  - sun angle
  - condensation dripping

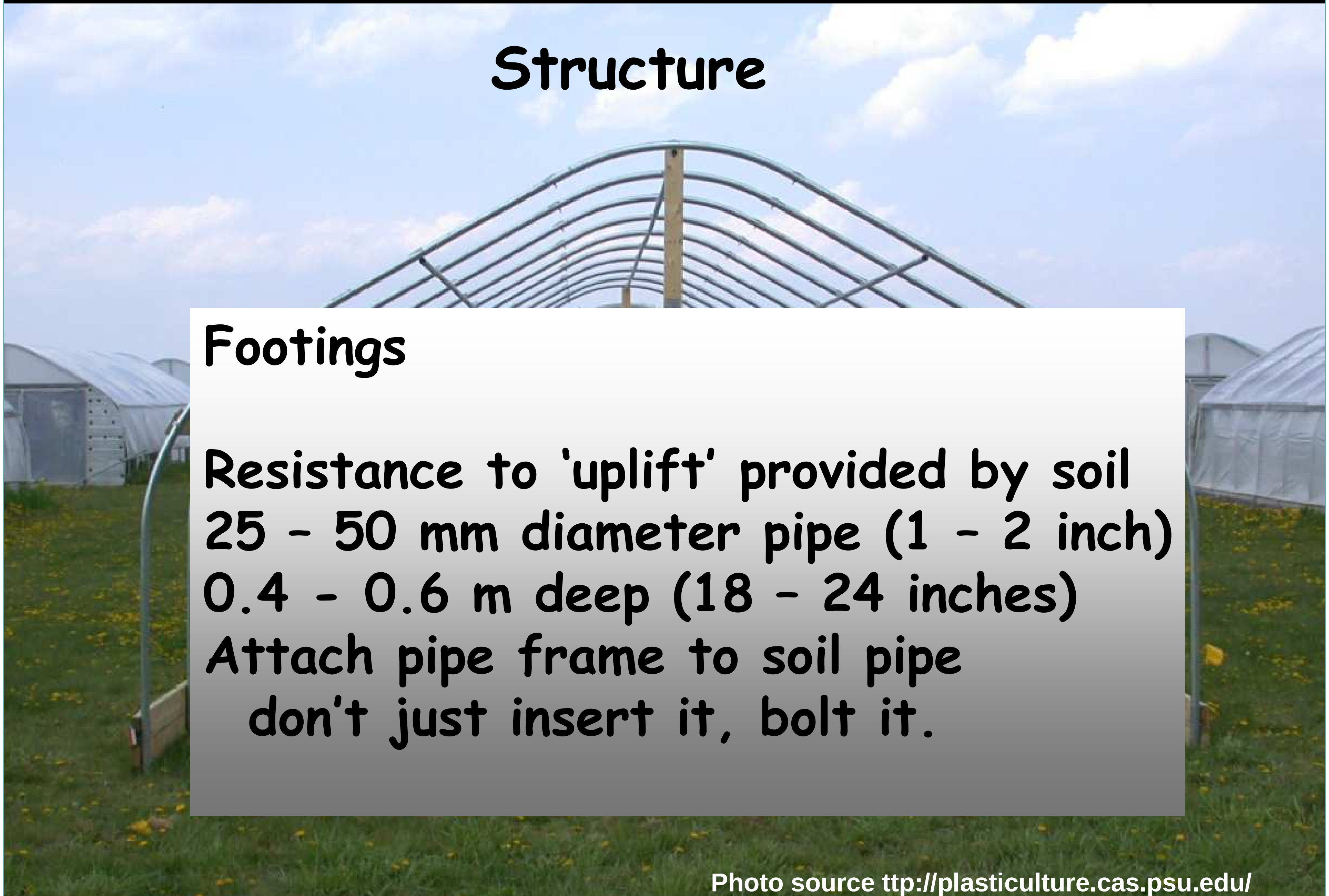
Condensation 'dripping' at 'leg' row [post support row]

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

Structure


Roof Slope
20 - 30º
Radius of curvature
'Drip' Line
Wind brace for
3-D stability
Photo source ttp://plasticulture.cas.psu.edu/

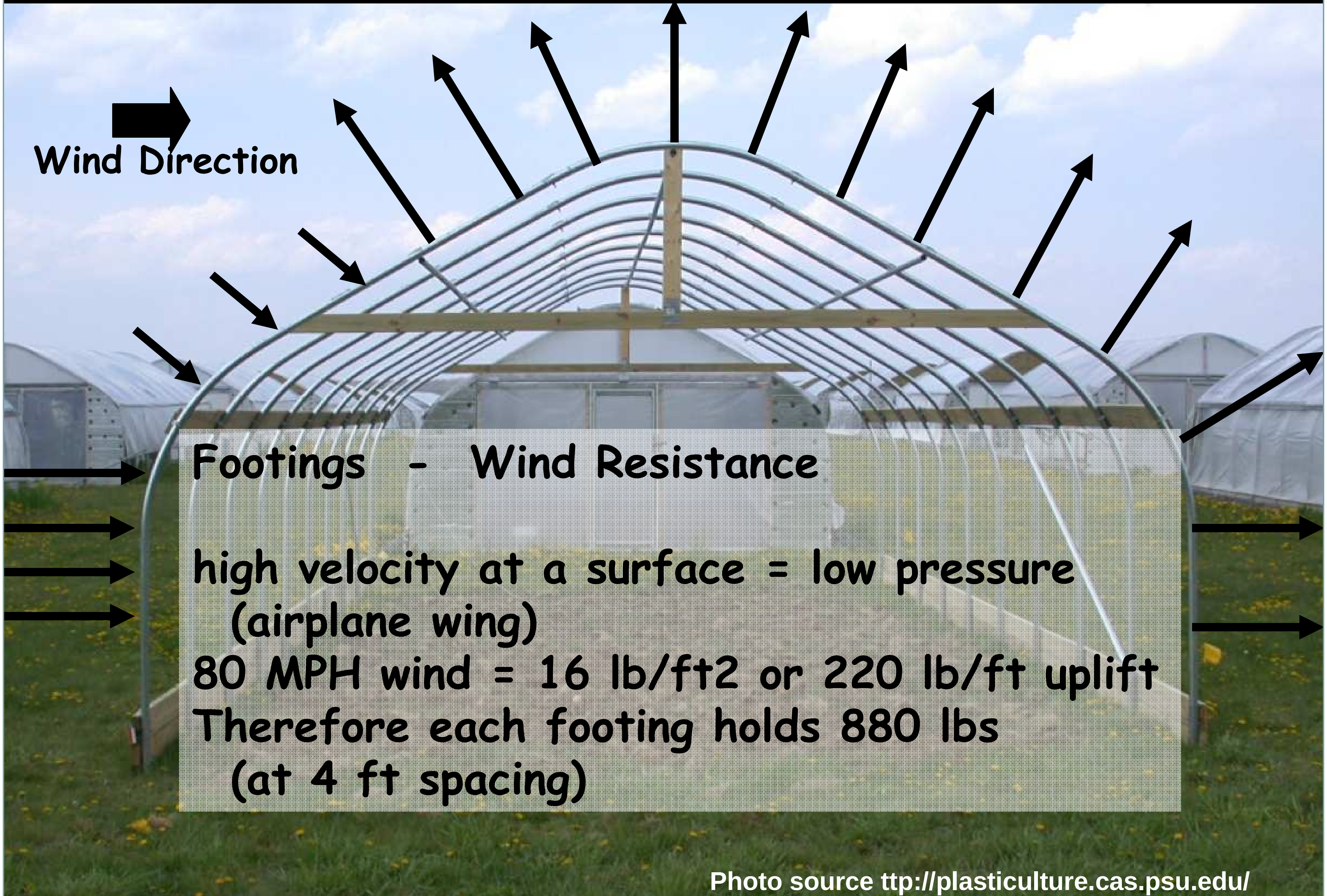
Structure

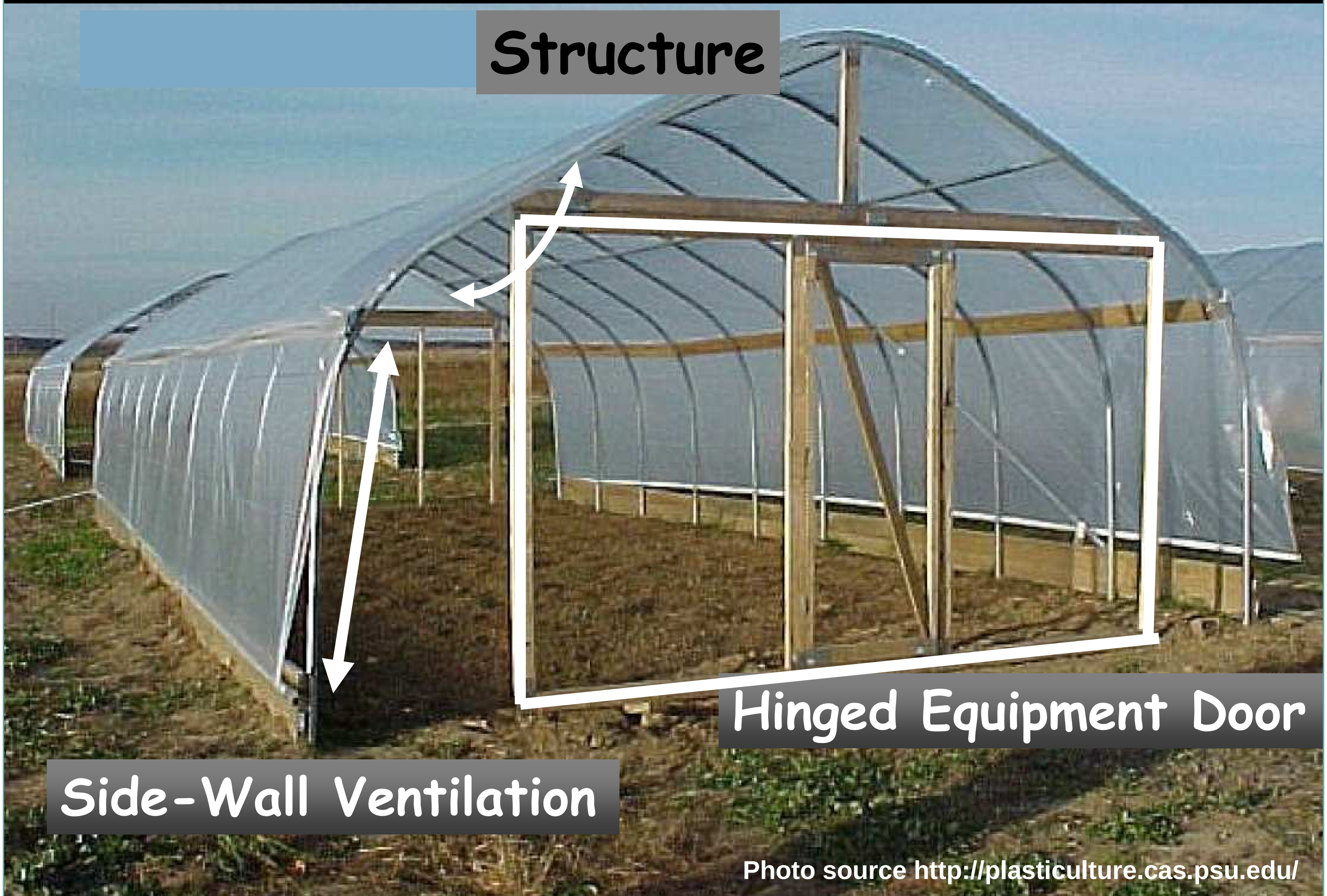


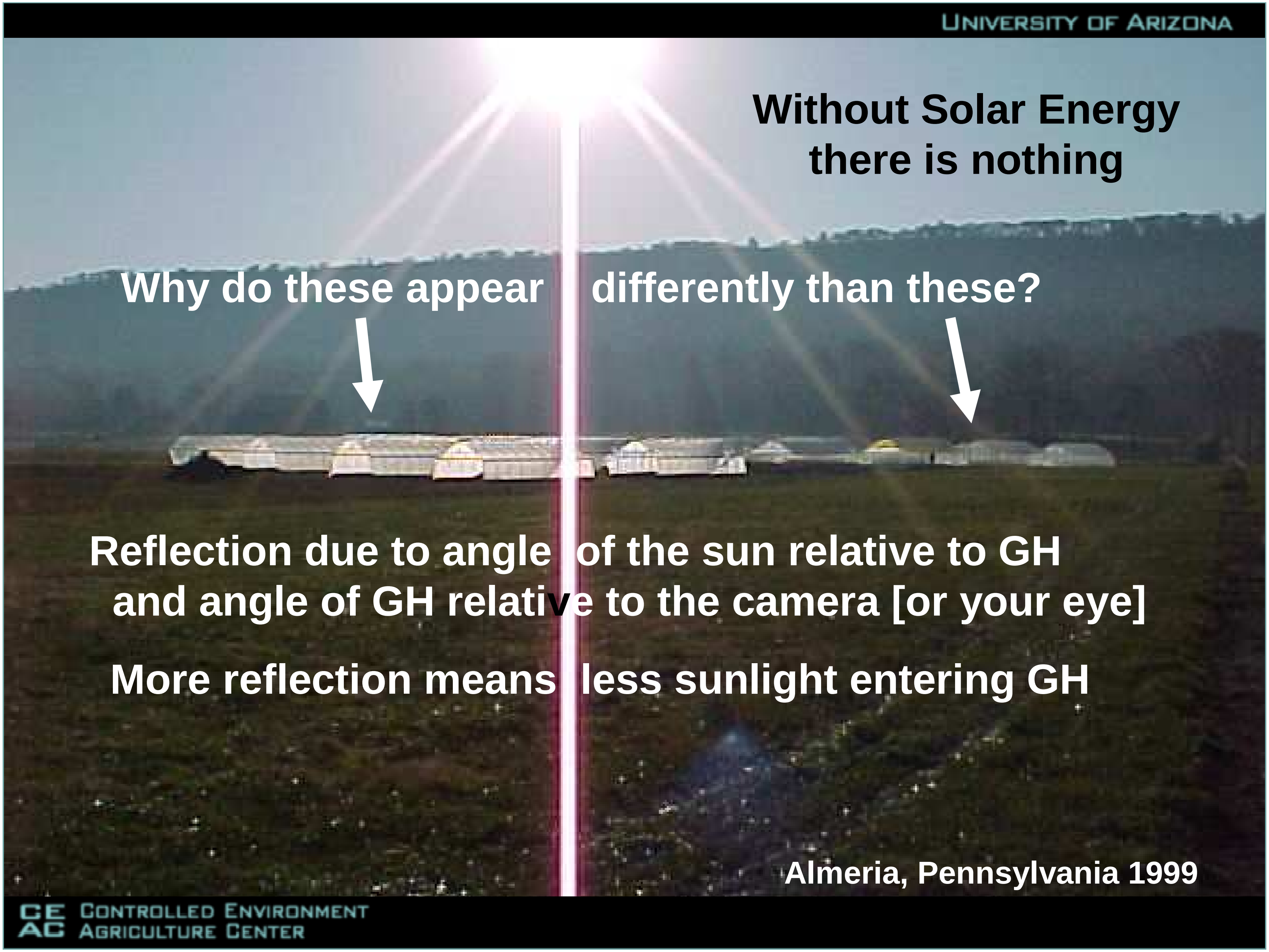
Footings

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.

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


Wind Direction
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/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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
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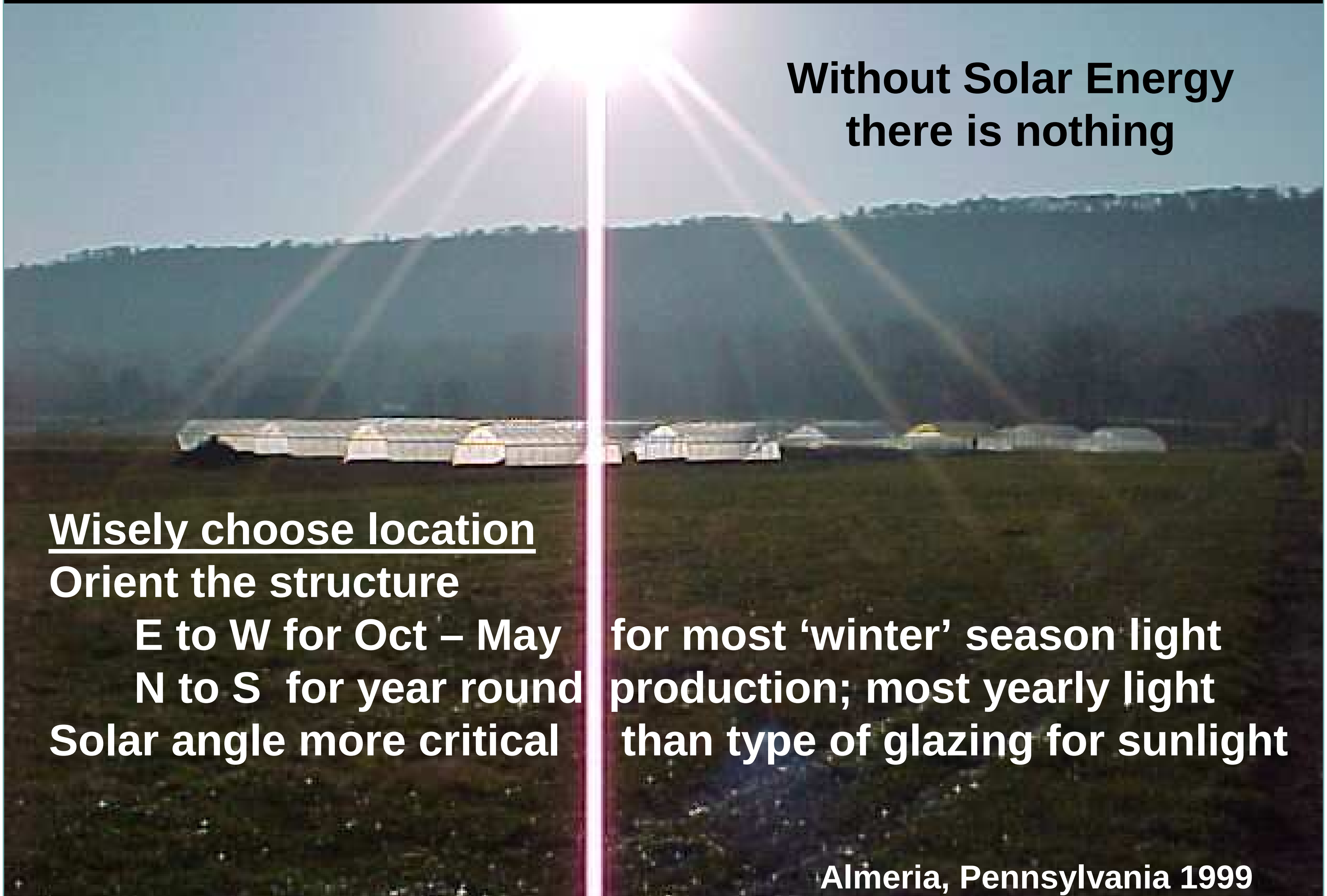
AGRICULTURE CENTER


Without Solar Energy
there is nothing
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

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?

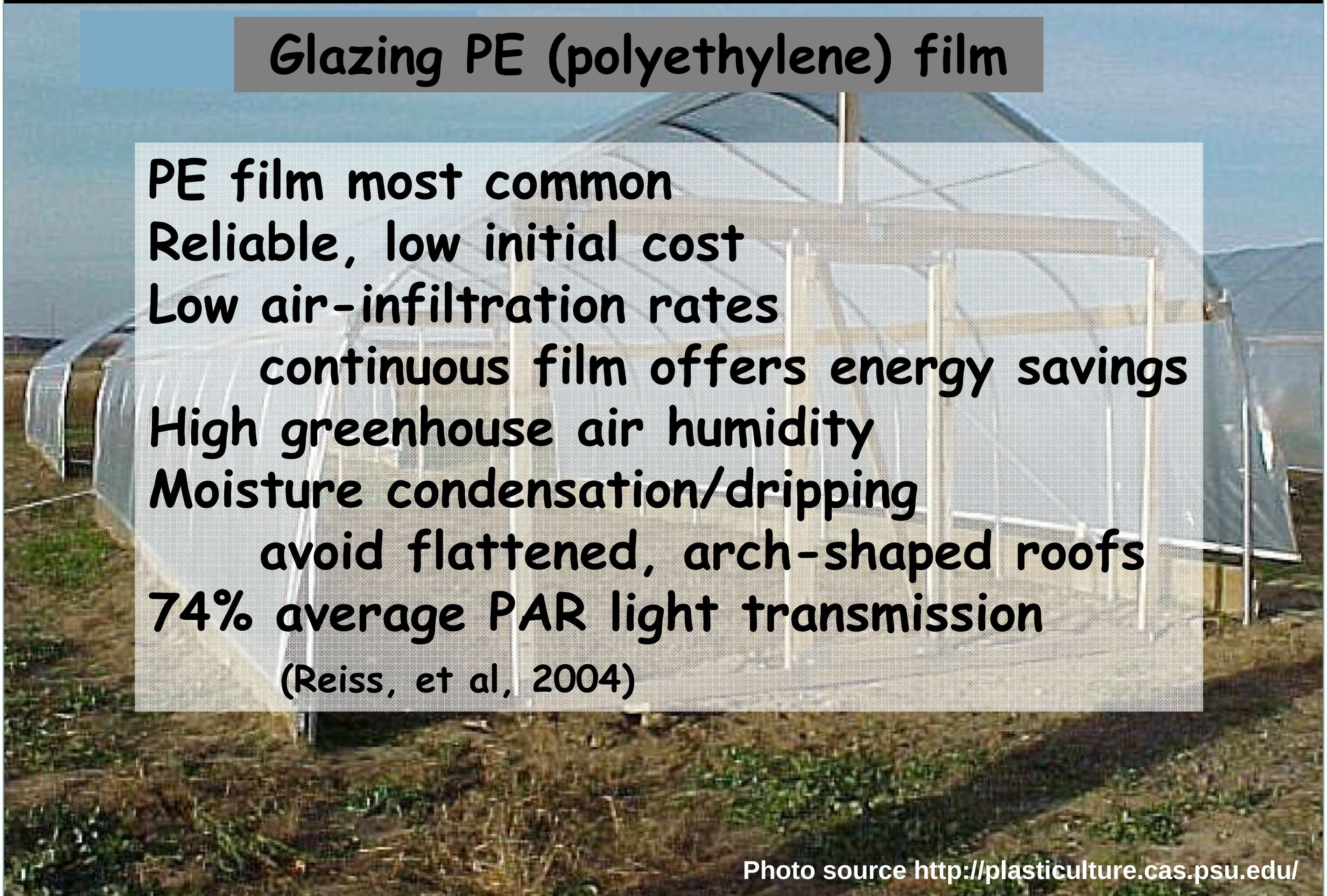
Single layer

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

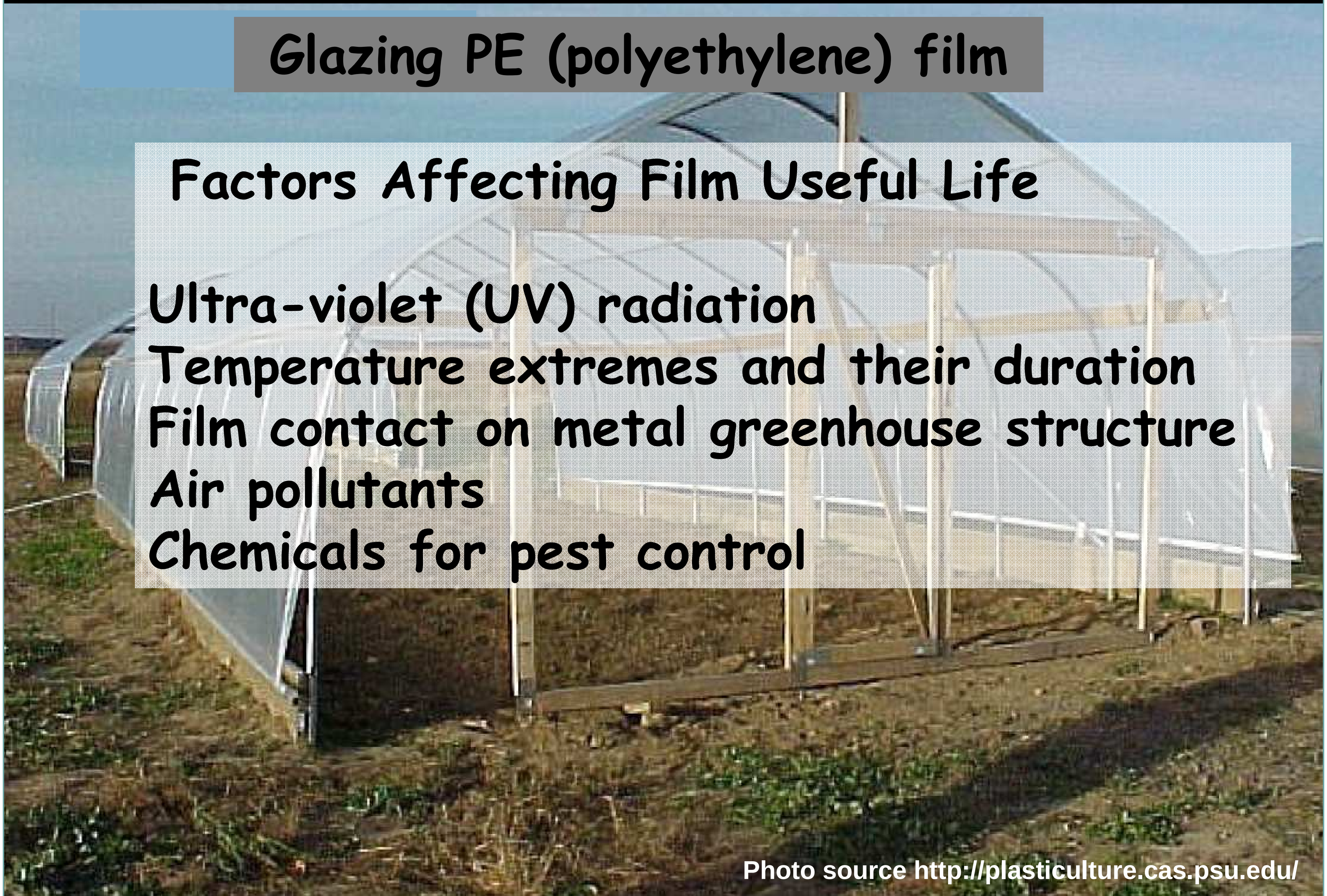
74% average PAR light transmission
(Reiss, et al, 2004)

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



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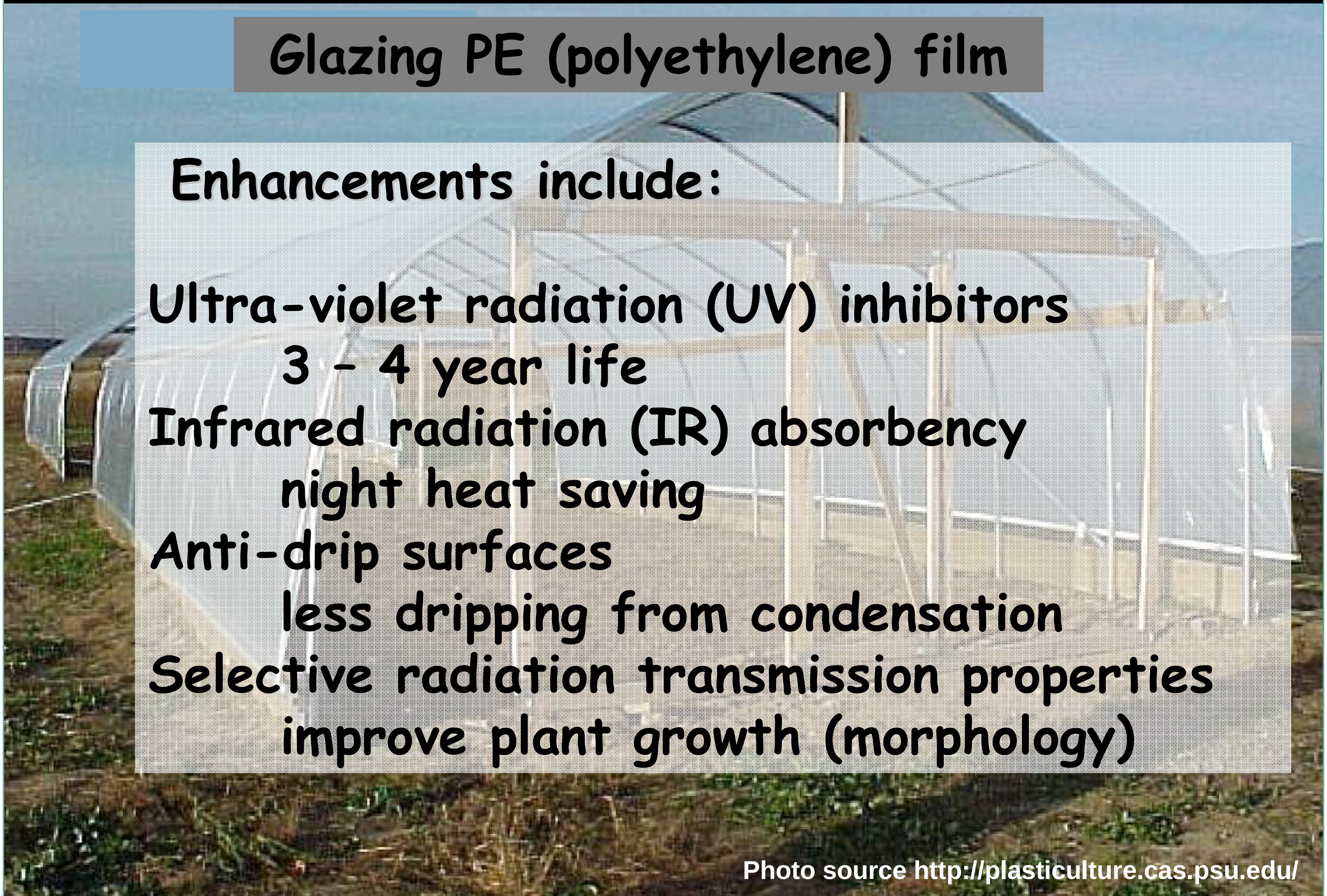
Glazing PE (polyethylene) film

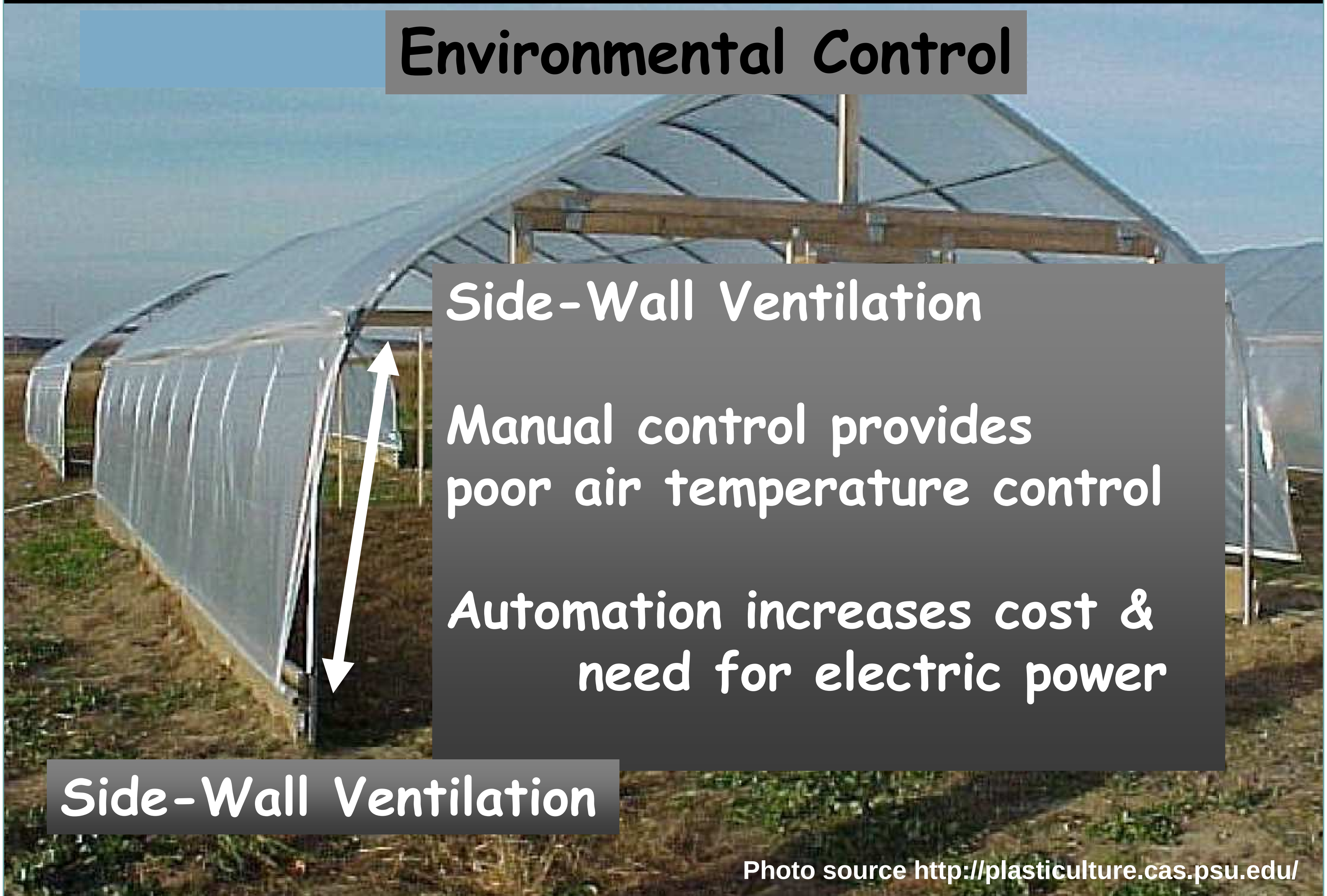


Enhancements include:

- 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)

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

Environmental Control



Side-Wall Ventilation

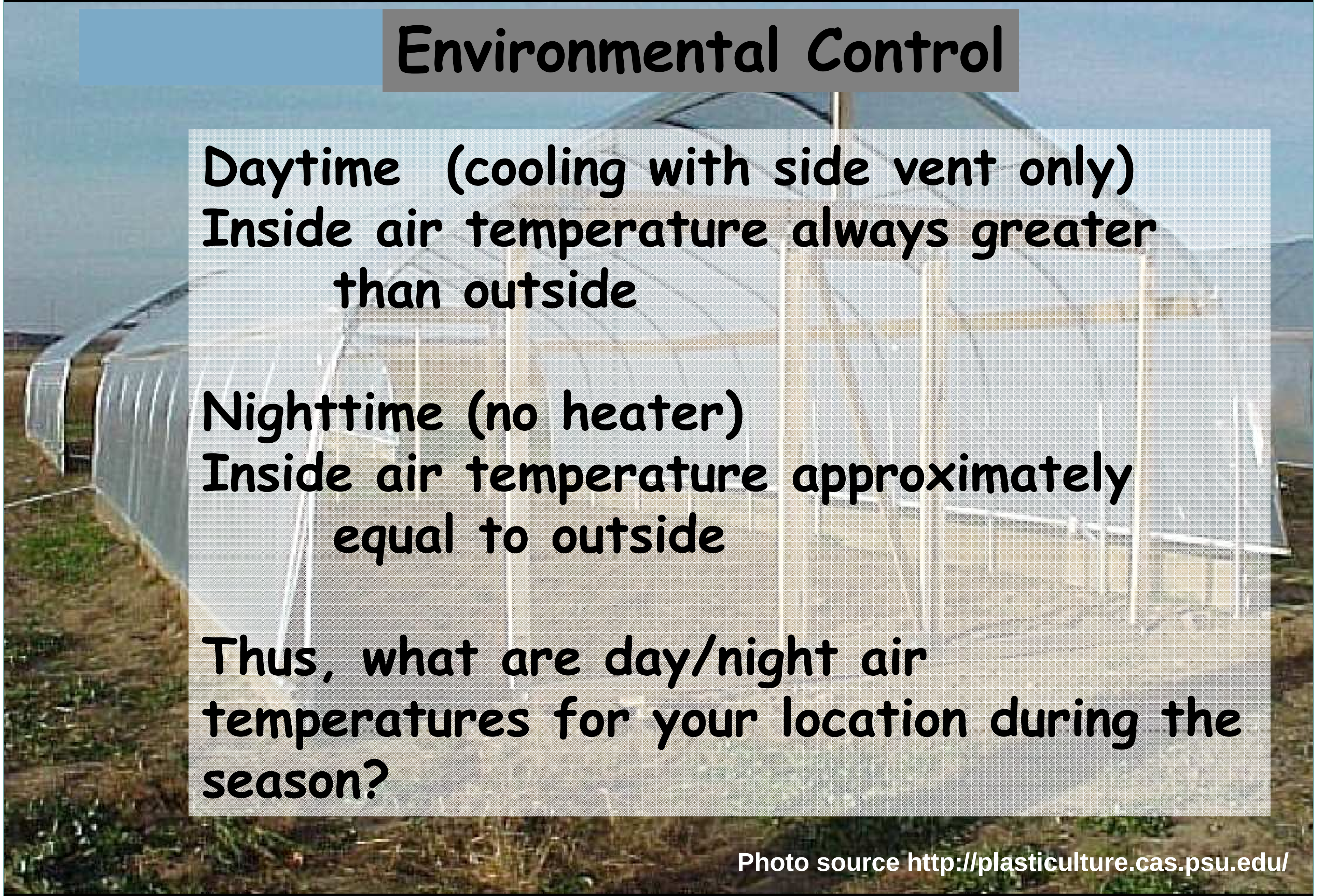
Manual control provides poor air temperature control

Automation increases cost & need for electric power

Side-Wall Ventilation

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

<u>Nighttime Air Temperature in Tunnel</u>
(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

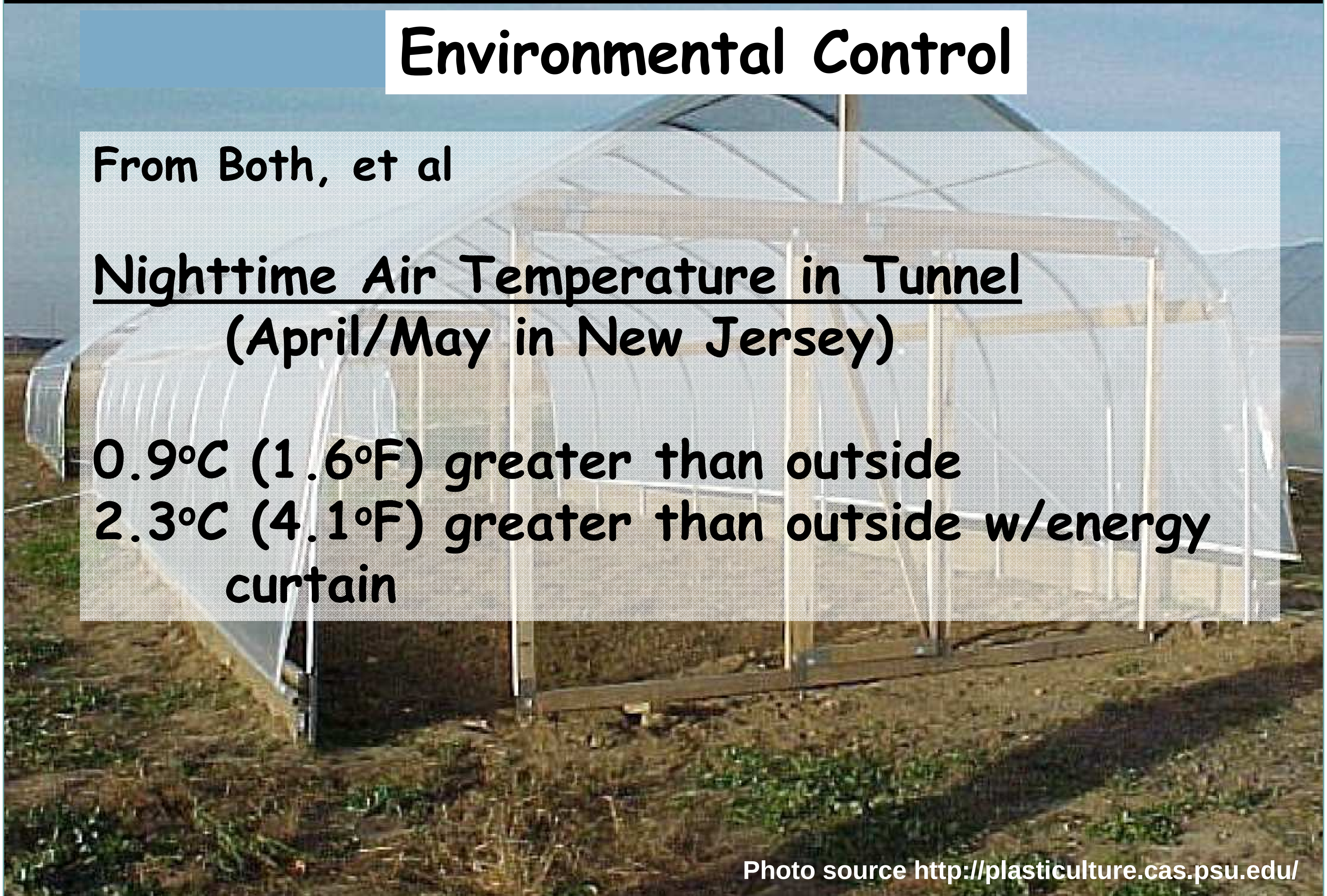
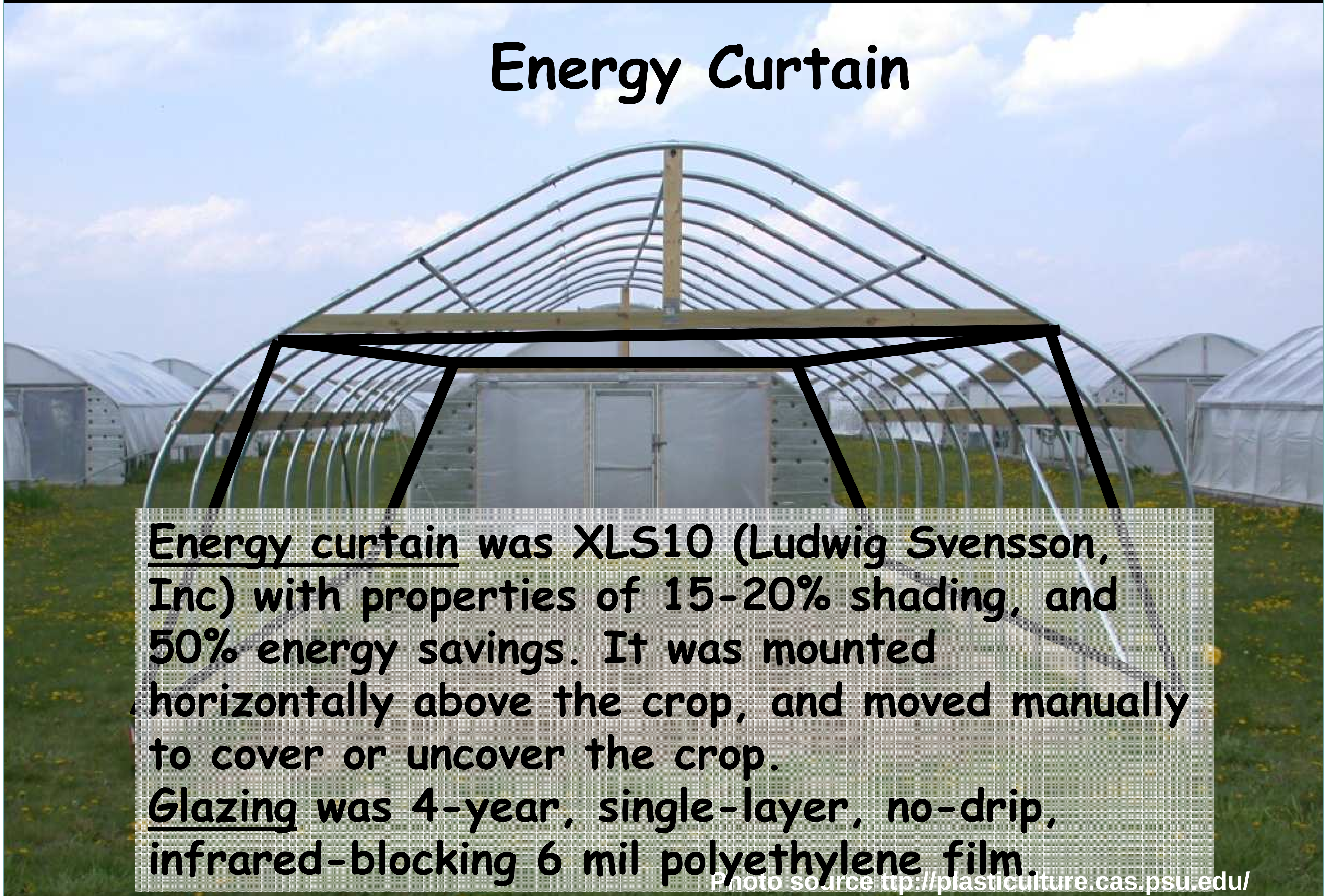


Photo source http://plasticulture.cas.psu.edu/

Energy Curtain

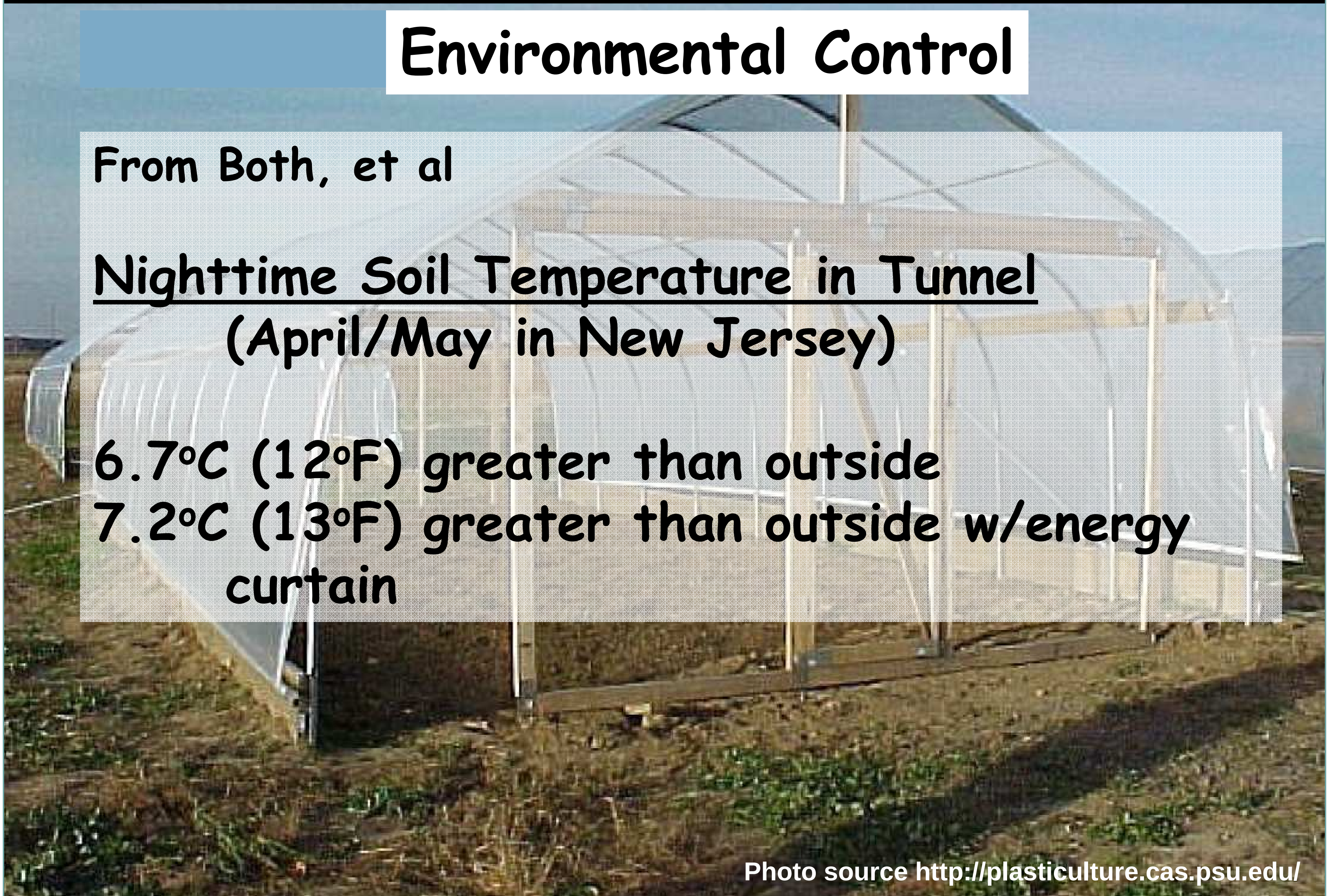


<u>Energy curtain</u> was XLS10 (Ludwig Svensson, Inc) with properties of 15-20% shading, and 50% energy savings. It was mounted horizontally above the crop, and moved manually to cover or uncover the crop.

<u>Glazing</u> was 4-year, single-layer, no-drip, infrared-blocking 6 mil polyethylene film.

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

Environmental Control

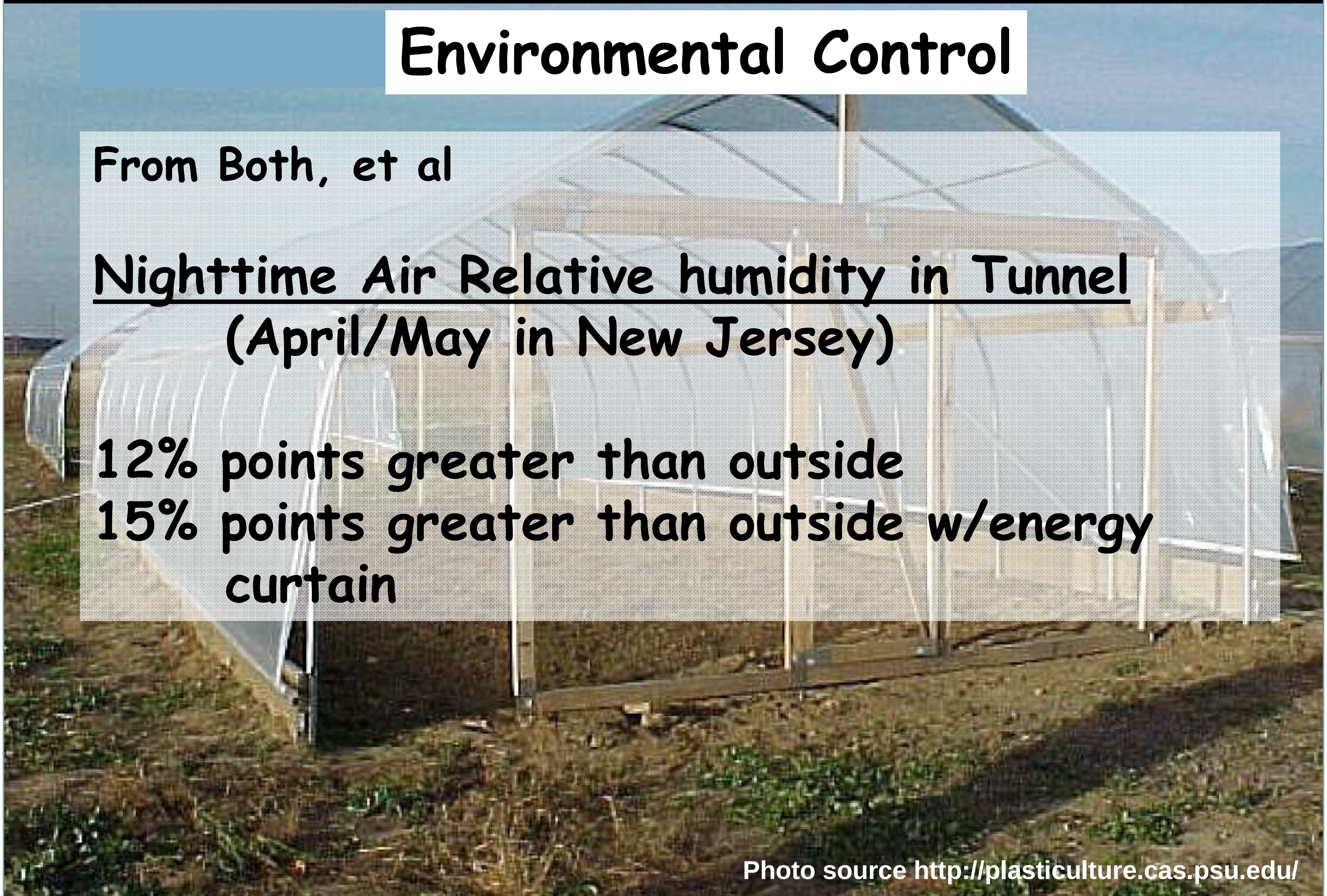


From Both, et al

<u>Nighttime Soil Temperature in Tunnel</u>
(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/

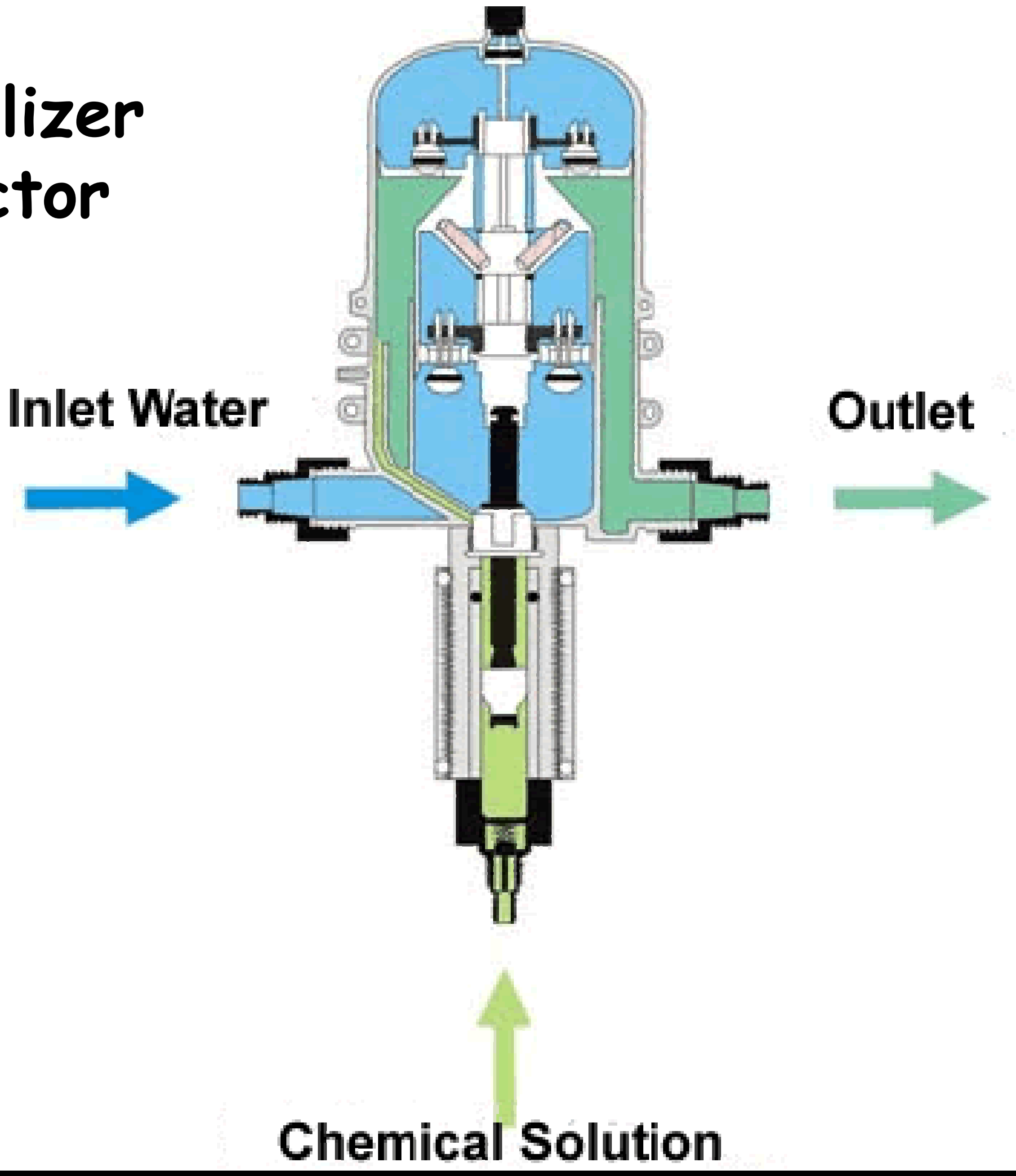
Fertigation

Cheap labor, that you can trust, is hard to find these days!

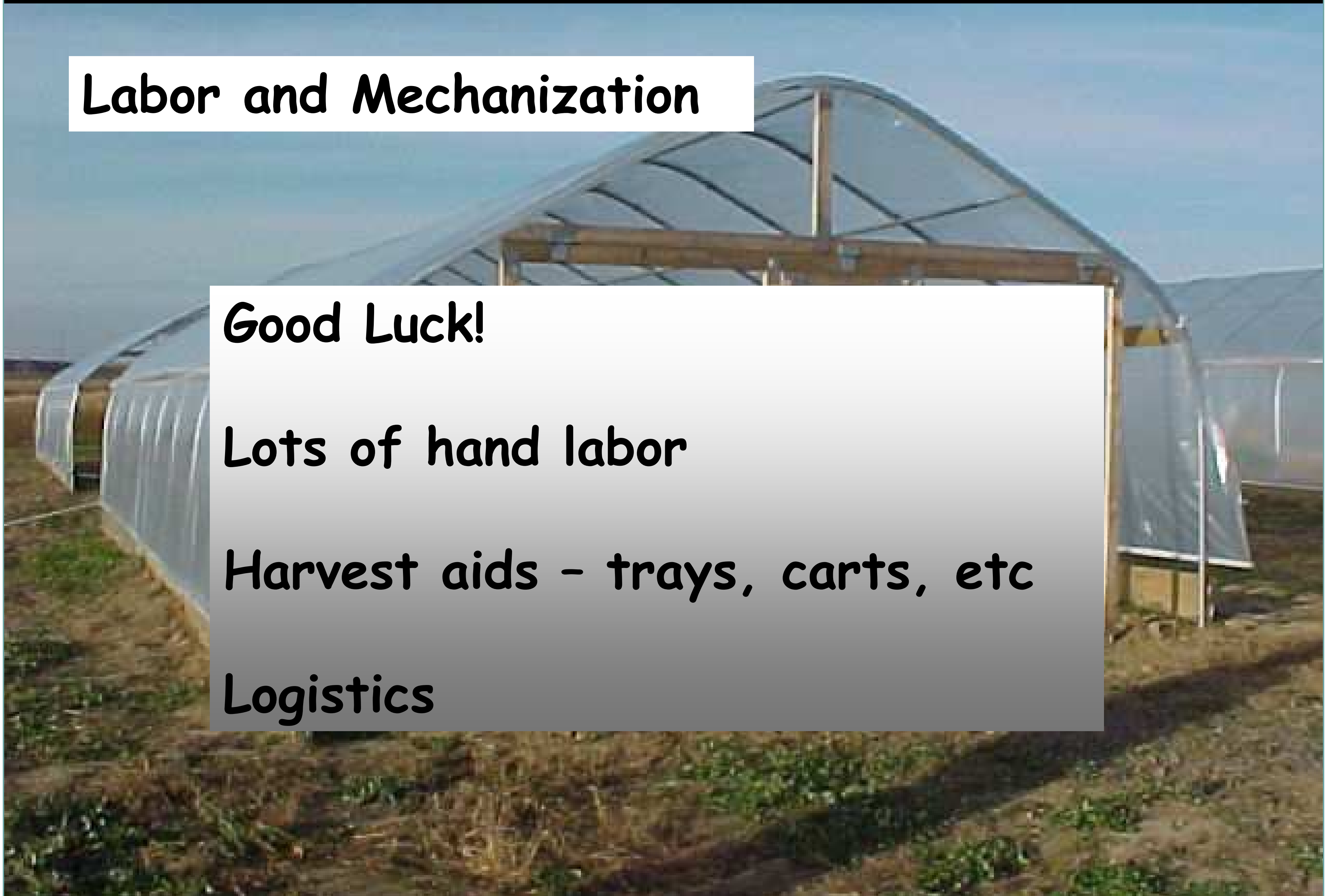
Acknowledge Plasticulture Center at Penn State for their passion and persistence in getting the message out about the next generation of modern high tunnels for use in 21st Century (October 1999)

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

Fertilizer Injector



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