Measurement of Leaf Gas Exchange Based on a New Single Step CO_2 Response Method for Rapidly Obtaining A Vs. C_i Curves

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Introduction

- A vs. C_i curves can identify the photosynthetic rate for plants under a variety of environmental or experimental conditions.
- Although a valuable part of the physiologist's toolkit, A vs. C_i curves are underutilized due to lengthy collection times (> 40 minutes per leaf).
- [1]Far-red (FR) radiation (700 – 750 nm) has been shown to contribute to photosynthesis in plants in conjunction with currently-defined photosynthetically active radiation (PAR; 400 – 700 nm). However, species- and cultivar-specific response to FR is not well-documented although FR is equivalent to roughly 19% of the photon flux of PAR[2].
- **Objective 1: We tested a novel, single-step CO_2 response to rapidly collect A vs. C_i curves in less time than traditional methods.**
- **Objective 2: Identify differences in the photosynthetic response of multiple species, and cultivars within species, to FR light.**

Results

- **Rapid collection of A vs. C_i curves agrees with steady-state data (Figure 1).**
  - **This approach reduces the data collection time from 40 minutes to 5 minutes.**
- **Species and cultivars within species varied greatly in response to FR light.**
  - For Swiss Chard (both cultivars) and Apple (Mcintosh and Gingergold), increasing FR increased the rate of assimilation across the A vs. C_i curves.
    - The opposite was the case for Lettuce (Green), Strawberry, and Apple (Gingergold), and no difference was seen for Lettuce (Red).
  - Large differences in the maximum assimilation rate were found between species and cultivars within species.
    - Apple: Paulared had the highest assimilation rate of all species/cultivars.
    - Lettuce/Swiss Chard: Green leaf types assimilated more rapidly than Red leaf types.
    - Strawberry: Assimilation rate was heavily reduced by any FR light.

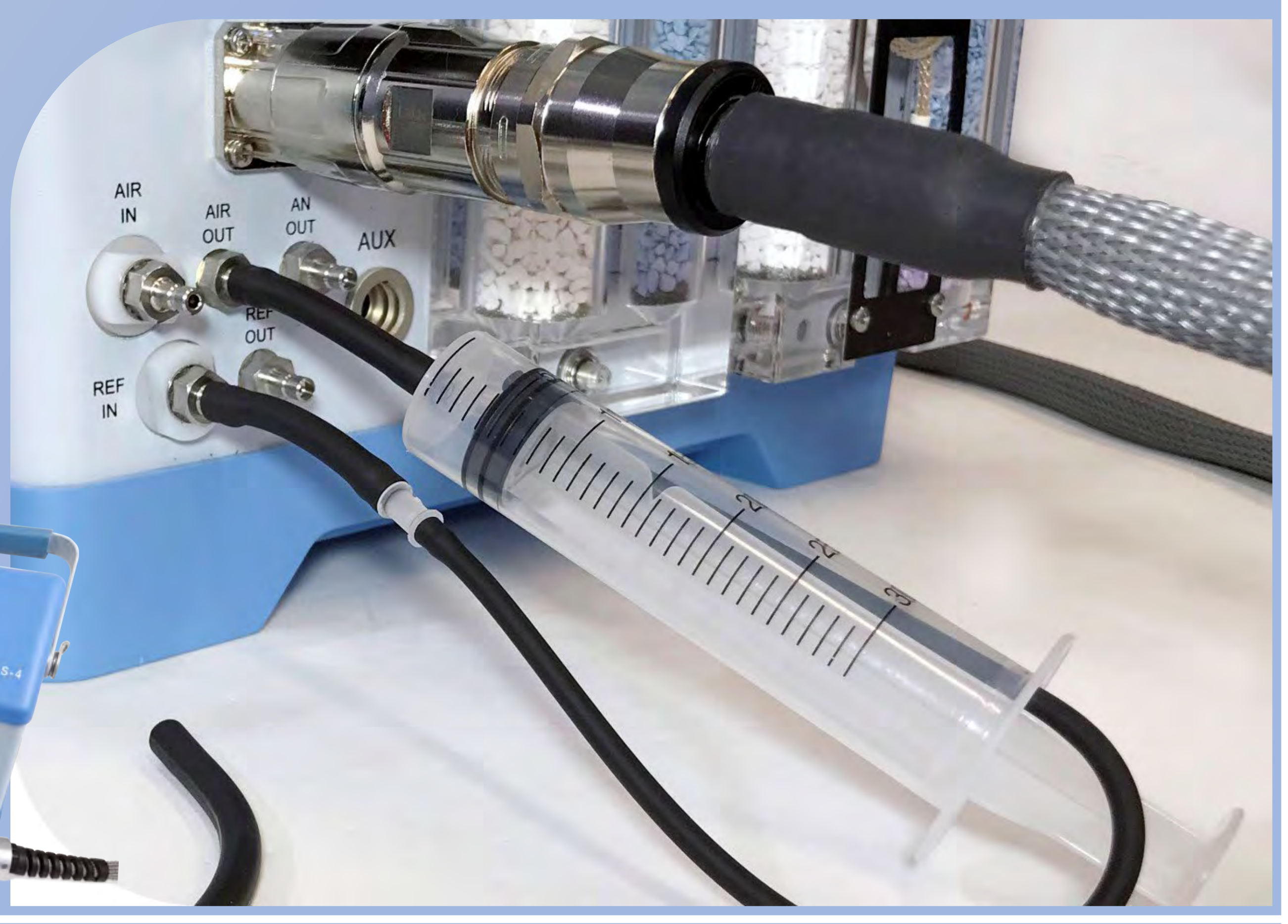

Image 1: The back of the CIRAS-4 console and the Ramp Path Equalizer used to correct the volume difference between reference and analysis infrared-gas analyzers (IRGAs).

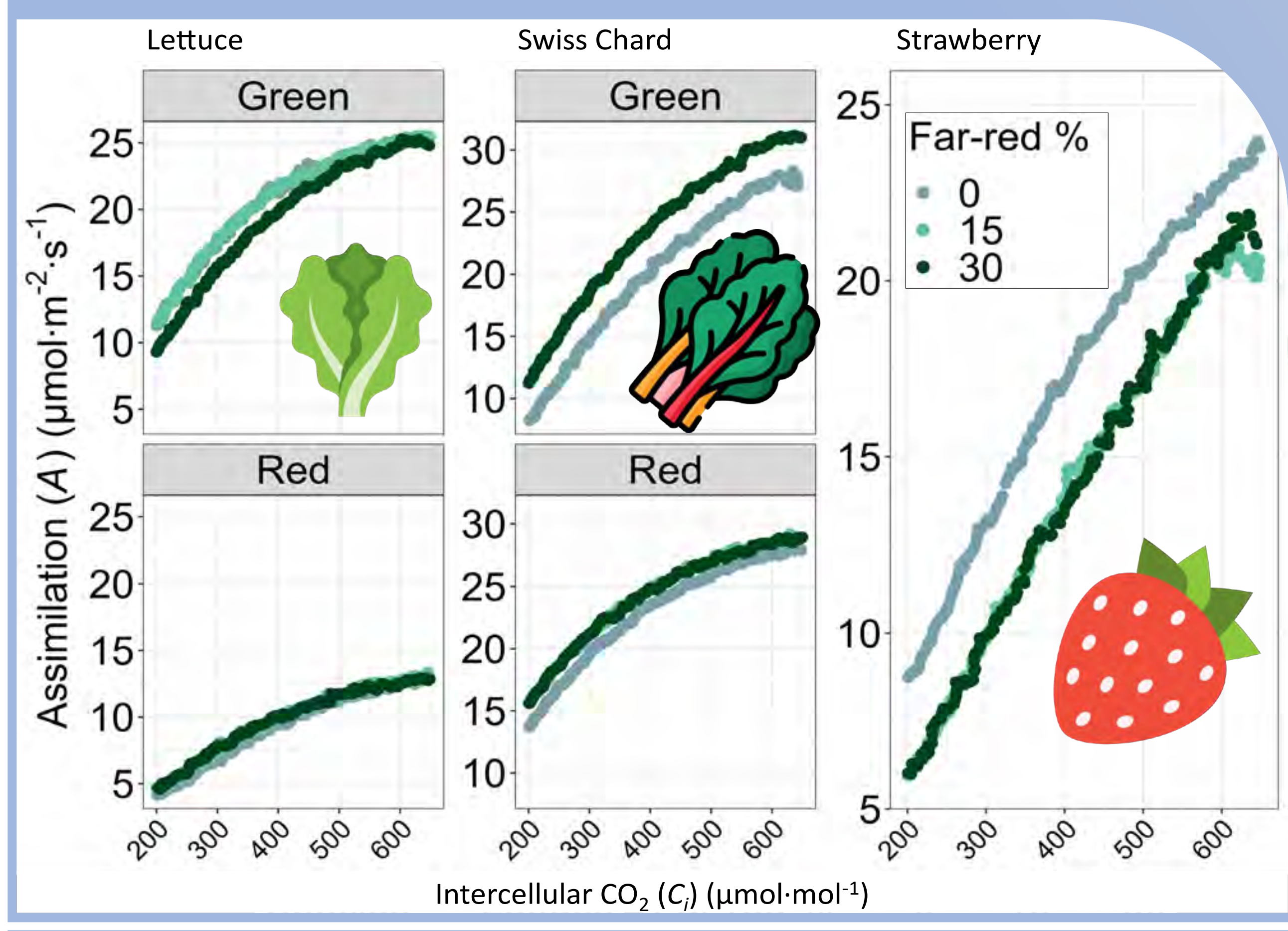

Figure 2: A vs. C_i curves for Lettuce (two cultivars), Swiss Chard (two cultivars), and Strawberry (one cultivar) in the open-field. CO_2 was ramped upward from 200 to 1000 µmol·mol^{-1} at a rate of 150 µmol·mol^{-1} using the SSCO$_2$R™ method.

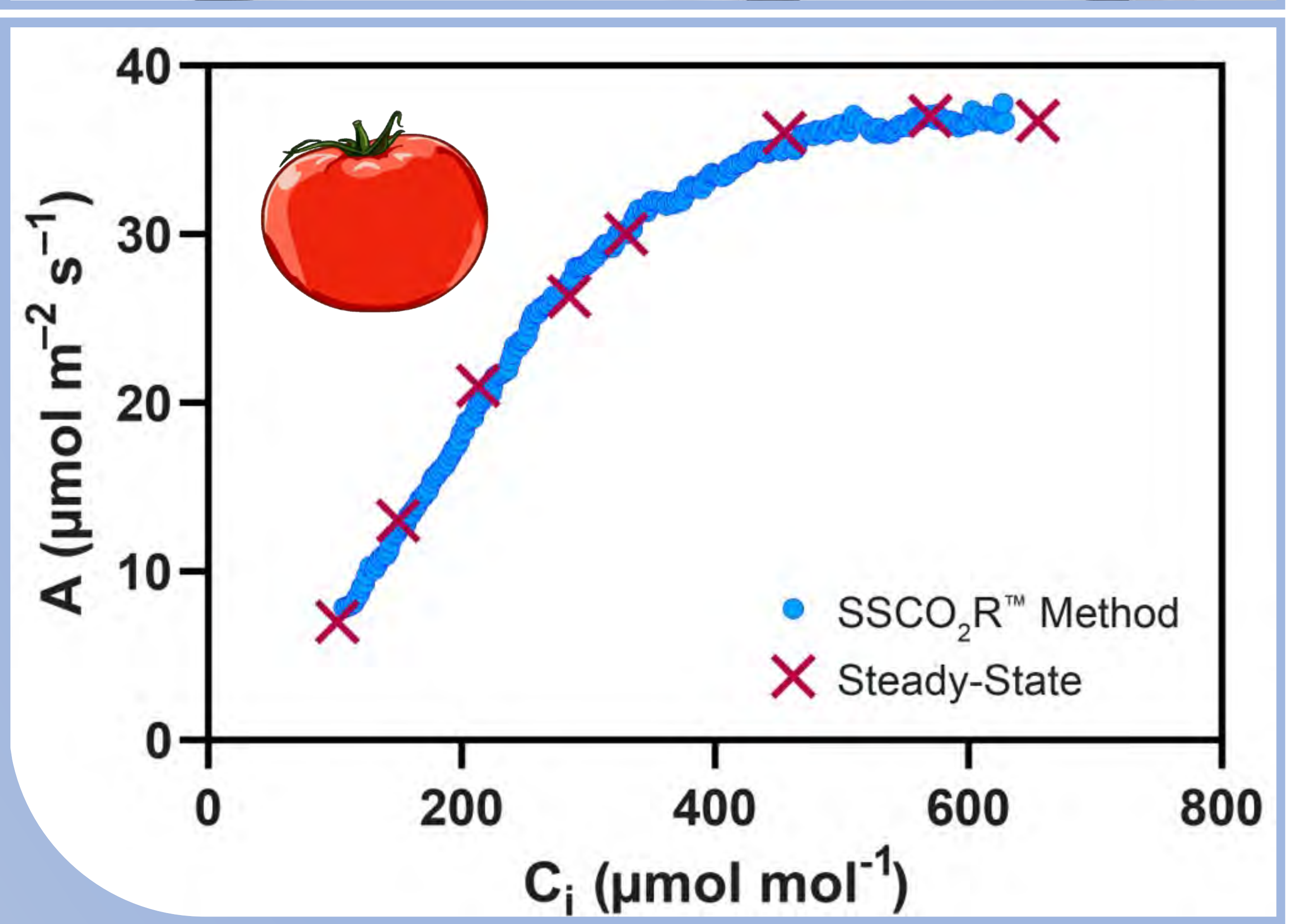

Figure 1: Relationships between CO_2 assimilation rate (A) and internal CO_2 (C_i) for a tomato leaf measured at 22 °C and 1500 µmol·m^{-2}·s^{-1} PPFD near midday in the field under steady-state CO_2 conditions and during an upward ramping of CO_2—at a rate of 200 mmol·mol^{-1}·min^{-1}, using the SSCO$_2$R™ Method.

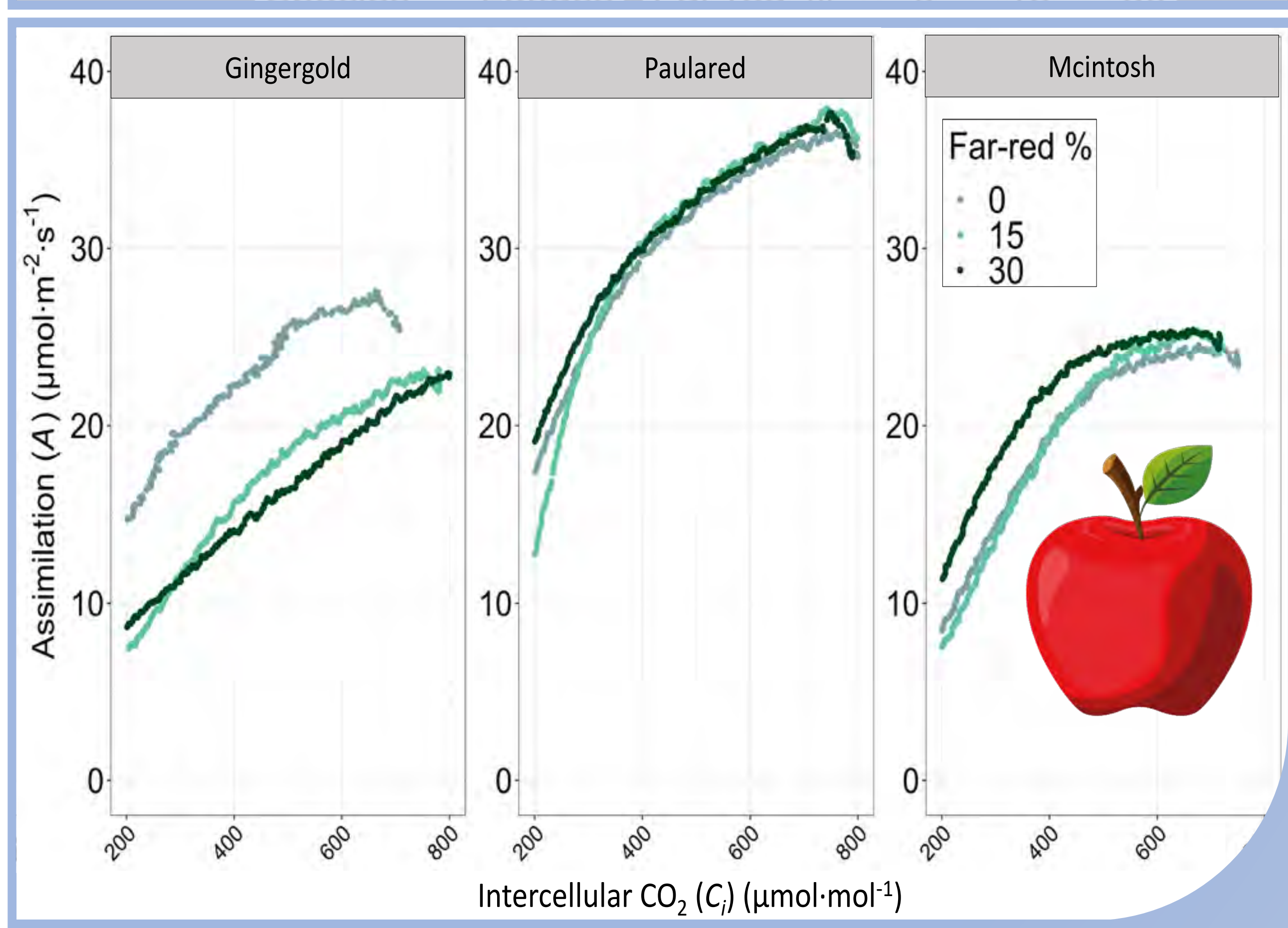

Figure 3: A vs. C_i curves for three cultivars of Apples in the open-field. CO_2 was ramped upward from 200 to 1000 µmol·mol^{-1} at a rate of 150 µmol·mol^{-1}·min^{-1} using the SSCO$_2$R™ method.

Materials and Methods

- A vs. C_i curves were collected in the field for leaves of a variety of crop species (Tomato, Lettuce, Swiss Chard, Strawberry, and Apple) using a traditional steady-state method (acclimating leaves at each level) and our single-step response method. (SSCO$_2$R™; ramping of CO_2 at a rate of 150 µmol·mol^{-1}·min^{-1}).
  - CO_2 was ramped upward from 100 to 800 µmol·mol^{-1} for tomato or 200 to 1000 µmol·mol^{-1} for all other species.
  - Light intensity was 1000 µmol·m^{-2}·s^{-1} of 1:1:1 B:G:R.
    - For all species besides tomato, each curve was collected with FR light replacing PAR photons (0, 15, or 30% FR).
  - Temperature was controlled at 22 or 25°C, and each curve was collected on the same leaf of each plant.

Conclusion

- Increasing exposure to FR light increased, decreased, or caused no change in assimilation across a range of CO_2.
  - For leafy type plants (Lettuce and Swiss Chard), this seemed related to the leaf color, as red leaves may reflect more FR light.
  - For apples, it is unclear why cultivar-specific differences occurred in response to FR light.
  - For strawberry, any FR light reduced the assimilation rate, suggesting FR light may be disrupting photosynthesis in this species or cultivar.
- **Rapid A vs C_i curves agree with steady-state data, affording researchers the ability to collect data in a fraction of the time as traditional methods.**
- **Species and cultivar responses to FR light are highly variable, suggesting there may be genetic or other causal links that modify the rate of photosynthesis when exposed to radiation greater than 700 nm.**

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[1] Zhen S, Bugbee B. 2020. Far-red photons have equivalent efficiency to traditional photosynthetic photons: Implications for redefining photosynthetically active radiation. Plant Cell Environ. 43(5):1259–1272. https://doi.org/10.1111/pce.13730.

[2] Zhen S, van Iersel MW, Bugbee B. 2022. Photosynthesis in sun and shade: the surprising importance of far-red photons. New Phytol. 236(2):538–546. https://doi.org/10.1111/nph.18375

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