Managing light, temperature, and relative humidity in greenhouses

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Outline

1. Maximizing light levels and the basics of supplemental and photoperiodic lighting
2. Controlling plant development by managing temperature
3. Effects of relative humidity on plant quality and disease

Lighting strategies influence…

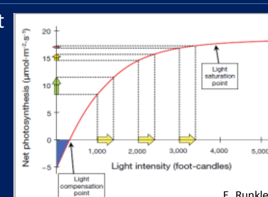
- Photosynthesis
- When some crops flower
- Crop quality

Measuring light intensity

Instantaneous measurement at one point in time

Common units are
- foot-candles
- micromoles/m²/second
- Watts/m²

Determine light saturation of leaves and when to pull shade



Most crops are light saturated at 4000 foot-candles

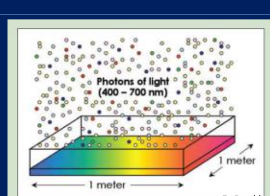
Measuring light quantity

Daily Light Integral (DLI)

Total light that reaches the crop and can be used for photosynthesis per day

Photosynthetically active radiation (PAR)

Correlated with growth and flowering



Units are moles of PAR light per m^2 per day

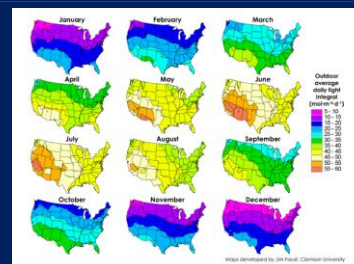
Comparing different light units

1. **Photometric (foot-candles, lumens, lux):** Based on perceived brightness. Measurements are biased towards the human eye.
2. **Radiometric (Watts/m^2):** Used to determine energy inputs or outputs in lighting systems, and is not specific to plants or people and may not represent light used for photosynthesis.
3. **Quantum (moles of photons of PAR light):** Specifically light used for photosynthesis. Refers to the number of photons between a 400 to 700 nm waveband. Used to calculate DLI and can be used with LEDs.

Several main factors affect light levels in greenhouses

1. Natural outdoor light levels
2. Shading materials and structure
3. Hanging baskets

Natural light levels vary by geographical location and month



- High light in summer, low light in winter/early spring
- Light levels can be 50% lower in the greenhouse

Shading materials reduce light levels in the greenhouse


Retractable shade curtain


Spraying whitewash paint

- Commonly used to diffuse light and lower greenhouse temperature
- May need to remove whitewash in early spring

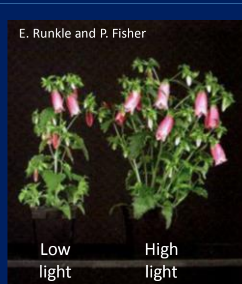
High density hanging baskets reduce light entering the greenhouse

- Avoid high density hanging baskets to maximize light quantity and quality for plants underneath

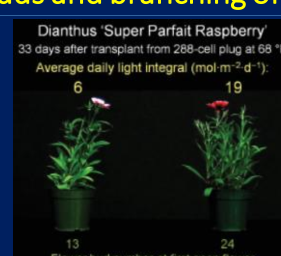
Supplemental lighting

Supplying artificial light to increase daily light integral and photosynthesis

Needed at northern latitudes during periods of low natural light



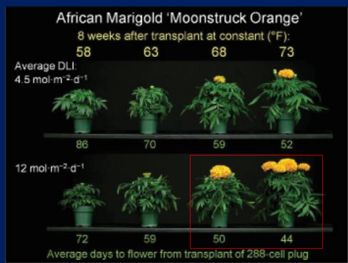
Higher daily light integral increased flower buds and branching of dianthus



E. Runkle and P. Fisher

- Also resulted in greater stem caliper and leaf thickness

Higher daily light integral reduced crop time in marigold



E. Runkle and P. Fisher

- Supply a DLI of at least 10 moles/m^2/day for finished crops

Vegetable crops that produce fruit benefit from even higher light levels

- Generally, 1% increase in DLI = 1% increase in fruit yield
- Recommended DLI for vine crops is 25 to 30 mol/m^2/day

Examples of supplemental lights used to increase daily light integral (DLI)


High pressure sodium (HPS)


High discharge LEDs

- Others include metal halide and mercury lamps
- Usually hang >7 ft above canopy for even distribution
- Fluorescent and incandescent bulbs are low intensity

Light sources differ in foot-candles and lux at the same level of PAR

Measurement Conversion Values

Light Source	μmol·m^{-2}·s^{-1}	Foot-candles	Lux	W·m^{-2} (total energy)
Sun	1	5.0	54	0.51
High-pressure sodium lamps	1	7.6	82	0.56
Metal halide lamps	1	6.6	71	0.59
Cool-white fluorescent lamps	1	6.9	74	0.54
Incandescent lamps	1	4.6	50	2.58

- Recommended to use micromoles/m^2/second of PAR

Summary of lighting strategies

Characteristics of Lighting Strategies

	Photoperiodic lighting	*Supplemental lighting*
Objective	Create a long day	Increase photosynthesis by increasing the DLI
Plants targeted	Those in which flowering is influenced by day length	Shade-avoiding (high light) plants
Plant responses	Inhibit flowering in short-day plants, promote flowering in long-day plants	Increased rooting, more branching, thicker stems, more flowers, sometimes faster flowering
Intensity desired (foot-candles)	10 or more	400 to 500
Time of year typically used	August to April	October to March
Time of day used	After sunset or during the middle of the night	During the day when it is cloudy and at night

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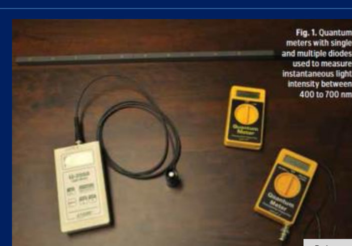
Measuring light intensity



- Handheld sensors usually cost between \$300 and \$1000
- Calibrate to sunlight and to 10,000 foot-candles (2,000 μmoles)
- Always take measurements at the canopy level

Measuring DLI (daily light integral)

- Mount in the greenhouse at canopy level
- Battery-powered, or use with a control computer

Calculate DLI from measured light intensity

Calculate daily light integral using a hand light meter

Calculating DLI Example

Light intensity values recorded once per hour from midnight to midnight (µmol·m⁻²·d⁻¹)	Average light intensity (µmol·m⁻²·d⁻¹)	Calculated DLI (mol·m⁻²·d⁻¹)
0, 0, 0, 0, 0, 44, 102, 198, 255, 410, 454, 600, 532, 627, 466, 376, 303, 187, 91, 45, 47, 44, 43, 0	201	17.37

- Divide average light intensity by 1 million, then multiply by 86,400 to estimate DLI

Six tips for using light sensors

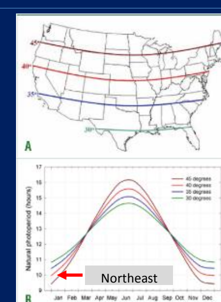
1. Make sure the sensor is level to the ground for accurate measurements. If sensors don't have a bubble, use a level.
2. Place the sensor just above the plant canopy. Light levels change vertically in the greenhouse. Place sensors near structural beams for hanging baskets.
3. Place sensors where they stay dry. Misting and watering overtop can interfere with light readings and damage sensors.
4. Place sensors in open areas. Avoid placement near gutters, walls, and shade spots.
5. Periodically clean sensors with distilled water or rubbing alcohol. Re-calibrate sensors every three or four years.
6. Understand the sensor output. If needed, convert to meaningful units.

Photoperiodic lighting

Photoperiod is number of hours of light per day

Some crops initiate flowering in response to long days (actually short nights)

Day length may need extended (shorter night) for some crops in fall and early spring



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Crops that have long-day, short-day, and day-neutral responses

	DAY-NEUTRAL PLANT	SHORT-DAY PLANT	LONG-DAY PLANT
Bedding plants			
Begonia	×		
Dahlia		×	
Geranium (Pelargonium)	×		
Impatiens	×		
Marigold, French (Tagetes)	×		
Pansy (Viola)			×
Petunia			×
Snapdragon (Anitirrhinum)			×
Herbaceous perennials			
Black-eyed Susan (Rudbeckia)			×
Campanula			×
Columbine (Aquilegia)	×		
Coreopsis			×
Hosta			×
Lobelia (Lobelia)			×
Shasta daisy (Leucanthemum)			×

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- Long day plants need approximately 13 hours of light
- Depends on crop species and variety

Low intensity lights are often used to extend the photoperiod for long days

R. Lopez

- Typically light for 4 hours after sunset, or 10pm to 2am
- Only need about 10 foot-candles of light
- High intensity lights are also effective if supplementing light

Earlier flowering, more compact growth for petunia with high light and long days

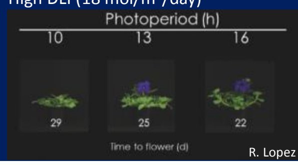
No flowering under short days (10 hours)

Similar time to flower at 13 and 16 hour days

Earlier flowering with higher light

Low DLI (6 mol/m²/day)

High DLI (18 mol/m²/day)



Shorten days for short-day plants using black-out cloth and curtains

- Short-day plants need <12 hours of day light to flower
- Use a reflective outside helps prevent heat build-up
- Close before sunset or before sunrise, and can re-open at night to let heat escape

Photoperiodic lighting strategies

Characteristics of Lighting Strategies E. Runkle

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Top tips for greenhouse lighting

1. Maximize available light. Shoot for greenhouse coverings with >50% light transmission. Common reduction in light comes from dirty polyethylene materials and hanging baskets.
2. Know how much light reaches the crop. Most bedding crops need 10 to 15 moles of light/m²/day. Make sure sensors are calibrated to sunlight and measure up to 10,000 foot-candles or 2000 µmoles/m²/second.
3. Consider structure when building greenhouses. East to west orientation has greater light transmission but lower uniformity and vice versa for north to south. North to south is recommended for better uniformity.
4. Consider installing retractable shade to diffuse light and increase light uniformity. Also used to alleviate midday temperatures on sunny days and retain heat at night.

Top tips for greenhouse lighting

5. Increase daily light integral (DLI) to accelerate flowering in spring crops. Supplement 75 to 100 µmoles/m²/second (400 to 600 foot-candles) with high pressure sodium lamps to shorten production time and increase quality in high light crops.
6. Control photoperiod using low-intensity lighting to manage flowering. Extend days or interrupt nights for long-day plants in fall and early spring. Photoperiodic lighting is relatively inexpensive compared to supplemental lighting.

Outline

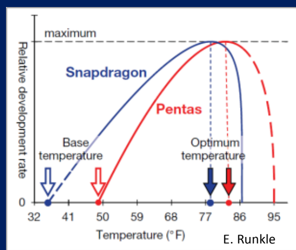
1. Maximizing light levels and the basics of supplemental and photoperiodic lighting
2. Controlling plant development by managing temperature
3. Effects of relative humidity on plant quality and management

Temperature drives plant developmental rate

Unfolding of leaves and flower buds

Growth stops at base temperature

Crops differ in base temperature and optimum temperature



Pentas performs better at warm temperatures compared to snapdragon

Base temperatures are related to cold tolerance and optimum temperature

- Cold tolerant crops have low base temperatures, prefer a cooler climate (60 to 70F)
- Cold sensitive crops have high base temperatures, prefer a warmer climate (72 to 80F)
- More info at http://www.flor.hrt.msu.edu/temperature/

Category	Base temperature (°F)
Cold tolerant	39 or lower
Cold temperate	40-45
Cold sensitive	46 or higher

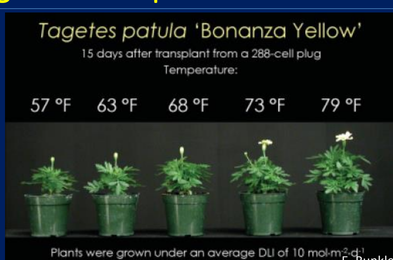
Examples of…

Cold-tolerant crops
Marigold, viola, osteospermum

Cold-temperate crops
Cosmos, marigold, rudbeckia

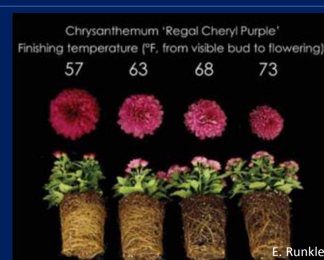
Cold-sensitive crops
Salvia, zinnia, portulaca, pentas

Growth and flowering increased in marigold as temperature increased



- Higher temperature resulted in greater number of leaves and open flowers

Growth and flower size decreased in chrysanthemum as temperature increased



- Also less rooting at higher temperature

Dealing with high temperature and cold-tolerant crops

Leaf yellowing/drop in alyssum

Chlorosis/stunting in ivy geranium

- Try and reduce temperatures (usually <85 degrees)
- Check that cooling and ventilation systems are working
- Pull shade curtains earlier, spray whitewash

Growing cold-tolerant crops too warm also promotes stem stretch

- Results in low quality plants
- Try to grow cooler or apply plant growth regulators

Dealing with cold temperature and cold-sensitive crops

- Crops sensitive below 65 degrees F
- Increase heating, pull energy curtains, and fix “leaks”
- Move plants away from cooling pads

Stunted celosia and leaf purpling when grown cold

Monitor greenhouse air and substrate temperature

- Measure air temperature near the canopy
- Substrate temperature above 65 degrees for most crops
- Handheld probes useful for spot measurements
- Periodically re-calibrate sensors

Tips on managing temperature

1. Determine the cold-tolerance of your crops. Cold-tolerant plants grow best at cooler average temperatures (60-70F) whereas cold-sensitive crops grow best at warmer temperatures (72-80F).
2. Place cold-tolerant and cold-sensitive crops in different greenhouses and adjust temperature accordingly. Some cold-tolerant crops have lower growth and quality when grown warm, and vice versa. If using one greenhouse, place cold-tolerant crops near cooling pads.
3. Consider under-bench heating to support healthy root growth. Cold-sensitive crops need root zone temperatures maintained above 65 degrees F to prevent stunted growth.

Tips on managing temperature (cont’d)

4. Consider installing retractable shade to reduce high midday temperatures on sunny days. High temperatures at noon can delay plant development and cause heat stress in some cold-tolerate crops.
5. Monitor air temperature at the plant canopy. Temperature increases as you move higher in the greenhouse. Use separate sensors for hanging baskets. Consider monitoring leaf temperature with infra-red sensors.
6. Monitor root zone temperature in crops grown cold. Substrate temperatures are often lower than air. Low root temperature with cold-sensitive crops can stunt growth and promote root disease.

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Relative humidity

What is relative humidity (RH)?

Amount of water vapor in air versus what the air can hold

Measured as a percentage of total saturation

Low humidity improves transpiration and uptake of some nutrients

High humidity favors disease

Diseases associated with high humidity

Botrytis blight

Powdery mildew

Diseases associated with high humidity

Impatiens downy mildew

High humidity decreases transpiration and uptake of calcium

Distortion on leaf margins

Blossom end rot

High humidity and edema

Edema ivy geranium

Relative humidity control

How do you decrease humidity?

- Increase ventilation using exhaust fans and ridge vents
- Improve air circulation

How do you increase humidity?

- Install fog systems
- Apply boom mist
- Water sidewalks

High relative humidity is needed to keep cuttings hydrated in propagation

Improve air circulation using horizontal or vertical air flow fans

Horizontal air flow (HAF)

Vertical air flow (VAF)

- Stirs and mixes air from top and bottom of the greenhouse
- Aim to create a breeze and moving leaves
- Direct HAF fans parallel to the ground to prevent non-uniform drying

Thanks for listening

Any questions?

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Light, temperature, and relative humidity in greenhouses—Part 2

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Outline

Part 2 will build upon concepts from Part 1 and will cover…

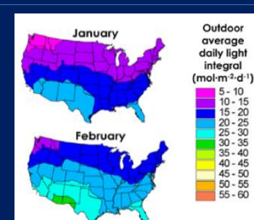
1. Advanced lighting strategies for young plants and finished crops
2. Average daily temperature and controlling growth with DIF
3. Understanding and managing vapor pressure deficit

How important is it to provide plug and liner crops with supplemental lighting?

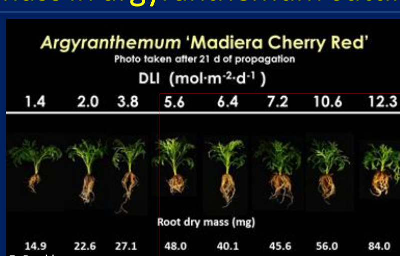
Production starts in January and February under low natural light

Can increase photosynthetic light by up to 50%

Usually cost benefits in terms of crop quality and reduced production time



Increasing daily light integral increased root mass in argyranthemum cuttings

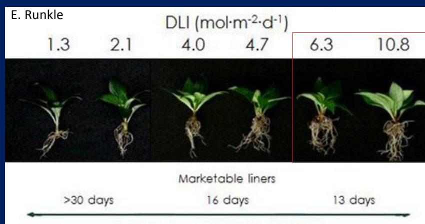


- Shoot mass also increased with increasing DLI

Increasing daily light integral increased root growth in seedling plugs

- DLI of 7 and 14 moles produced similar quality crops

Increased daily light integral reduced crop time in New Guinea impatiens



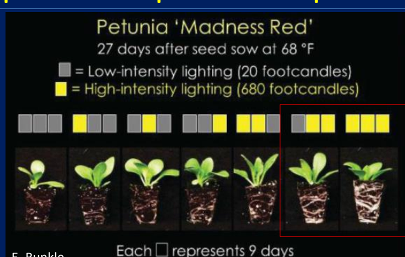
- ~3 to 4 week crop time with low DLI
- ~2 week crop time at DLI >6 moles/m²/day

Increasing daily light integral decreased stretching for more compact plants

Increasing daily light integral (DLI)

- Plants stretch and “search” for light at low DLI
- Compact plants perform better in shipping and transplant

Can you apply supplemental lighting for only part of the production phase?



- Best when high intensity lighting is constant
- Alternatively, provide lighting during last 3 weeks

What is the target daily light integral when growing young plants?

For most crops, provide 5 to 8 moles/m²/day of diffuse light

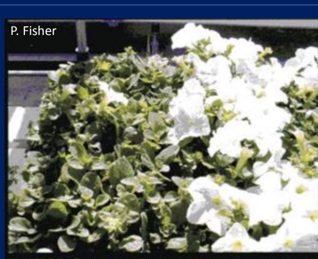
A few young plant crops benefit from >12 moles/m²/day

R. Lopez

DLI (mol·m^{-2}·d^{-1})	Maximum light intensity umol·m^{-2}·s^{-1} (foot-candles)	Average light intensity umol·m^{-2}·s^{-1} (foot-candles)
1.6	74 (370)	37 (185)
2.8	173 (865)	63 (315)
5.4	411 (2,055)	122 (610)
8.4	749 (3,745)	190 (950)

- Maintain average light intensity at >600 foot-candles to ensure adequate lighting for cuttings and seedling plugs

Is there a benefit to providing plugs of long-day plants with artificial long days?



- High light and long days shorten finished crop time

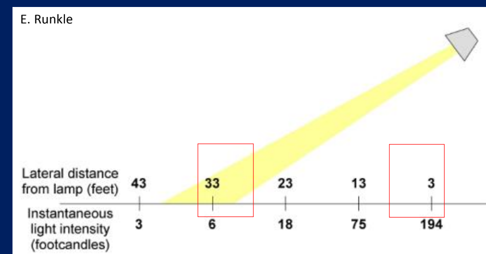
Cyclic lighting for night interruption for long-day crops

- Idea is to use fewer lights or less on-time for energy savings
- Intermittent lighting from low intensity bulbs or booms
- Lights on every 20 minutes for 40 seconds (10 µmoles/m²/sec)

Cyclic night interruption lighting using high pressure sodium beamflickers

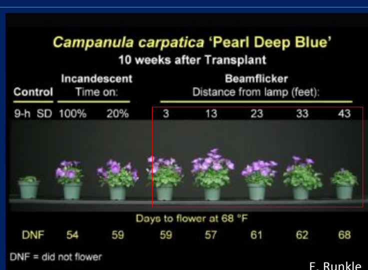
- High intensity light with rotating reflector
- Narrow light constantly passes back and forth over crops

Light intensity becomes when greater closer to the beamflicker



- Need 10 foot-candles to trigger flowering

Crops further from the beamflicker had reduced flower number



- Most uniform flowering within 20 feet of the beamflicker
- Set adjacent beamflickers to have intersecting light paths

Does the source of artificial light matter when providing photoperiodic lighting?

Lamp type		Short-day plants	Long-day plants
Incandescent		X	X
Fluorescent (including CFLs)[1]		X	X[3]
Mix incandescent + CFL[1]		X	X
HID (HPS, MH, mercury, Beamflicker)[2]		X	X
LEDs	White	X	X[3]
	Red	X	X[3]
	Red + far-red	X	X
	Far-red	X	X
	Blue	X	X
	Green	X	X

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- Some crops need both red and far red light

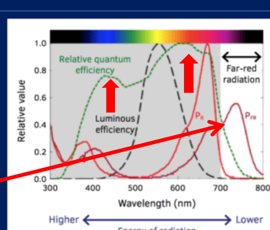
Light quality effects on plant growth

Blue light results in compacted plants

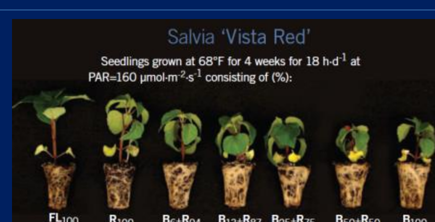
Red light (R) is responsible for leaf and stem expansion

Far red light (FR) is absorbed but not used for photosynthesis

Plants become soft and leggy with a high FR:R ratio



Salvia grown with red versus blue light



Decreasing red and increasing blue light

- Red light promotes stem and leaf expansion
- Blue light promotes compact plants and dark green leaves

Plants filter out blue and red light through leaves

However, FR light passes through or is reflected

Avoid high density hanging baskets since plants underneath receive more FR light

Tightly spaced plants receive more FR in their under-canopy, causing stretch

Space plants when they start "kissing" and before they are "hugging"

Artificial light sources differ in red to far red light ratios

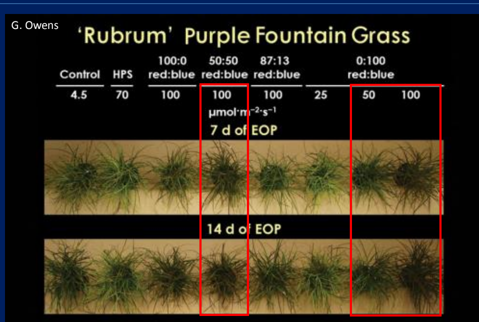
Light Distribution

Light source	Light distribution percentage				Red to far red ratio
	Blue	Green	Red	Far red	
Cool-white fluorescent lamp	21	52	24	2	10.7
High-pressure sodium lamp	5	51	38	6	6
Incandescent lamp	2	13	34	52	0.7
Metal halide lamp	18	49	25	8	3
Sun (direct sun and sky)	23	26	26	25	1

- Less stretch, more compact growth, with high pressure sodium and fluorescent bulbs

What about green light?

Research on enhancing foliage color with high blue light from LEDs



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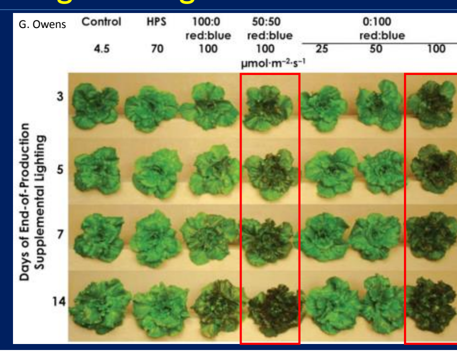


Tips on lighting strategies

1. Consider supplemental lighting when growing young plants in early spring. Maintaining a daily light integral of 5 to 8 moles/m^2/day will increase young plant quality and reduce time to flower after transplant.

2. Consider extending the photoperiod for long-day crops using cyclic night interruption. Using fewer lamps has potential to save on electrical costs.

3. Pay attention to light quality effects on plant growth. Tight spacing and high density hanging baskets reduce light quality and lead to plant stretch. LEDs delivering specific wavelengths of light can promote compact growth and improve crop appearance for added value.

Adjusting temperature set-points based on average daily temperature (ADT)

- ADT takes into account the time spent at each temperature set-point
- Correlated more with growth compared to 24 average temperature
- Adjust temperature set-points to control growth and save on fuel costs

Steps for calculating ADT

Step 1: For each temperature period, multiply the temperature by the hours delivered

Step 2: Add these values together

Step 3: Divide by 24

Example for calculating average daily temperature (ADT)

Step	Temperature (F)	Number of hours	Time	Value
1	83	10	8am to 6pm	830
1	66	6	6pm to 12am	396
1	63	8	12am to 8am	504
2				1730
3				ADT = 72.1

- Typical ADT is between 68 and 75 degrees for most crops
- Adjust temperature periods to save fuel, but maintain ADT to finish on time

Manage stem stretch and plant height by controlling temperature DIF

DIF is the difference in day and night temperatures

Zero DIF
Same day and night temperatures

Manage stem stretch and plant height by controlling temperature DIF

DIF is the difference in day and night temperatures

Zero DIF
Same day and night temperatures

Positive (+) DIF
Day is warmer than the night

Positive (+) DIF

Manage stem stretch and plant height by controlling temperature DIF

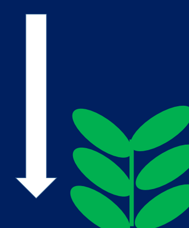
DIF is the difference in day and night temperatures

Zero DIF
Same day and night temperatures

Positive (+) DIF
Day is warmer than the night

Negative (-) DIF
Day is cooler than the night

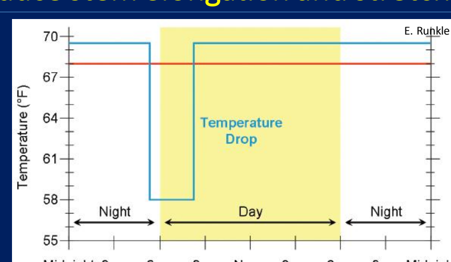
Negative (-) DIF



Negative DIF reduces internode length and promotes more compact growth

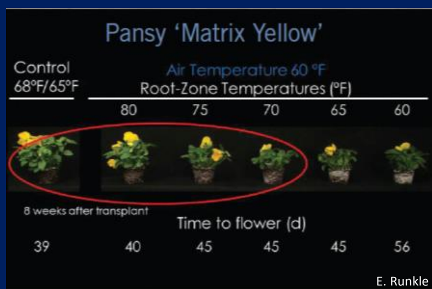
- Plants had same development at same ADT, regardless of DIF
- High night temperatures with high ADT can cancel -DIF

Provide a morning temperature drop to reduce stem elongation and stretch



- 5 to 15 degree drop in temperature ~2 to 3 hours before sunrise
- Can be very effective at reducing height for some crops

Increased root zone temperature resulted in earlier flowering with pansies grown cool



- Under-bench heating can shorten crop time for some cool crops

Tips on temperature strategies

1. Adjust set-points for a desired average daily temperature (ADT) and save on fuel costs. Crops will finish on time if ADT is maintained even though night temperatures are lowered to reduce heating.
2. Control DIF to manage stem elongation and stretch. Avoid positive DIF greater than 25 degrees. Negative DIF can be used on some crops for more compact growth.
3. Consider morning temperature drops to promote compact growth and harden plants before shipping. Adjust set-points or ventilate to drop temperatures 5 to 15 degrees 2 to 3 hours before sunrise. Allow temperatures to return to normal 2 hours after sunrise.

Download Virtual Grower software

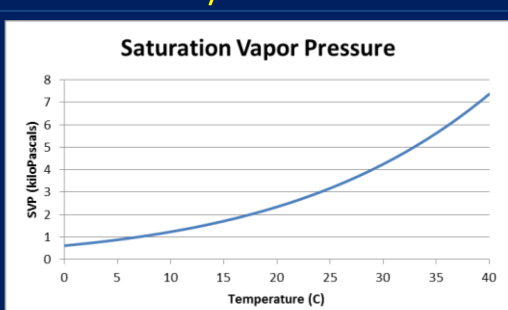
- Free, easy-to-use software developed by USDA-ARS
- Simulates your greenhouse
- Calculates energy costs and benefits of supplemental lighting, CO_2, greenhouse shading and material options
- Great tool for northern growers

Link to Virtual Grower 2.5
https://www.ars.usda.gov/midwest-area/wooster-oh/application-technology-research/docs/virtual-grower/

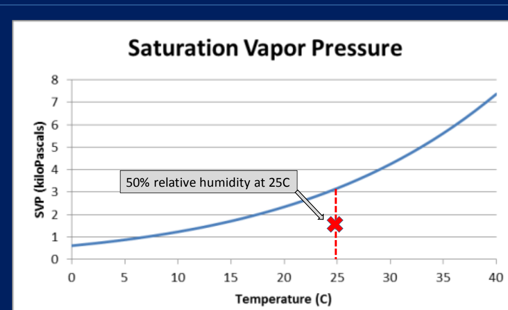
VPD = Vapor pressure deficit

- VPD = difference between vapor pressure in leaf (assumed to be at 100% RH) and vapor pressure in air.
- Related to temperature and relative humidity

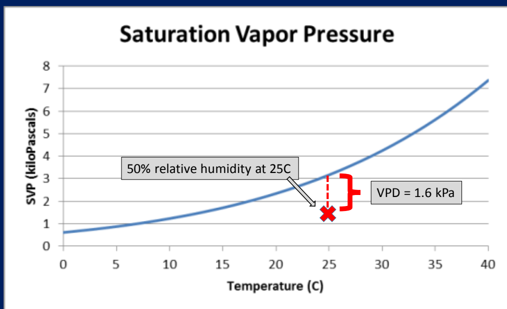
Warm air holds more water at 100% relative humidity



VPD = vapor pressure deficit



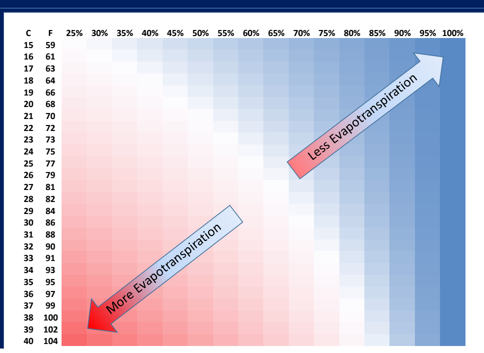
VPD = vapor pressure deficit



VPD = Vapor pressure deficit (kPa)

C	F	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
15	59	1.3	1.2	1.1	1.0	0.9	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.3	0.2	0.1	0.0
16	61	1.4	1.3	1.2	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.5	0.4	0.3	0.2	0.1	0.0
17	63	1.5	1.4	1.3	1.2	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0
18	64	1.5	1.4	1.3	1.2	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0
19	66	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.9	0.8	0.7	0.5	0.4	0.3	0.2	0.1	0.0
20	68	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.9	0.8	0.7	0.6	0.5	0.4	0.2	0.1	0.0
21	70	1.9	1.7	1.6	1.5	1.4	1.2	1.1	1.0	0.9	0.7	0.6	0.5	0.4	0.2	0.1	0.0
22	72	2.0	1.9	1.7	1.6	1.5	1.3	1.2	1.1	0.9	0.8	0.7	0.5	0.4	0.3	0.1	0.0
23	73	2.1	2.0	1.8	1.7	1.5	1.4	1.3	1.1	1.0	0.8	0.7	0.6	0.4	0.3	0.1	0.0
24	75	2.2	2.1	1.9	1.8	1.6	[illegible]	1.3	1.2	1.0	0.9	0.7	0.6	0.4	0.3	0.1	0.0
25	77	2.4	2.2	2.1	1.9	1.7	1.6	1.4	1.3	1.1	1.0	0.8	0.6	0.5	0.3	0.2	0.0
26	79	2.5	2.4	2.2	2.0	1.8	[illegible]	1.5	1.3	1.2	1.0	0.8	0.7	0.5	0.3	0.2	0.0
27	81	2.7	2.5	2.3	2.1	2.0	1.8	1.6	1.4	1.2	1.1	0.9	0.7	0.5	0.4	0.2	0.0
28	82	2.8	2.6	2.5	2.3	2.1	1.9	1.7	1.5	1.3	1.1	0.9	0.8	0.6	0.4	0.2	0.0
29	84	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4	0.2	0.0
30	86	3.2	3.0	2.8	2.5	2.3	2.1	1.9	1.7	1.5	1.3	1.1	0.8	0.6	0.4	0.2	0.0
31	88	3.4	3.1	2.9	2.7	2.5	2.2	2.0	1.8	1.6	1.3	1.1	0.9	0.7	0.4	0.2	0.0
32	90	3.6	3.3	3.1	2.9	2.6	2.4	2.1	1.9	1.7	1.4	1.2	1.0	0.7	0.5	0.2	0.0
33	91	3.8	3.5	3.3	3.0	2.8	2.5	2.3	2.0	1.8	1.5	1.3	1.0	0.8	0.5	0.3	0.0
34	93	4.0	3.7	3.5	3.2	2.9	2.7	2.4	2.1	1.9	1.6	1.3	1.1	0.8	0.5	0.3	0.0
35	95	4.2	3.9	3.7	3.4	3.1	2.8	2.5	2.2	2.0	1.7	1.4	1.1	0.8	0.6	0.3	0.0
36	97	4.5	4.2	3.9	3.6	3.3	3.0	2.7	2.4	2.1	1.8	1.5	1.2	0.9	0.6	0.3	0.0
37	99	4.7	4.4	4.1	3.8	3.5	3.1	2.8	2.5	2.2	1.9	1.6	1.3	0.9	0.6	0.3	0.0
38	100	5.0	4.6	4.3	4.0	3.6	3.3	3.0	2.6	2.3	2.0	1.7	1.3	1.0	0.7	0.3	0.0
39	102	5.2	4.9	4.5	4.2	3.8	3.5	3.1	2.8	2.4	2.1	1.7	1.4	1.0	0.7	0.3	0.0
40	104	5.5	5.2	4.8	4.4	4.1	3.7	3.3	2.9	2.6	2.2	1.8	1.5	1.1	0.7	0.4	0.0

VPD = vapor pressure deficit (kPa)



VPD drives evaporation

Air **warm**
low relative humidity (**dry**)
Low vapor pressure

High VPD
Rapid drying

Leaf warm,
100% relative humidity (**wet**)
High vapor pressure

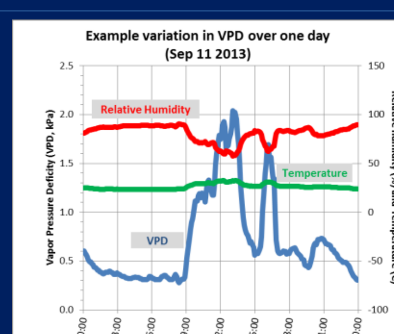
VPD drives evaporation

Air **cool**
High relative humidity (**wet**)
High vapor pressure

Low VPD
Slow drying

Leaf warm,
100% relative humidity (**wet**)
High vapor pressure

VPD varies throughout the day



Managing VPD for greenhouse crops

Tips from Michigan State University

Bedding plants
- 0.3 kPa for propagation
- >0.5 kPa for finished plants

Greenhouse tomato
- 0.8 kPa for high yield
- 2.0 kPa is too dry, cracks fruit

High VPD (>1 kPa) increases the risk of wilting

Thanks for listening

Any questions?

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