Co-Optimization of Duckweed Biomass, Nutritional Quality, & Input Use Efficiency

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DUCKWEED: NUTRIENT DENSE CROP FOR EXPLORATION

Duckweeds (family Lemnaceae) are tiny flowering plants with enormous potential for bioregenerative space life support. Also known as water lentils or water meal, these small angiosperms are gaining global recognition as a powerful and ecologically friendly means of absorbing nutrients from wastewater. In addition, duckweed has a very high nutritional density and little fibrous material, making it a 100% edible and potentially valuable fresh food supplement to crew diets on long-duration exploration missions.

Spirodela (Large), *Wolffia* (Small), and *Lemna* (Medium) – Landesman (2010)

Space Lab Technologies, LLC and researchers in plant biology at the University of Colorado at Boulder are working to **establish duckweed as a nutrient dense space crop for deep space exploration**.

WHAT IS DUCKWEED?

- Smallest flowering plant on Earth
- Among the fastest growing plants in the world
- Over 40 species
- Can grow free floating or submerged
- Found in still/slow flowing fresh water
- Common in lakes, ponds, canals, rice fields, ditches, even mud

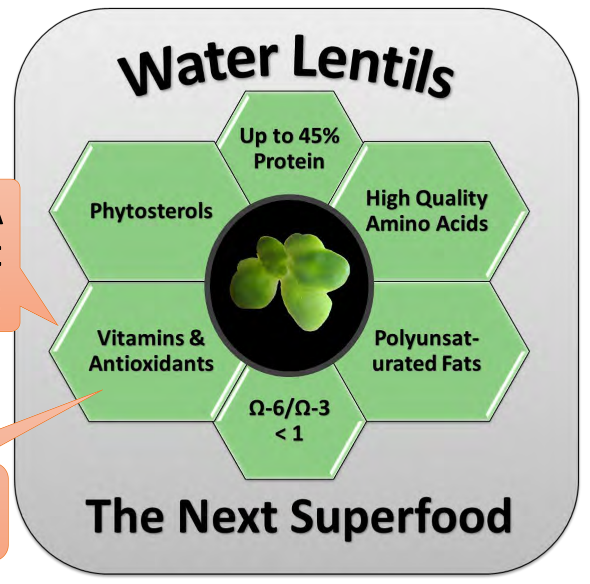
Fronds:

- Oval shaped vegetative bodies
- 1-20 mm across & grow singly or in small groups
- Take up gases and nutrients
- Permanently open stomata on top
- Cutin (waxy, water repellant coating) on top
- Air sacs provide buoyancy
- Vascular system practically absent
- Little structural tissue needed (floating)

Roots: provide mechanical stability

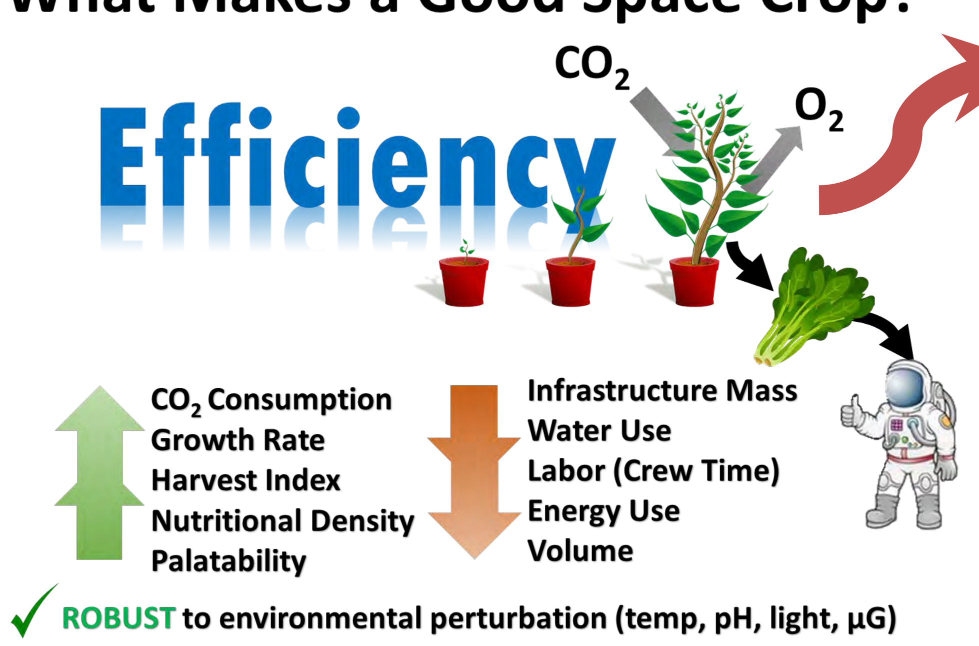
Reproduction:

- Primarily asexual budding
- Flowering rarely observed
- Up to 10 daughters in 10 days before dying
- Doubles biomass in 1-3 days (ideal conditions)



AN ATTRACTIVE PLANT FOR SPACE

What Makes a Good Space Crop?



1. 100% Harvest Index
2. Can be eaten raw
3. Highly nutritious
4. High growth rate
5. Vegetative budding
6. Thrives in high CO_2
7. Grows in 24-hr light
8. Grows in shallow water
9. Environmentally robust
10. Palatable
11. Grows in dark on sugar
12. Has a dormant state
13. Prefers ammonium-N
14. Have been grown in µG

THE INNOVATION: CO-OPTIMIZATION OF YIELD & QUALITY

Food Production Mitigates Deep Space Exploration Health Risks

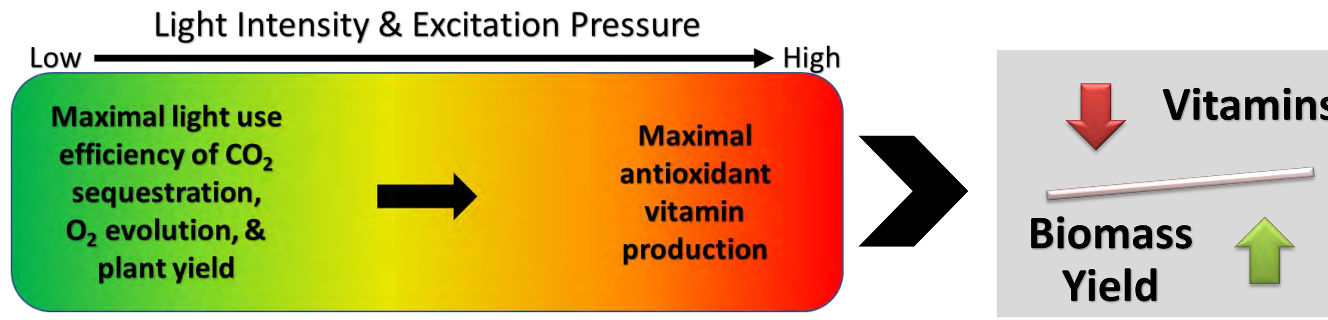
- Packaged food loses palatability & nutrients
- Food rich in nutrients, e.g. zeaxanthin can combat adverse effects of space radiation
- Plants reduce the adverse psychological impacts of isolation, high stress, & distance

A LIGHT RECIPE TO CO-OPTIMIZE:

1. **Edible biomass yield**
2. **Micronutrient content**
3. **Protein content**
4. **Energy efficiency**

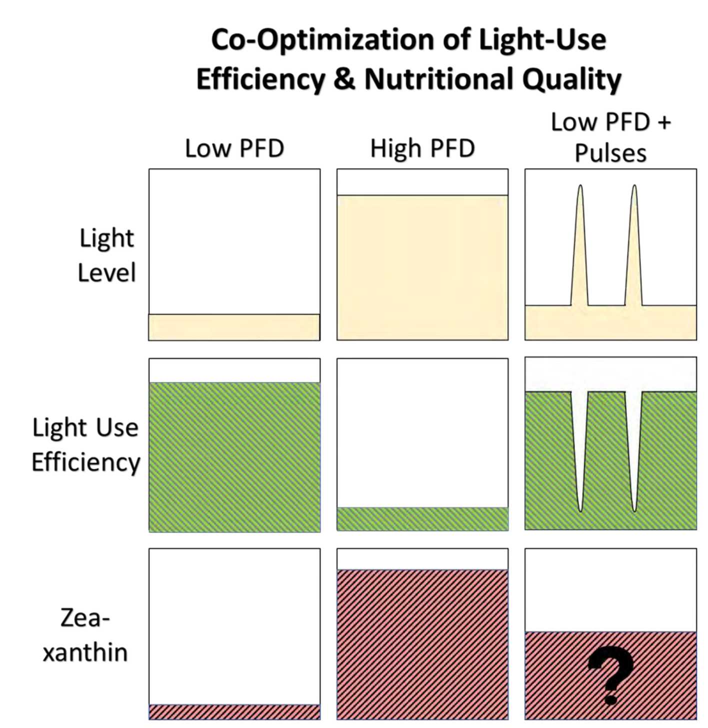
UNDER SPACE RELEVANT CO_2 LEVELS (up to 1%)

Challenge is Co-optimization



Plants growing in the shade of a forest canopy will still make a lot of zeaxanthin if they receive some high-light pulses.

Sunflecks under a *Eucalyptus* canopy, 1994
Photograph by WW Adams



A combination of low background light and a few high-light pulses will boost vitamin production in duckweed without loss of yield.

Dr. Demmig-Adams and Adams demonstrated technique with Arabidopsis thaliana.

TRISH BRASH 1801 Research Objectives:

1. Determine continuous photon flux density (PFD) for maximal yield at space relevant CO_2 levels, and pulse PFD for micronutrient enhancement at space relevant CO_2 levels.
2. Demonstrate increase in micronutrient (vitamin/antioxidant & omega-3 fatty acid) without loss of yield, by way of supplemental higher-intensity light pulses.
3. Determine spectral quality effects on yield, nutrient content, and energy use efficiency.

Response Variables:

- Relative growth rate (RGR)
- Photosynthetic Capacity (O_2 evolution)
- Excitation pressure (chl. fluorescence)
- Pigments (chlorophyll, zeaxanthin, β-carotene, etc.)
- Macronutrients, esp. protein

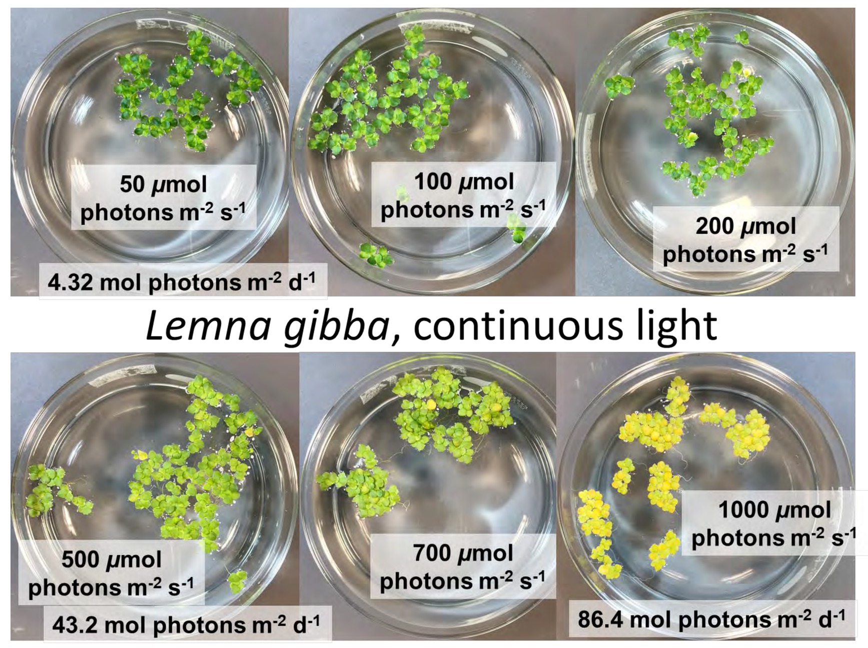
Treatment Variables:

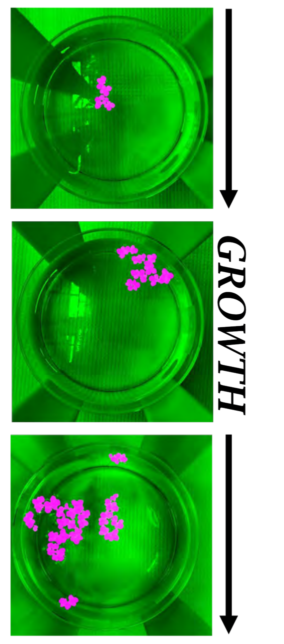
- Continuous & pulse PFD (50 to 1000 µmol/m2-s)
- CO_2 concentration (0.04-1%),
- Spectral quality (white, red, blue, green)
- Species (*Lemna gibba* & *Wolffia arrhiza*)

TRISH BRASH 1801: YEAR 1 GROWTH TEST RESULTS

Growth Conditions

- **Nutrient Medium:** 1L ½ strength Schenk & Hildebrandt
- **pH:** 5.5
- **Temperature:** 25 °C
- **Initial Frond Density:**
  - 20 *L. gibba*
  - 200 *W. arrhiza*
- **Acclimation:** 3 days
- **Growth Period:** 4 days





Lemna gibba Grown Under Ambient CO_2

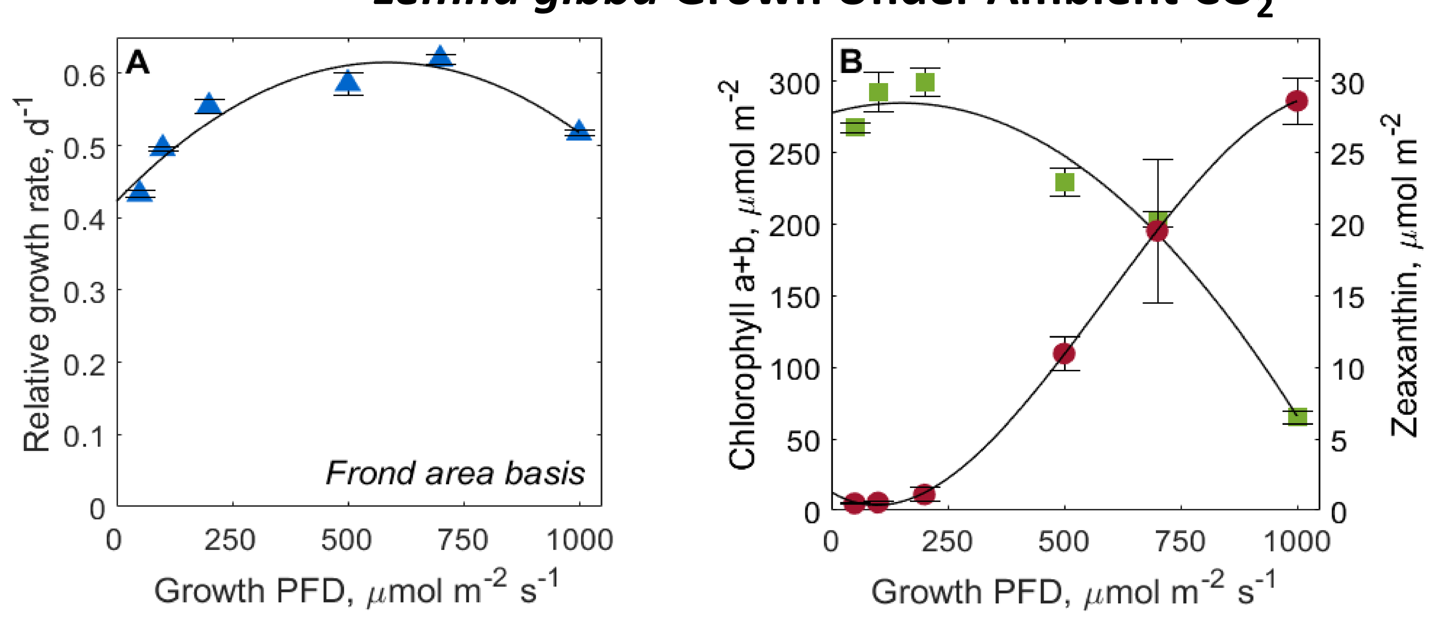


Figure 1. A) Relative growth rate (i.e. rate constant for exponential growth) calculated as $(\ln X_2 - \ln X_1)/T$, where X_2 is the frond area at test end, X_1 is frond area at test start, and T is the test duration. **B)** Content (leaf area basis) of chlorophyll (absorbs light) and the carotenoid pigment zeaxanthin (dissipates potentially damaging excitation energy not utilized in photosynthesis as harmless heat). PFD = photon flux density of continuous light.

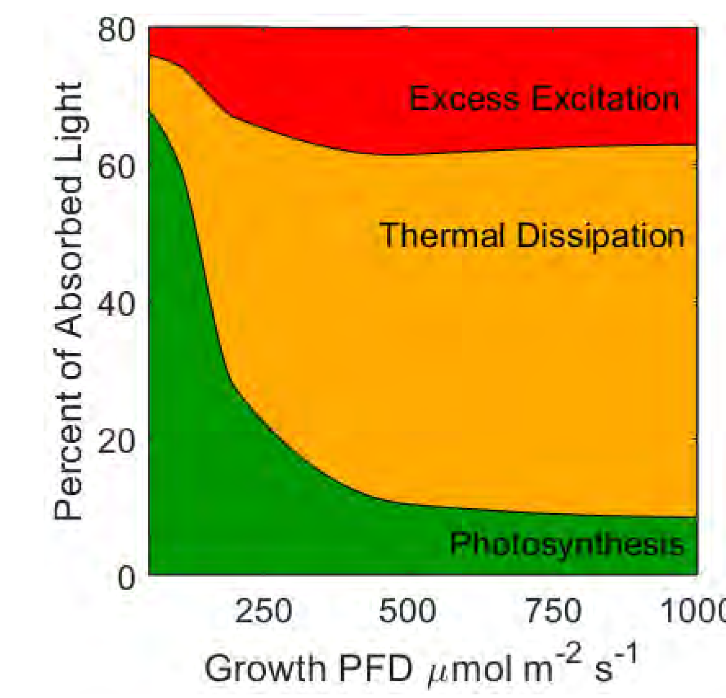


Figure 2. Allocation of absorbed light to photosynthesis, thermal dissipation (of excitation energy not utilized in photosynthesis), and the remaining fraction of (excess) excitation energy (going neither into photosynthesis nor thermal dissipation) as a function of growth light intensity. PFD = photon flux density of continuous light.)

Year 1 Conclusions:

- *L. gibba* maintains a remarkably constant growth rate over a wide range of light intensities, by increasing light-absorbing chlorophyll under low light supply and increasing antioxidant zeaxanthin for protection against intense light (***Figure 1***).
- The fraction of light absorbed by photosystem II (PSII) decreases rapidly from 50 to 200 µmol m^{-2} s^{-1} indicating that duckweed needs relatively low light intensity for PSII photochemistry, and subsequent rapid growth (***Figure 2***).

Next Steps:

- Determine the growth saturating PFD for elevated CO2 levels (up to 1%),
- Validate that pulsed lighting boosts anti-oxidant production without a decreased growth rates (at ambient & elevated CO2),
- Investigate spectral quality effects on growth and antioxidant production.

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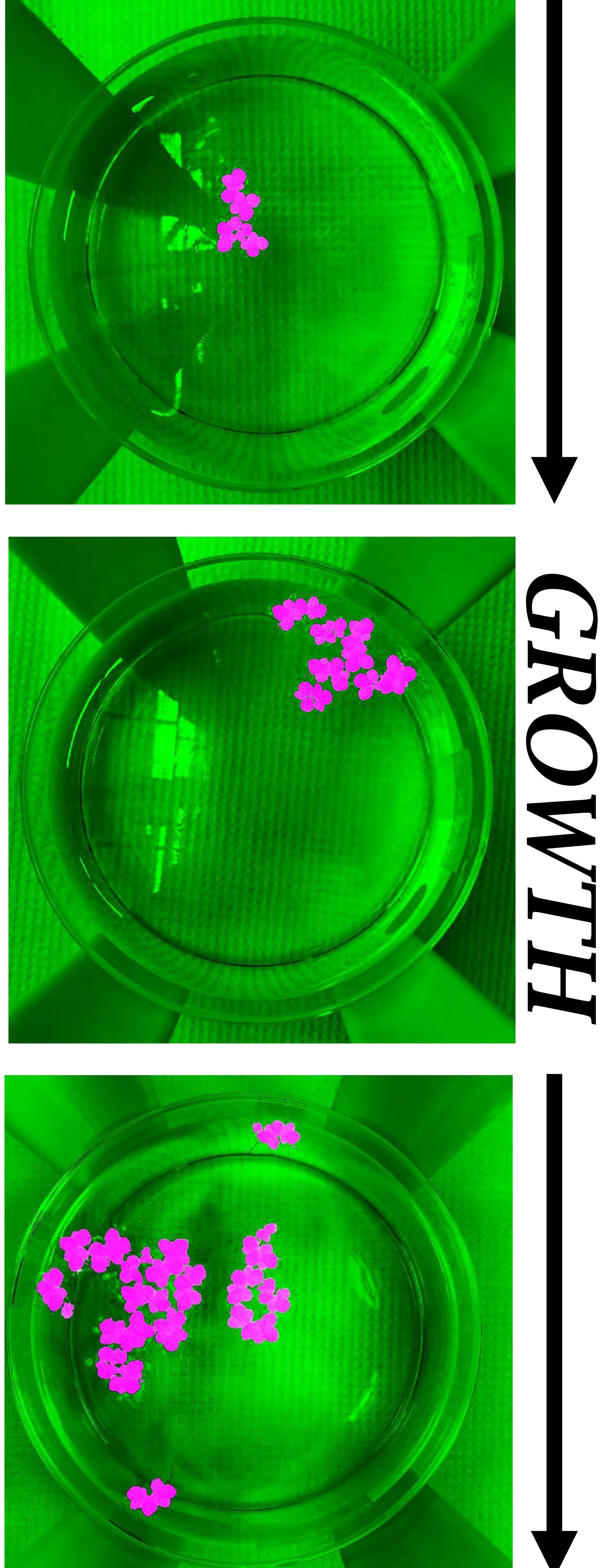
GROWTH