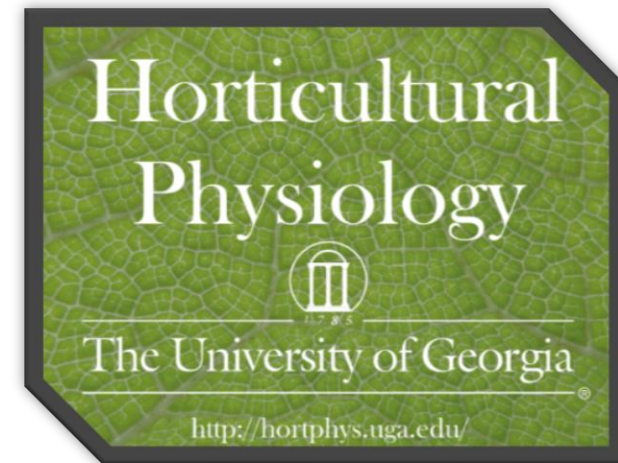


# Lettuce Tolerates Fluctuating Light, Potentially Reducing Energy Costs in Controlled Environment Agriculture (CEA)

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# Supplemental Lighting

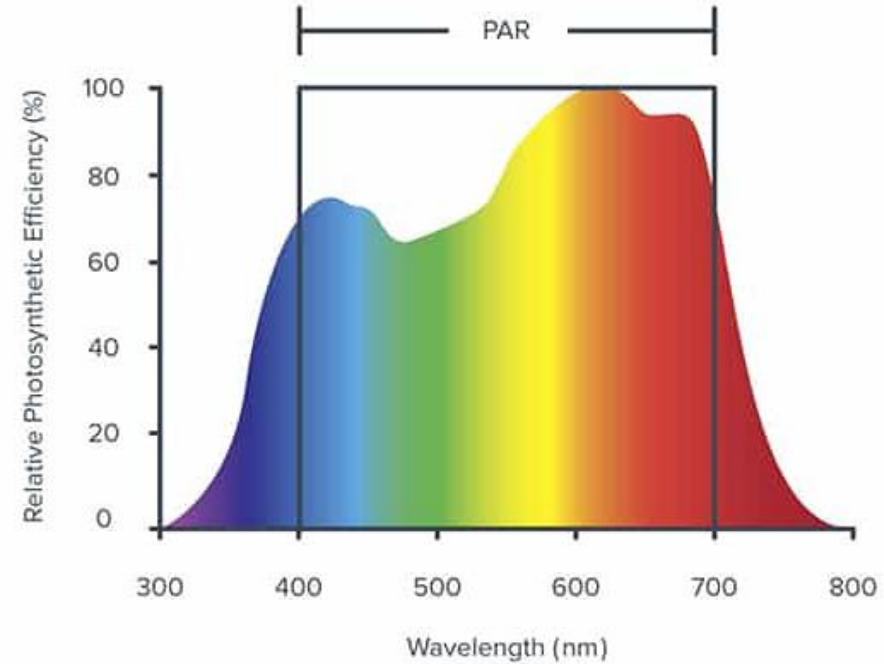
- Necessary for consistent year-round production
  - Due to season and day-to-day fluctuations in light level
- \$600 million (US) on electricity alone
- LEDs as opposed to High Pressure Sodium
  - Flexible and easily controlled
  - Uses less energy

# Key Terms

- Photosynthetically active radiation (PAR) 400-700 nm
- PPFD-Photosynthetic Photon Flux Density ( $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ )
  - Light is measured in PPFD because photosynthesis is a quantum driven process not an energy driven process

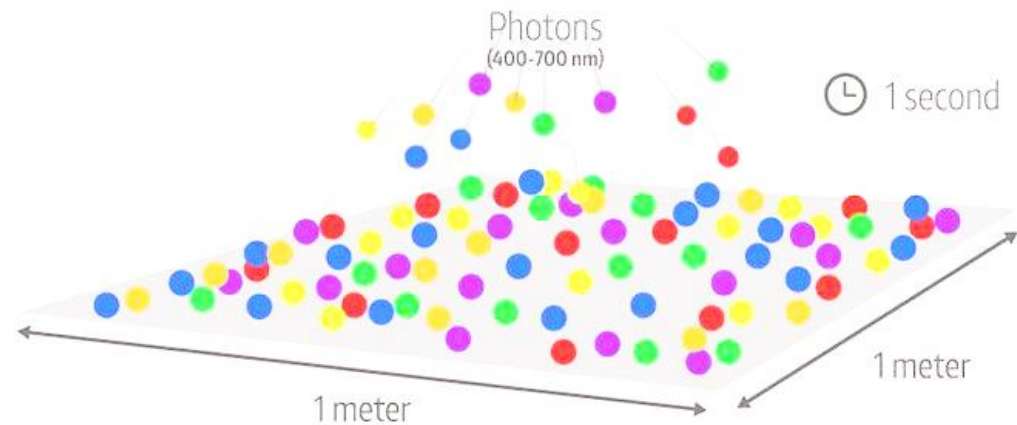
<https://www.greenbudguru.com/what-is-par-light-measurement>

<https://www.atophort.com/news/how-to-choose-a-reliable-led-grow-light-part-one.html>



Photosynthetic Photon Flux Density (PPFD)

Light source



# Variable Electricity Prices (VEP)

Provide lighting during off peak times

Growers-  
Reduce costs

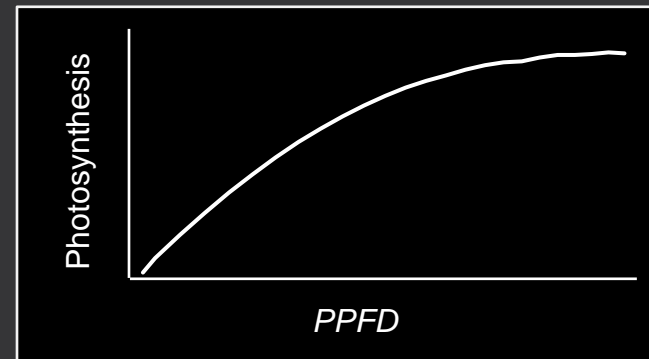
Utility Companies-  
Lower strain on electricity  
grid

*VEP are  
offered by  
utility  
companies  
based on  
demand*

*Means of  
energy  
management  
for CEA, the  
second  
highest  
energy user  
behind  
datacenters*

How do plants respond to fluctuating lights?

- Objectives:
  - Determine the growth effects due to fluctuating lights
  - Understand physiological reason for differences in growth
- Hypothesis:
  - A constant PPFD will result in more photosynthesis and increased biomass production, compared to fluctuating PPFD.



Photosynthesis increases asymptotically with increasing PPFD



Little Gem



Green Salad Bowl

# Experimental Design

- Two cultivars of lettuce (*Lactuca sativa*)
  - Little Gem
  - Green Salad Bowl

# Treatments

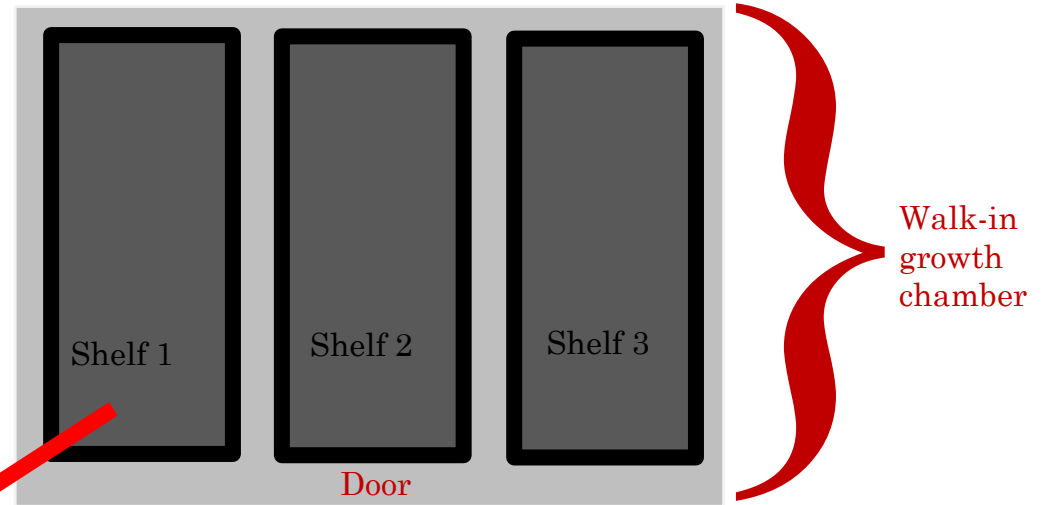
**15 mins of high *PPFD* and 15 of a low *PPFD***

- 1) 400/0  $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$  **Worst Treatment**
- 2) 360/40  $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$
- 3) 320/80  $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$
- 4) 280/120  $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$
- 5) 240/160  $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$
- 6) 200/200  $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$  **Best Treatment**

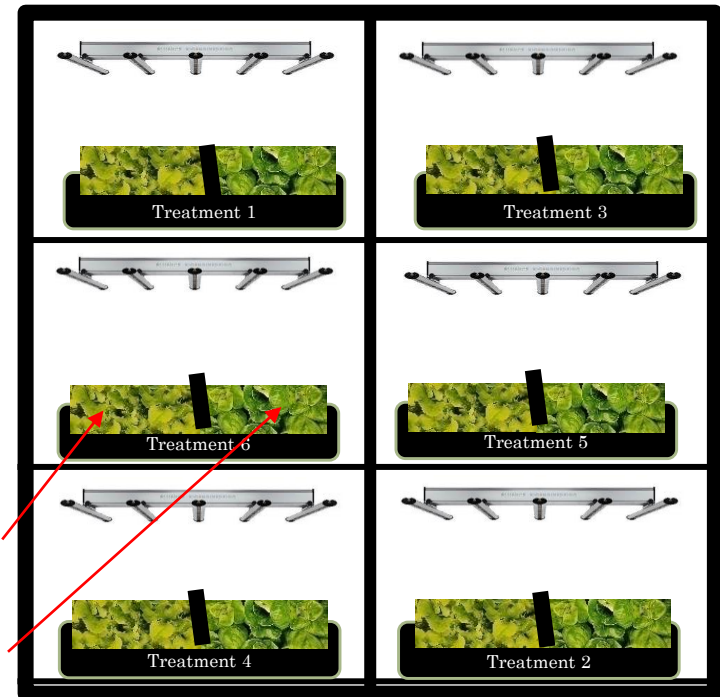
# Walk-in growth chamber set-up



Overhead: 3 shelving units = 3 replications



Shelf 1

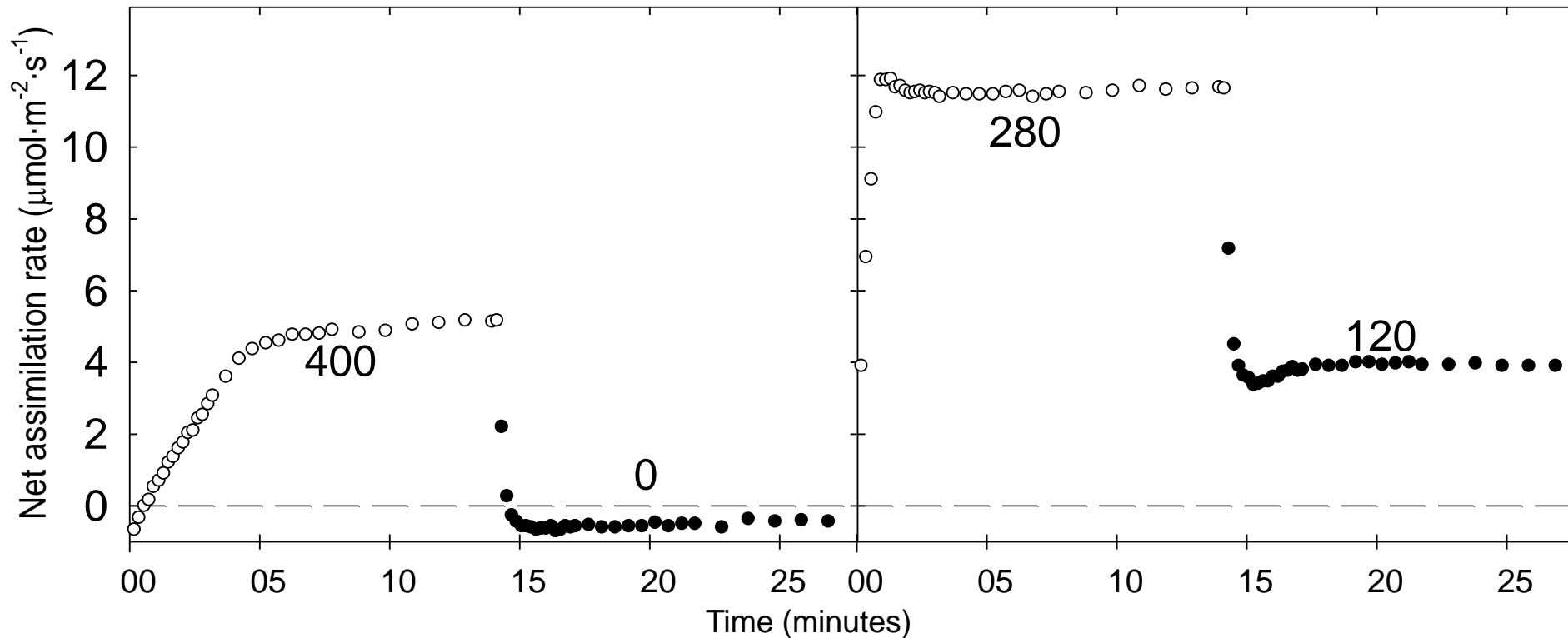


Green salad bowl

Little gem

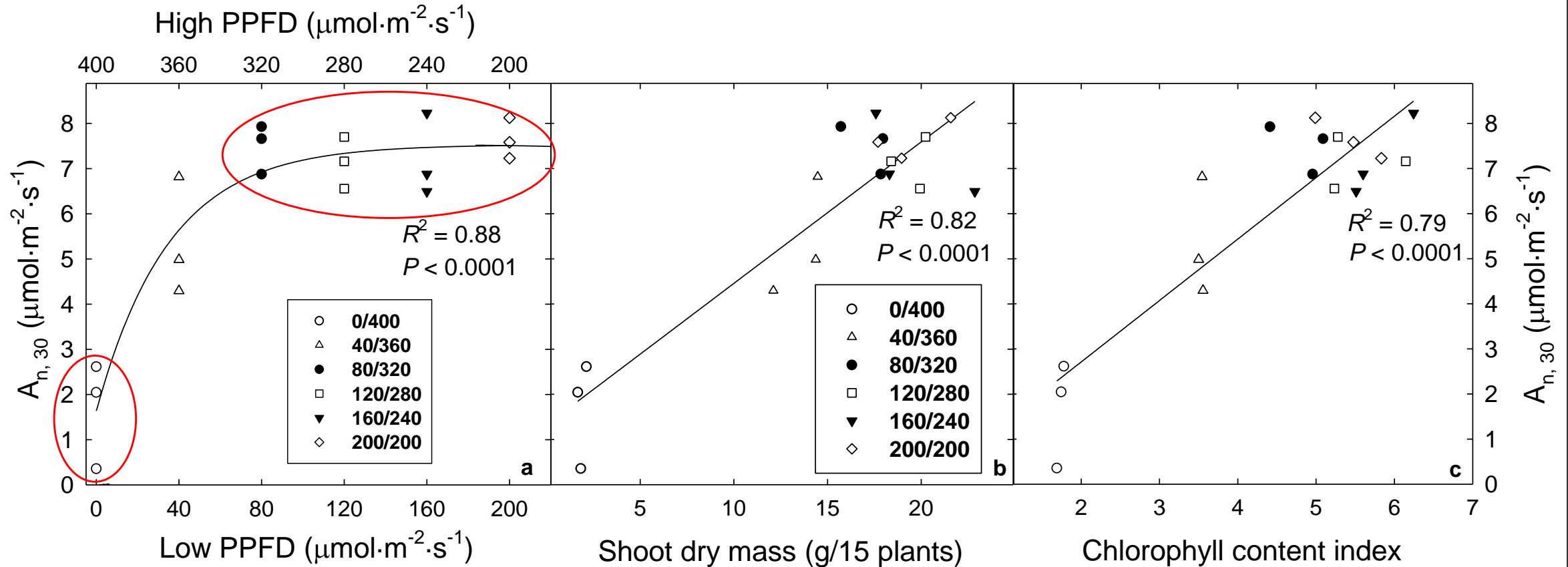


# Net assimilation ( $A_n$ )



- Negative  $A_n$  rates in the low fluctuation of the 400/0 treatment
- The rates of  $A_n$  are higher for the 280/120 treatment despite a higher PPFD of 400 in the 400/0 treatment

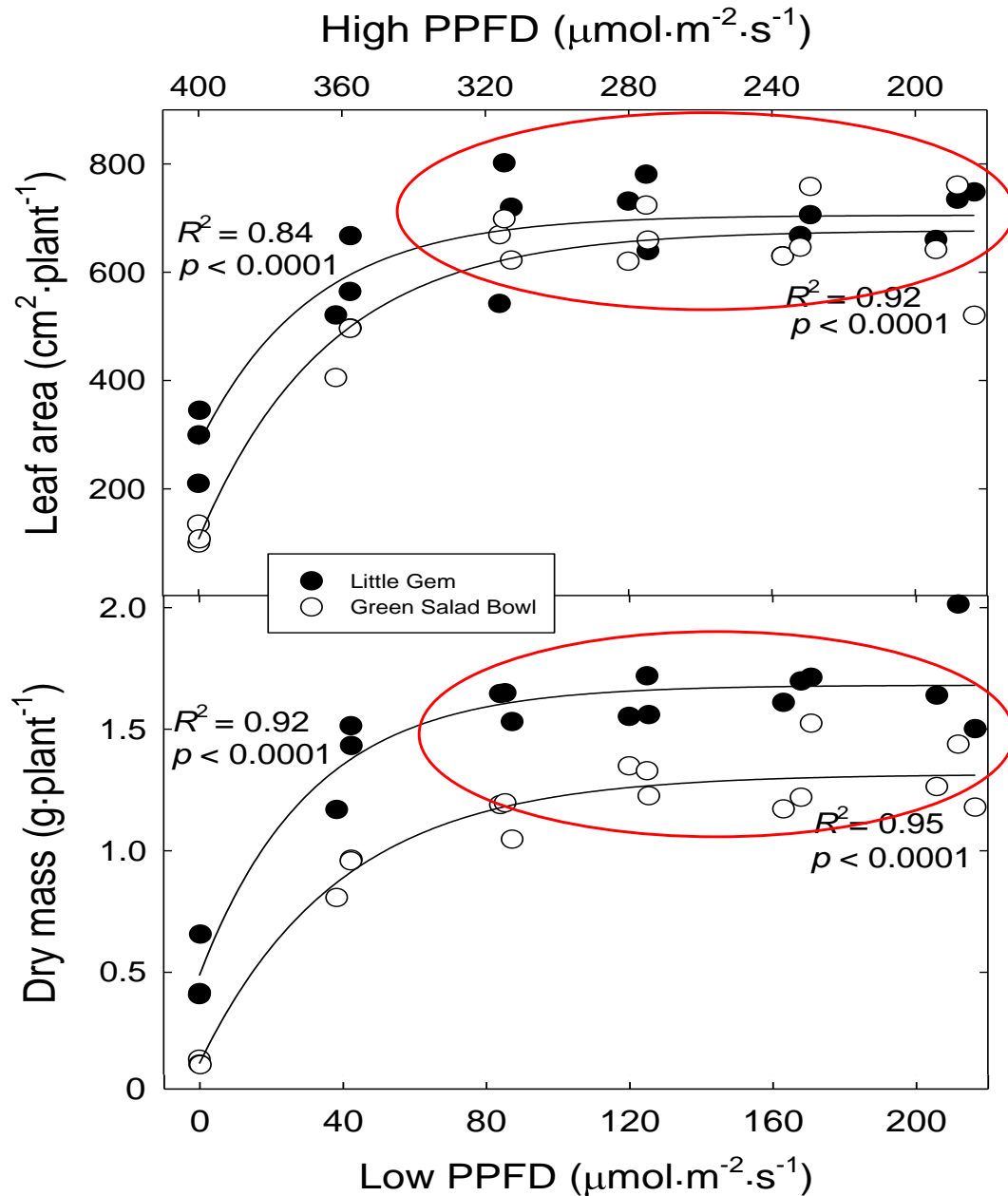
# PPFD, averaged assimilation, and growth



- Asymptotic increase in  $A_{n,30}$  as fluctuations decrease
- Rates of assimilation correlate positively to dry mass and Chlorophyll content index

# Growth responses

- Asymptotic increase in leaf area and dry mass
- Similar results in the small fluctuation treatments
  - Lettuce can tolerate fluctuating lights



# Little Gem



Green Salad Bowl

## Conclusions

Lettuce tolerates a wide range of fluctuating light levels

Extreme fluctuations decrease growth

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# Practical Implications

- Tolerance suggest that adjusting to variable prices is possible
- Potentially decrease
  - Cost for growers
  - Grid strain on utility companies



# Present Studies using Variable Electricity Prices

Implementation by Shirin Afzali and Dr. Javad Mohammadpour Velni

- Controlling lighting based on real time pricing, using Raspberry Pi micro-computer

# Acknowledgements



## Lighting Approaches to Maximize Profits



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# Questions or Comments