Plant Biotechnology

Bayer Russia Plant Biotechnology Conference

July 2023

Introduction to Plant Health in Controlled Environments

Bayer Russia Biotechnology Conference

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Career Path Influenced My Strengths and Styles

Daniel Warnock

SIGNATURE THEMES

Learner

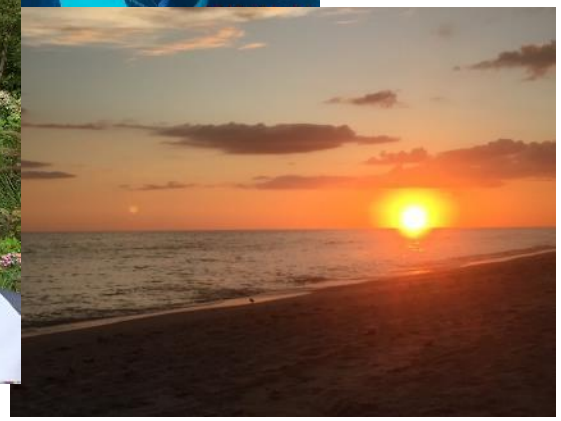
Achiever

Maximizer

Connectedness

Relator

StrengthsFinder®



- Team/relationship centric with emphasis on stewardship and improving life
- Delivering creative solutions to complex problems through application of scientific discovery
- Steady and Conscientious

My Path to St. Louis

Education and Training:

- 1980-1993: Warnock's Chrysanthemum Farm – Crop Production Specialist and Sales
- 1990: B. Sc. Agriculture, University of Georgia, Athens, Georgia;
  - Major: Horticulture
- 1993: M. Sc., University of Georgia, Athens, Georgia;
  - Major: Horticulture
- 1998: Ph. D., University of Minnesota, St. Paul, Minnesota;
  - Major: Horticulture, Minor: Plant Breeding and Genetics
- 1998-2010: University of Illinois – Faculty of Horticulture
- 2010-Present: Monsanto/Bayer – Controlled Environments

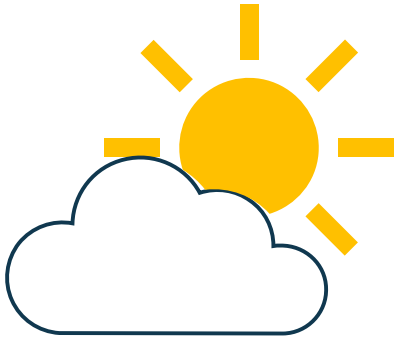
- Senior Research Scientist
  - Provide novel solutions to emerging needs while onboarding new technologies as a subject matter expert in controlled environment spaces. Deliver robust data to enable strategic decisions for controlled environment success at Bayer

Introduction to Plant Health: Agenda

Topic 1	Think Like The Plant
Topic 2	Environmental Control Levers to Pull
Topic 3	Action and Reaction
Topic 4	Environmental Control Parameters
Topic 5	Summary

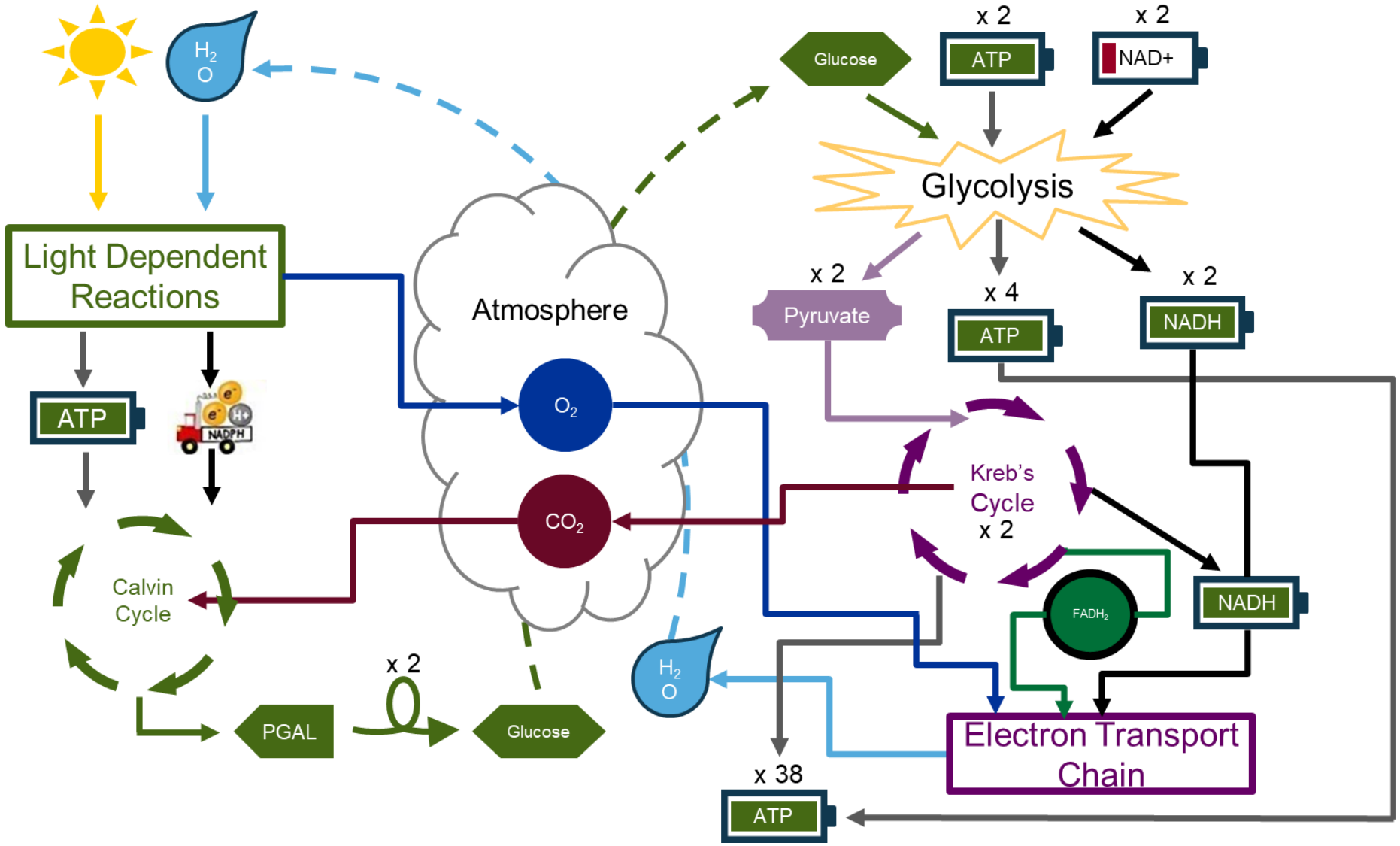
Think Like the Plant: Physiology

- Everything essential must be close for survival
- For success in a greenhouse, we must provide adequate
  - Light
  - Temperature
  - Water
  - Nutrients
  - Carbon Dioxide
- A potted plant is an island sitting on a sea of concrete
  - Everything associated with plant survival may be in limited supply



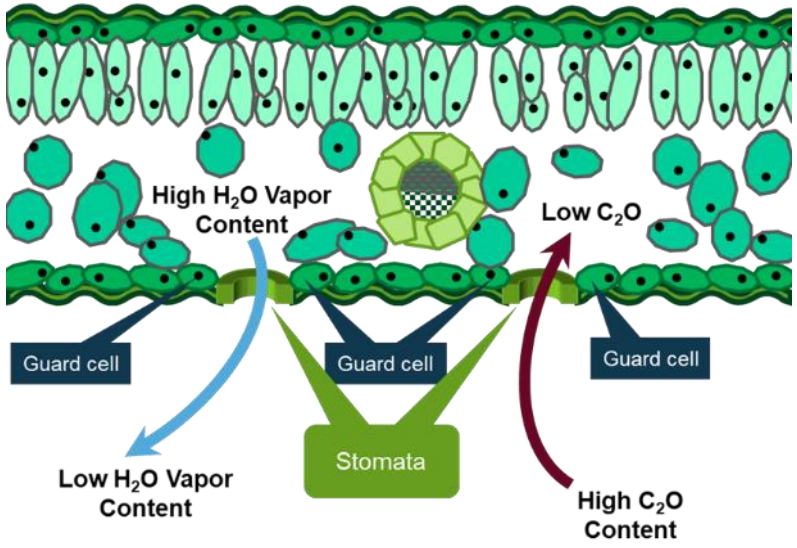
Think Like the Plant: Physiology

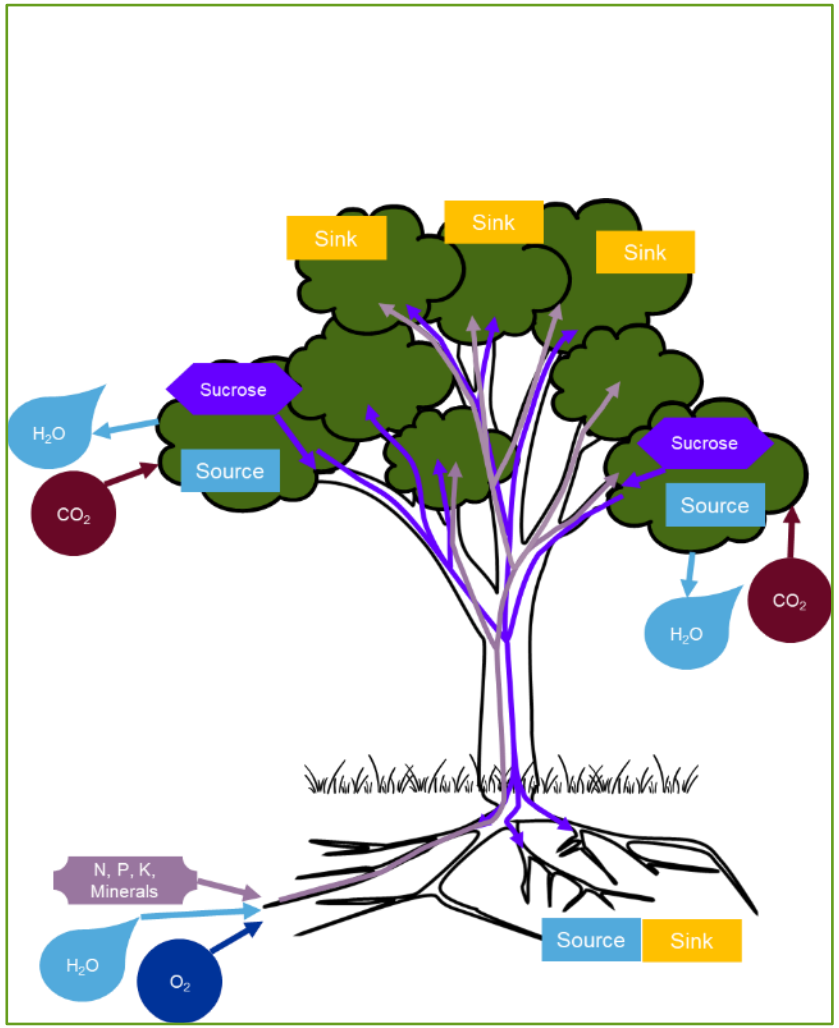
- Ability to control 5 essentials varies by:
  - Mechanical equipment available
  - Geographic location
  - Availability and quality of consumable inputs
  - Personnel experience
- Temperature > Water/Nutrients > Light > Humidity > CO_2 for easiness of control



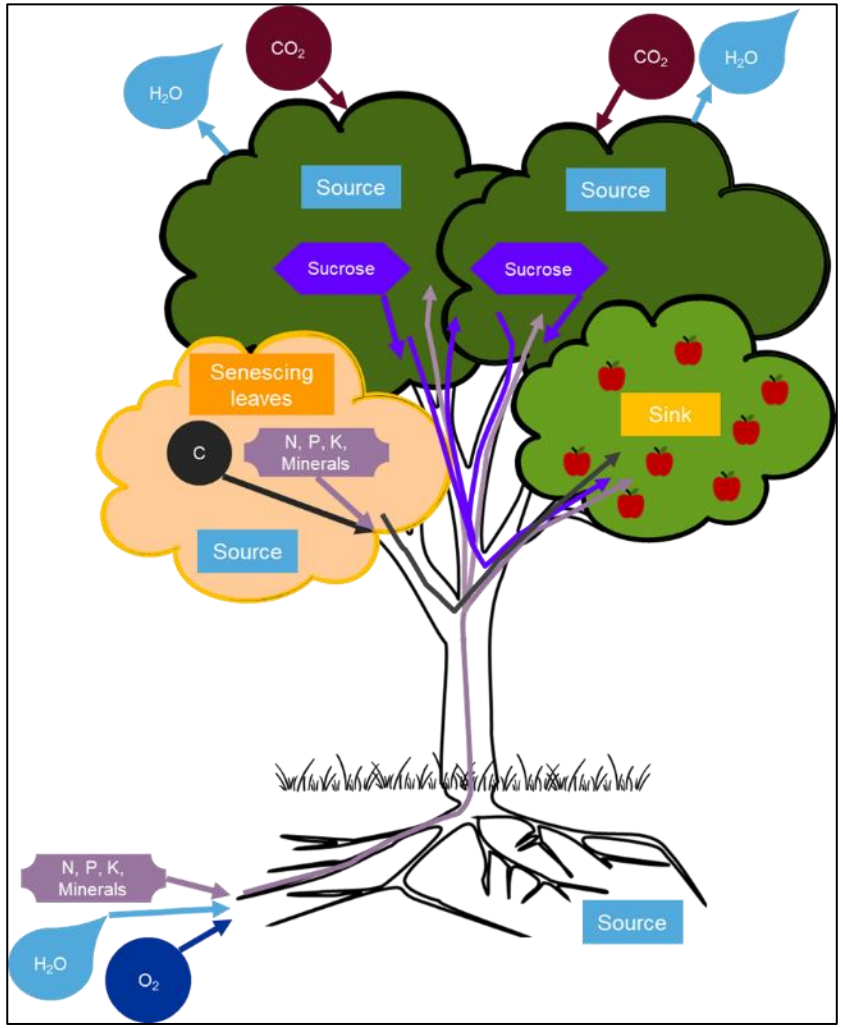
Think Like the Plant: Physiology

- Transpiration drives transport
- Stomata opening and closing is a balancing act
- Any stress during production limits growth but may speed fruiting





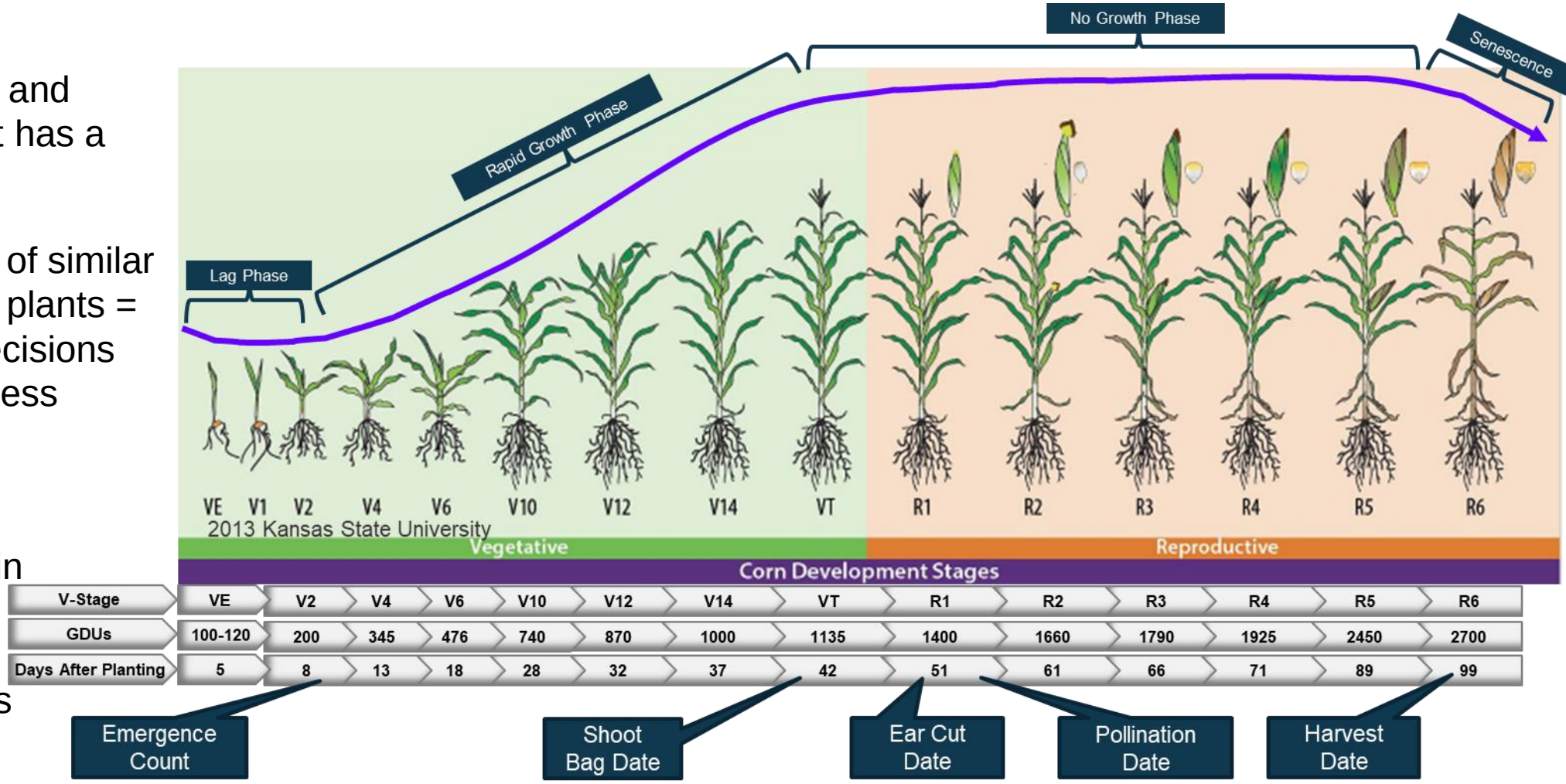
Vegetative Phase



Fruiting Phase

Think Like the Plant: Physiology

- Plant growth and development has a pattern
- Monoculture of similar aged (sized) plants = optimized decisions and limits stress
- Mixed crops or different aged plants in the same space = compromises

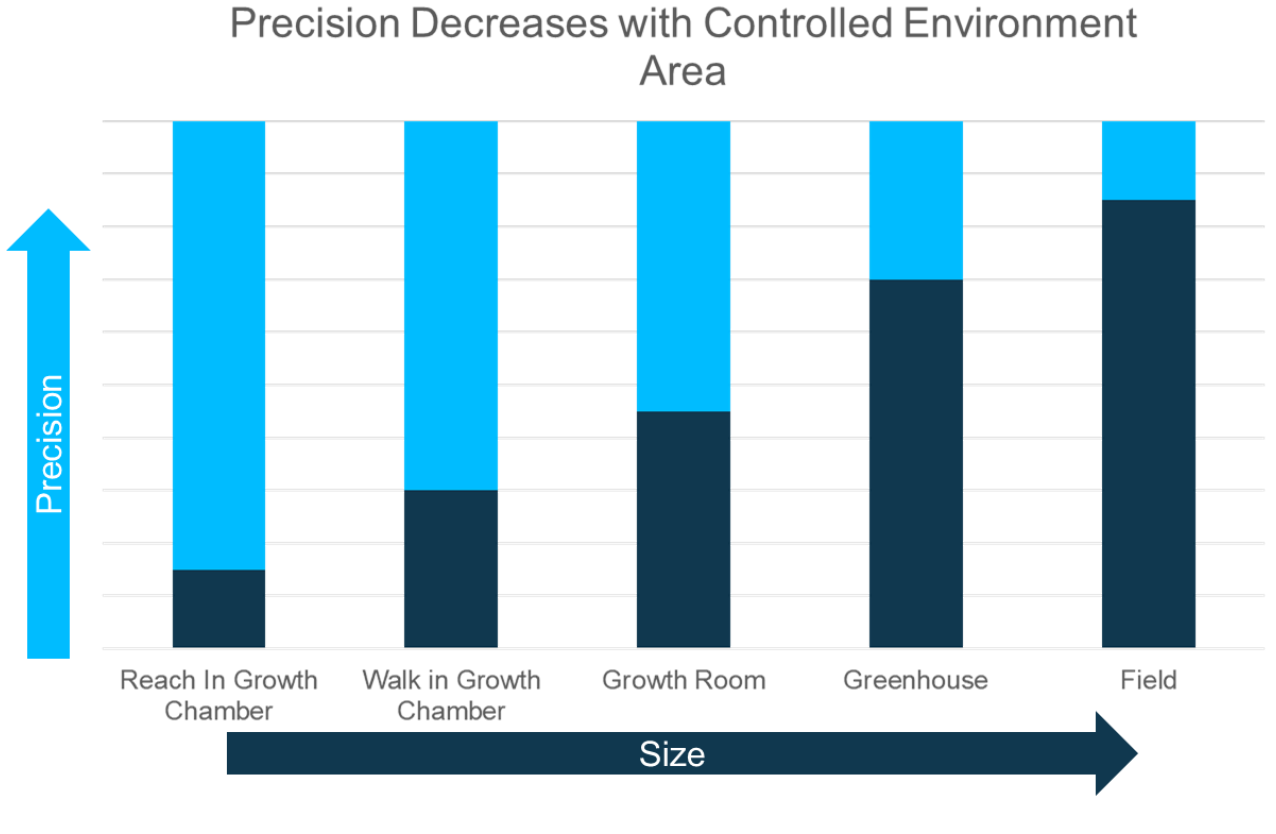


Think Like the Plant: Communication and Signals

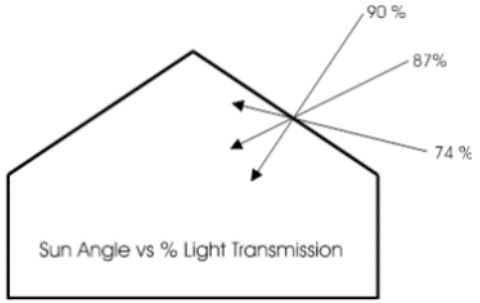
- Plants express stress in various ways
  - Slowed growth rate
  - Atypical phenotypes
  - Color changes
  - Necrosis
  - Missing tissue
  - Fungal growth
- If you can see it, it is too late the damage is done

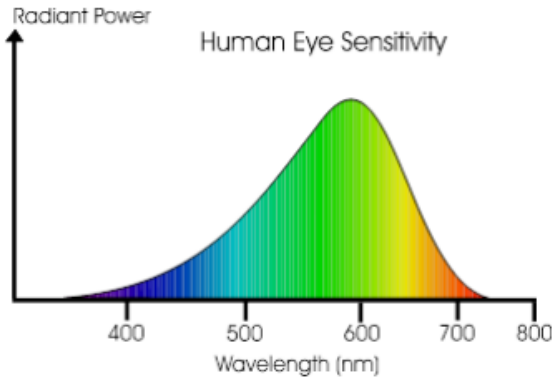
Environmental Control Levers to Pull: Managed vs Controlled

- 5 Levers to pull in Controlled Environments
  1. Light
  2. Temperature
  3. Water
  4. Nutrients
  5. Carbon Dioxide
- Ease of manipulation varies by facility mechanics, size, location, and the time of year
- Liebig's law of minimum

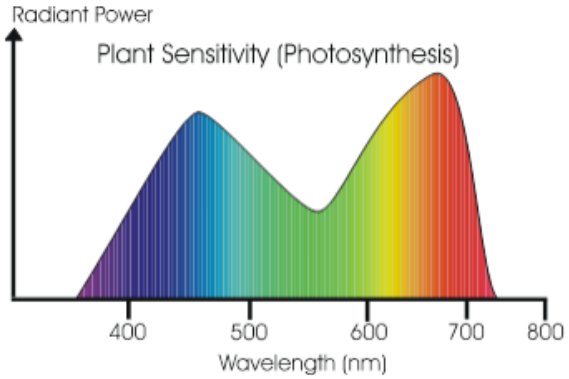


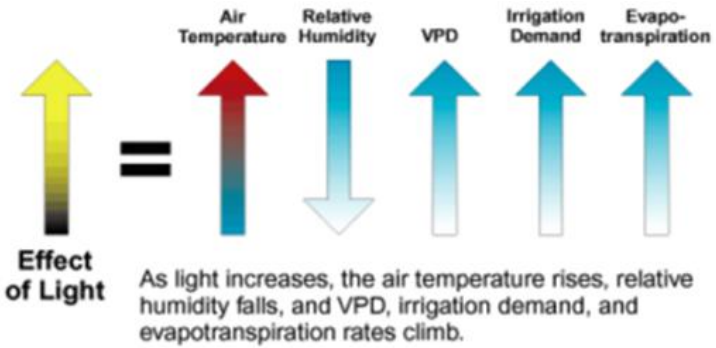
Action and Reaction: Light





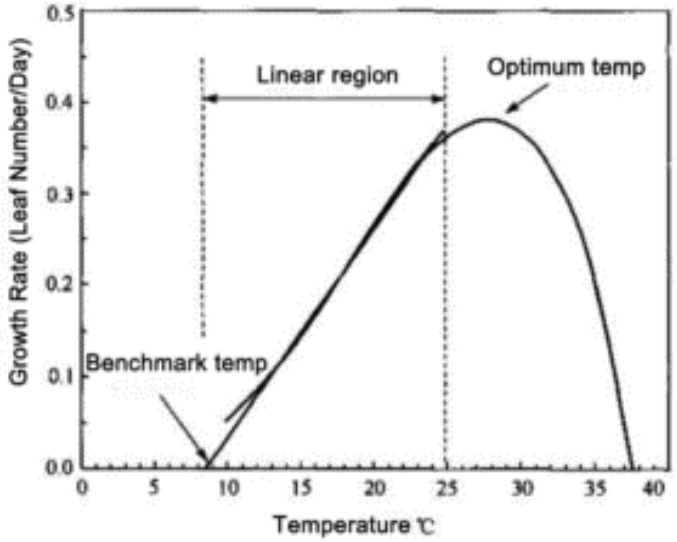
- Gas/Energy
- In northern climates PAR light is often limited especially in winter
- Use Daily light integral (DLI) – Light accumulated per day (mol/m^2/day)
- Agronomic crops are high light users. Minimum of 25 mol/m^2/day
- Supplemental light sources vary in quality and quantity of PAR light
- Greenhouse lighting must meet minimum target during winter season

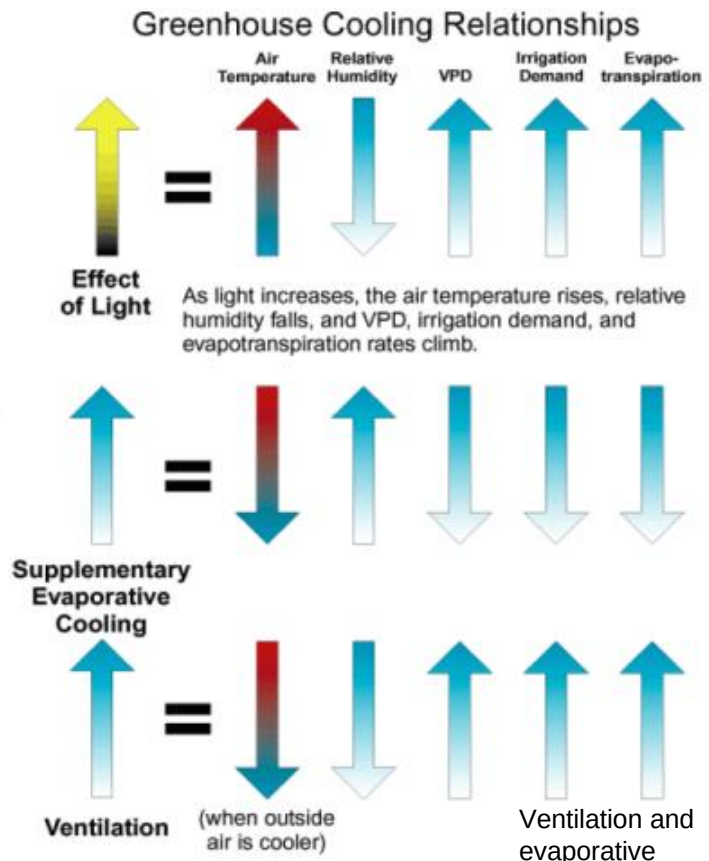




Action and Reaction: Temperature

- Accelerator/Speed
- Each crop has an optimum temperature for growth and development
- Greenhouse manages air temperature not leaf temperature
- Thermal layers may impact upper canopy health and pollen viability

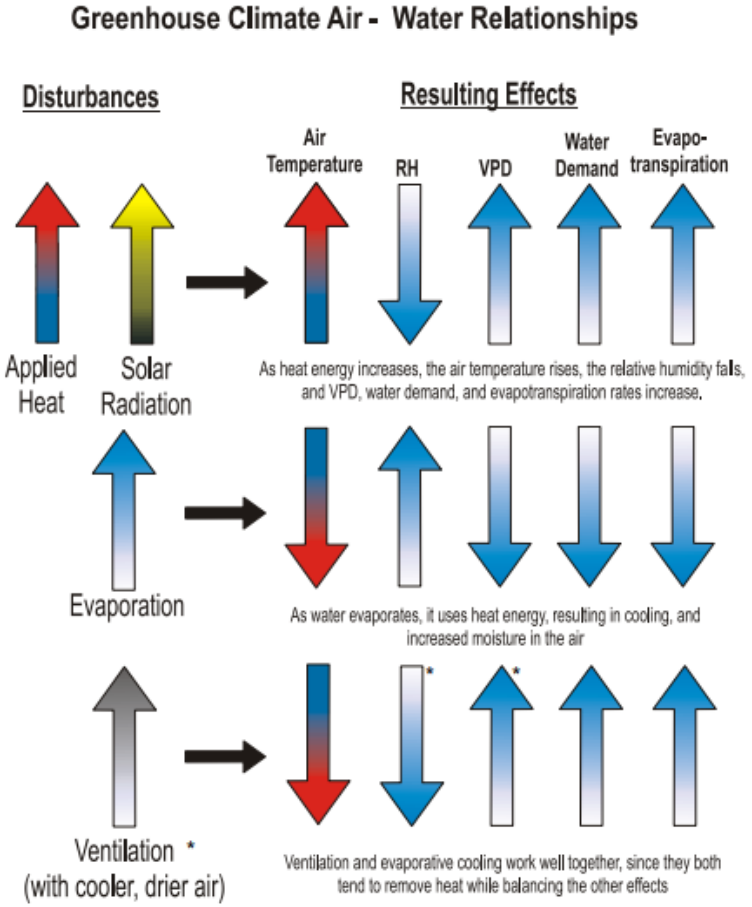




Ventilation and evaporative cooling work well together as they both increase cooling while balancing the other climate effects.

Action and Reaction:
Water - Irrigation/Fertigation

- Oil
- Rooting medium impacts water holding capacity, aeriation, and plant health – Avoid using topsoil in pots
- Seasonal transitions are difficult to manage – Daily fluctuations
- Early life stage management may impact late-stage development
- Agronomic crops are not bred for production in greenhouses



Ventilation alone may not always decrease the relative climate humidity, depending on the amount of moisture in the incoming air and how much the greenhouse temperature is decreased. However, in greenhouses, ventilation for humidity control is usually combined with reheating to the target setpoint, resulting in a net reduction in the relative humidity.

Action and Reaction: Water – Humidity/VPD

- Brakes on internal transport and CO_2 capture
- Vapor Pressure Deficit (VPD) in greenhouses is approximation based on air temperature and RH
- Too high = closed stomata to conserve H_2O and thus no CO_2 capture

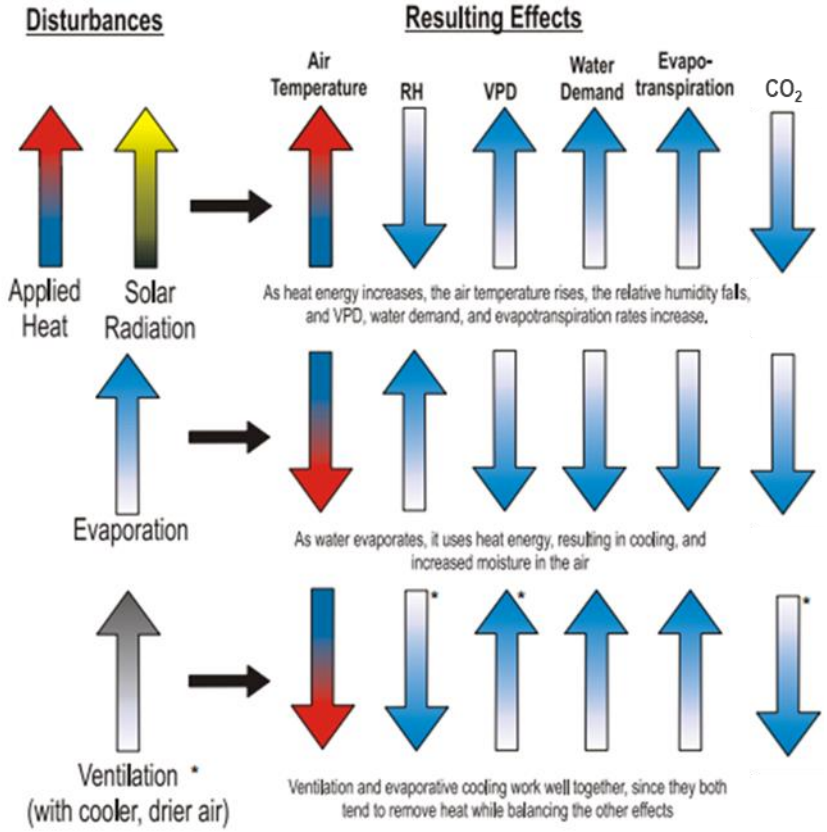
RH (%)

(°C)	100	98	96	94	92	90	88	86	84	82	80	78	76	74	72	70	68	66	64	62	60	58	56	54	52	50	48	46	44	42	40	38	36	34	32	30	28	26	24	22	20	18	16	14	12	10
10	0.00	0.02	0.05	0.07	0.10	0.12	0.15	0.17	0.20	0.22	0.25	0.27	0.29	0.32	0.34	0.37	0.39	0.42	0.44	0.47	0.49	0.52	0.54	0.56	0.59	0.61	0.64	0.66	0.69	0.71	0.74	0.76	0.79	0.81	0.83	0.86	0.88	0.91	0.93	0.96	0.98	1.01	1.03	1.06	1.08	1.11
12	0.00	0.03	0.06	0.08	0.11	0.14	0.17	0.20	0.22	0.25	0.28	0.31	0.34	0.36	0.39	0.42	0.45	0.48	0.50	0.53	0.56	0.59	0.62	0.65	0.67	0.70	0.73	0.76	0.79	0.81	0.84	0.87	0.90	0.93	0.95	0.98	1.01	1.04	1.07	1.09	1.12	1.15	1.18	1.21	1.23	1.26
14	0.00	0.03	0.06	0.10	0.13	0.16	0.19	0.22	0.26	0.29	0.32	0.35	0.38	0.42	0.45	0.48	0.51	0.54	0.58	0.61	0.64	0.67	0.70	0.74	0.77	0.80	0.83	0.86	0.90	0.93	0.96	0.99	1.02	1.06	1.09	1.12	1.15	1.18	1.21	1.25	1.28	1.31	1.34	1.37	1.41	1.44
16	0.00	0.04	0.07	0.11	0.15	0.18	0.22	0.25	0.29	0.33	0.36	0.40	0.44	0.47	0.51	0.55	0.58	0.62	0.65	0.69	0.73	0.76	0.80	0.84	0.87	0.91	0.95	0.98	1.02	1.05	1.09	1.13	1.16	1.20	1.24	1.27	1.31	1.35	1.38	1.42	1.45	1.49	1.53	1.56	1.60	1.64
18	0.00	0.04	0.08	0.12	0.17	0.21	0.25	0.29	0.33	0.37	0.41	0.45	0.50	0.54	0.58	0.62	0.66	0.70	0.74	0.78	0.83	0.87	0.91	0.95	0.99	1.03	1.07	1.11	1.16	1.20	1.24	1.28	1.32	1.36	1.40	1.44	1.49	1.53	1.57	1.61	1.65	1.69	1.73	1.77	1.82	1.86
20	0.00	0.05	0.09	0.14	0.19	0.23	0.28	0.33	0.37	0.42	0.47	0.51	0.56	0.61	0.65	0.70	0.75	0.79	0.84	0.89	0.94	0.98	1.03	1.08	1.12	1.17	1.22	1.26	1.31	1.36	1.40	1.45	1.50	1.54	1.59	1.64	1.68	1.73	1.78	1.82	1.87	1.92	1.96	2.01	2.06	2.10
22	0.00	0.05	0.11	0.16	0.21	0.26	0.32	0.37	0.42	0.48	0.53	0.58	0.63	0.69	0.74	0.79	0.85	0.90	0.95	1.00	1.06	1.11	1.16	1.22	1.27	1.32	1.37	1.43	1.48	1.53	1.59	1.64	1.69	1.74	1.80	1.85	1.90	1.96	2.01	2.06	2.11	2.17	2.22	2.27	2.33	2.38
24	0.00	0.06	0.12	0.18	0.24	0.30	0.36	0.42	0.48	0.54	0.60	0.66	0.72	0.78	0.84	0.90	0.95	1.01	1.07	1.13	1.19	1.25	1.31	1.37	1.43	1.49	1.55	1.61	1.67	1.73	1.79	1.85	1.91	1.97	2.03	2.09	2.15	2.21	2.27	2.33	2.39	2.45	2.51	2.57	2.63	2.69
26	0.00	0.07	0.13	0.20	0.27	0.34	0.40	0.47	0.54	0.61	0.67	0.74	0.81	0.87	0.94	1.01	1.08	1.14	1.21	1.28	1.34	1.41	1.48	1.55	1.61	1.68	1.75	1.82	1.88	1.95	2.02	2.08	2.15	2.22	2.29	2.35	2.42	2.49	2.55	2.62	2.69	2.76	2.82	2.89	2.96	3.03
28	0.00	0.08	0.15	0.23	0.30	0.38	0.45	0.53	0.60	0.68	0.76	0.83	0.91	0.98	1.06	1.13	1.21	1.29	1.36	1.44	1.51	1.59	1.66	1.74	1.81	1.89	1.97	2.04	2.12	2.19	2.27	2.34	2.42	2.49	2.57	2.65	2.72	2.80	2.87	2.95	3.02	3.10	3.17	3.25	3.33	3.40
30	0.00	0.08	0.17	0.25	0.34	0.42	0.51	0.59	0.68	0.76	0.85	0.93	1.02	1.10	1.19	1.27	1.36	1.44	1.53	1.61	1.70	1.78	1.87	1.95	2.04	2.12	2.21	2.29	2.38	2.46	2.55	2.63	2.72	2.80	2.88	2.97	3.05	3.14	3.22	3.31	3.39	3.48	3.56	3.65	3.73	3.82
32	0.00	0.10	0.19	0.29	0.38	0.48	0.57	0.67	0.76	0.86	0.95	1.05	1.14	1.24	1.33	1.43	1.52	1.62	1.71	1.81	1.90	2.00	2.09	2.19	2.28	2.38	2.47	2.57	2.66	2.76	2.85	2.95	3.04	3.14	3.23	3.33	3.42	3.52	3.61	3.71	3.80	3.90	3.99	4.09	4.18	4.28
34	0.00	0.11	0.21	0.32	0.43	0.53	0.64	0.74	0.85	0.96	1.06	1.17	1.28	1.38	1.49	1.60	1.70	1.81	1.91	2.02	2.13	2.23	2.34	2.45	2.55	2.66	2.77	2.87	2.98	3.08	3.19	3.30	3.40	3.51	3.62	3.72	3.83	3.94	4.04	4.15	4.25	4.36	4.47	4.57	4.68	4.79
36	0.00	0.12	0.24	0.36	0.48	0.59	0.71	0.83	0.95	1.07	1.19	1.31	1.43	1.54	1.66	1.78	1.90	2.02	2.14	2.26	2.38	2.49	2.61	2.73	2.85	2.97	3.09	3.21	3.33	3.45	3.56	3.68	3.80	3.92	4.04	4.16	4.28	4.40	4.51	4.63	4.75	4.87	4.99	5.11	5.23	5.35
38	0.00	0.13	0.26	0.40	0.53	0.66	0.79	0.93	1.06	1.19	1.32	1.46	1.59	1.72	1.85	1.99	2.12	2.25	2.38	2.52	2.65	2.78	2.91	3.05	3.18	3.31	3.44	3.58	3.71	3.84	3.97	4.11	4.24	4.37	4.50	4.64	4.77	4.90	5.03	5.17	5.30	5.43	5.56	5.70	5.83	5.96
40	0.00	0.15	0.29	0.44	0.59	0.74	0.88	1.03	1.18	1.33	1.47	1.62	1.77	1.92	2.06	2.21	2.36	2.51	2.65	2.80	2.95	3.10	3.24	3.39	3.54	3.69	3.83	3.98	4.13	4.28	4.42	4.57	4.72	4.87	5.01	5.16	5.31	5.46	5.60	5.75	5.90	6.05	6.19	6.34	6.49	6.64
42	0.00	0.16	0.33	0.49	0.66	0.82	0.98	1.15	1.31	1.48	1.64	1.80	1.97	2.13	2.30	2.46	2.62	2.79	2.95	3.12	3.28	3.44	3.61	3.77	3.94	4.10	4.26	4.43	4.59	4.75	4.92	5.08	5.25	5.41	5.57	5.74	5.90	6.07	6.23	6.39	6.56	6.72	6.89	7.05	7.21	7.38
44	0.00	0.18	0.36	0.55	0.73	0.91	1.09	1.27	1.46	1.64	1.82	2.00	2.18	2.37	2.55	2.73	2.91	3.09	3.28	3.46	3.64	3.82	4.00	4.19	4.37	4.55	4.73	4.91	5.10	5.28	5.46	5.64	5.82	6.01	6.19	6.37	6.55	6.73	6.92	7.10	7.28	7.46	7.64	7.83	8.01	8.19

Dangerous
High Stress
Flower
Vegetative
Nursery
Fungal Pathogens
Dew Point

Action and Reaction:
Carbon Dioxide/Oxygen

- Spark Plug?
- Difficult to manage in open and semi-closed greenhouses due to ventilation needs
- Low levels in crop canopy may limit growth during winter without air exchanges
- Supplemental CO_2 beneficial when possible



Increased ventilation will lower supplemental CO_2 levels unless internal CO_2 levels are below ambient

Environmental Control Parameters: Climate

- During rapid growth phase target even environment without excessive growth rate
- Plant growth slows with reproductive development so target carbon reallocation
- As plant senescence (grain fill) occurs, target drier environment with cooler temperatures

Climate Controls	Vegetative	Reproductive	Range of Control Values
Average Daily Setpoint Temperature	Lower	Higher	20 – 28° C: higher temperatures at higher light levels
Day-Night Temperature Difference	Smaller	Larger	0 – 5° C
Start time for heating in the morning	Earlier	Later	4 hours before sunrise to sunrise
Afternoon temperature increase	None or small	Larger	0 – 2.5° C
Start Time for Day-Night Temperature Decrease	Earlier	Later	2 hours before to 2 hours after sunset
Speed of Day-Night Temperature Decrease	Slower	Faster	0 - 4° C per hour
Humidity deficit	Decrease	Increase	8 - 15 mB
Vapor Pressure Deficit	Lower	Higher	0.8 – 1.5 kPa
CO_2 enrichment	More	Less	350 – 1500 ppm: Higher CO_2 at higher light levels

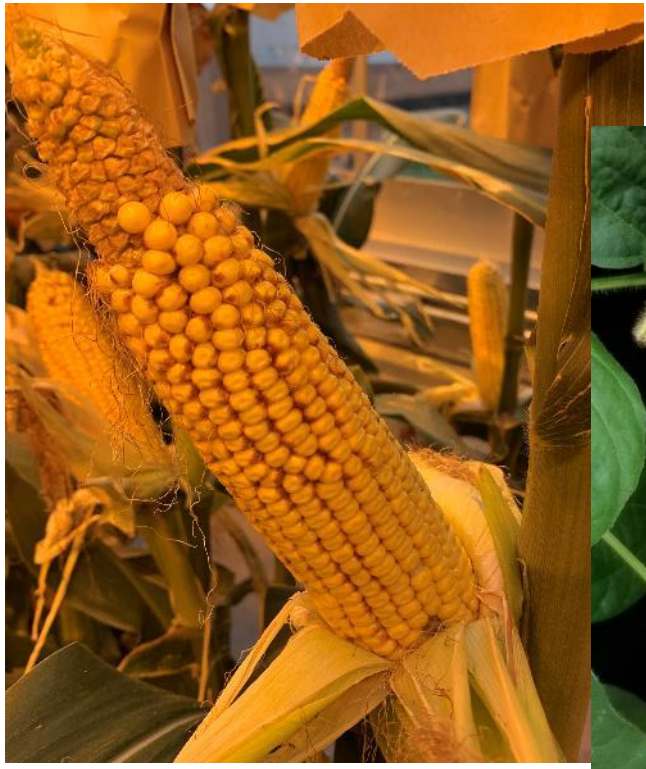
Environmental Control Parameters: Fertigation

- During rapid growth phase plant will be utilizing nutrients and water at increasing rate
- Plant growth slows with reproductive development but avoid drought stress during flowering and pollination
- As plant senescence (grain fill) occurs water use will decrease
  - Last 2 weeks of cycle

Watering Controls	Vegetative	Reproductive	Range of Control Values
EC Growing Medium	Decrease	Increase	1.8 - 4.5 EC
EC Irrigation Water	Decrease	Increase	2.0 - 2.8 EC
Substrate Water Content	Increase	Decrease	45 - 65%
Day-Night Water Content Decrease	Decrease	Increase	2 - 10% (5 - 15% with Rockwool)
Irrigation cycle length and frequency	Short and Higher	Long and Lower	50 - 150 ml per dripper
Start time first irrigation	Earlier	Later	1 - 3 hours after sunrise/lights on
Stop time last irrigation	Later	Earlier	3 - 5 hours before sunset/lights off

Summary: Survival is Key

- Environmental management early in crop cycle impacts later developmental stages
  - Early mistakes may be impactful
- Limiting factors vary by crop, location, season, and greenhouse mechanics
  - Manage what you have available
  - There are limits to what can be controlled
- For every lever pulled there is a reaction with the other levers
- Balancing act between open and closed stomates
- Water management is critical for success
- When stressed the plant wants to survive



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Thank you!

Any questions?