Plants prefer ammonium as a N source: Implications for space crop production.

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NASA Postdoctoral Program

SPACE CROP PRODUCTION

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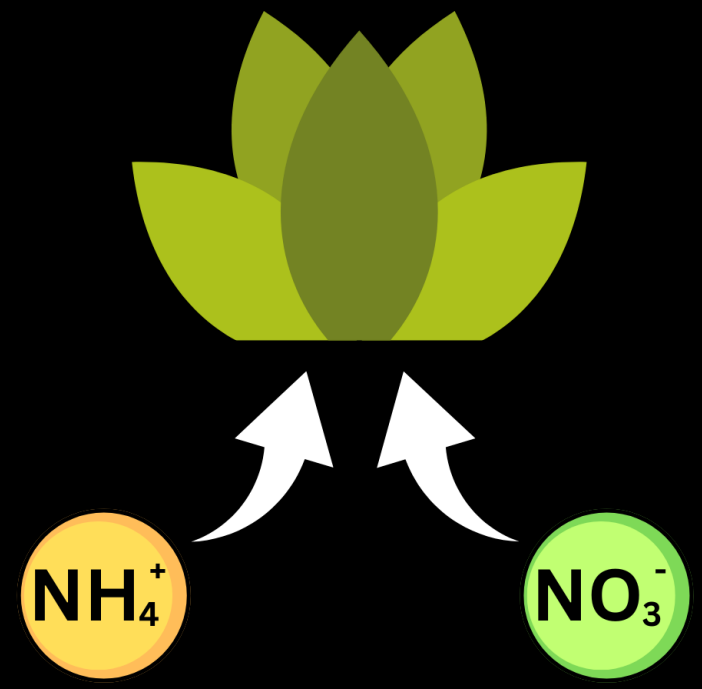
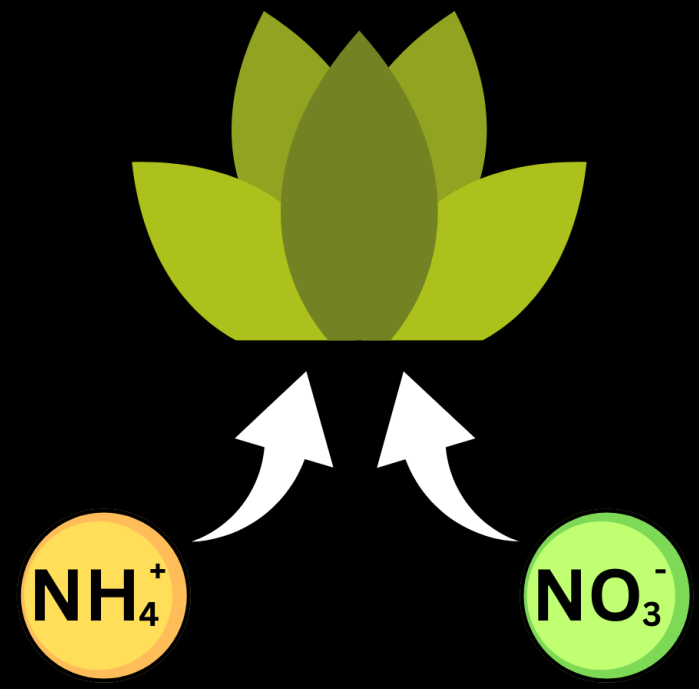
Nitrogen (N) uptake and preference

- Crucial nutrient for plant survival
- Inorganic forms used in agriculture
- Major inorganic forms include ammonium (NH_4^+) and nitrate (NO_3^-)
- Plants can show preference for different N forms
- Key factors include environment, physiology and growth substrate.



Nitrogen (N) uptake and preference

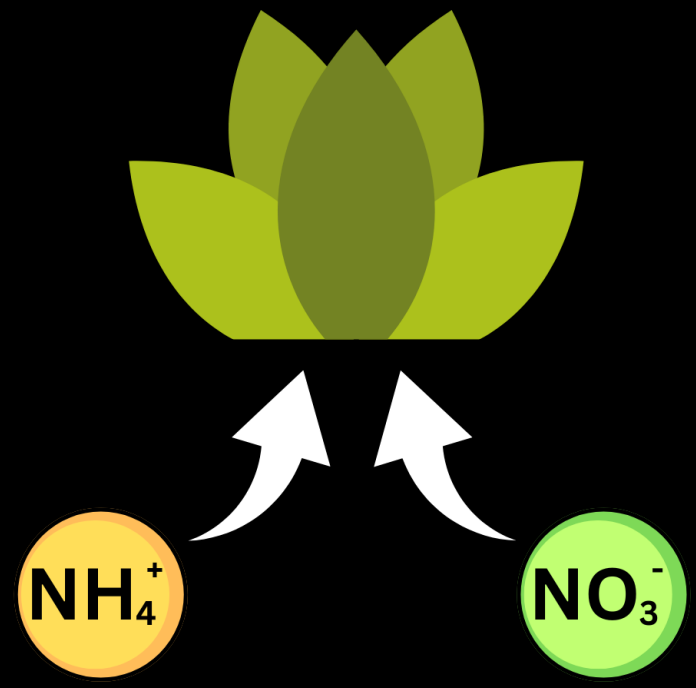
- N preference is plastic, driven by the dominant pool of N in a given environment.
- Nitrification is a major driver in agricultural soils.
- In hydroponics systems, dominant N pool is driven by the nutrient solution, and physiology becomes more important.



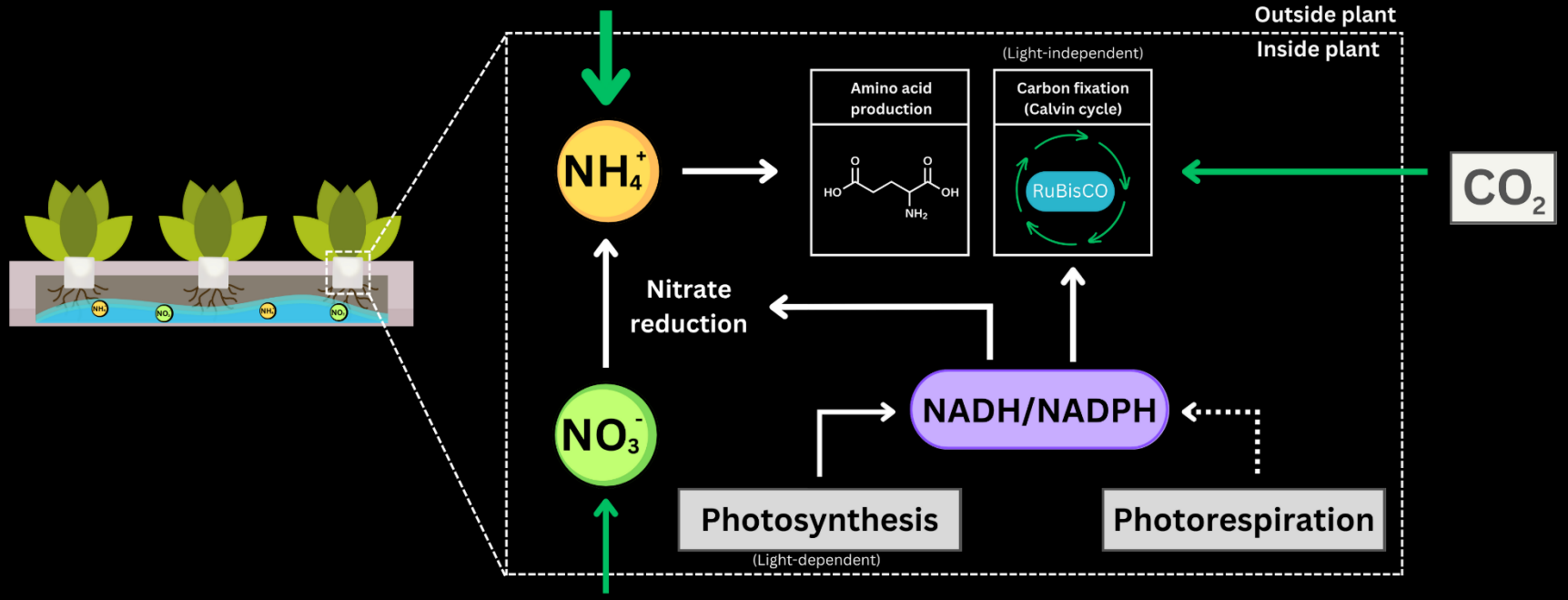
Nitrogen (N) uptake and preference

NH_4^+ assimilation is ~45 % more energetically efficient than NO_3^- assimilation…

… But NH_4^+ also becomes toxic to plants at relatively low concentrations (5 mM).

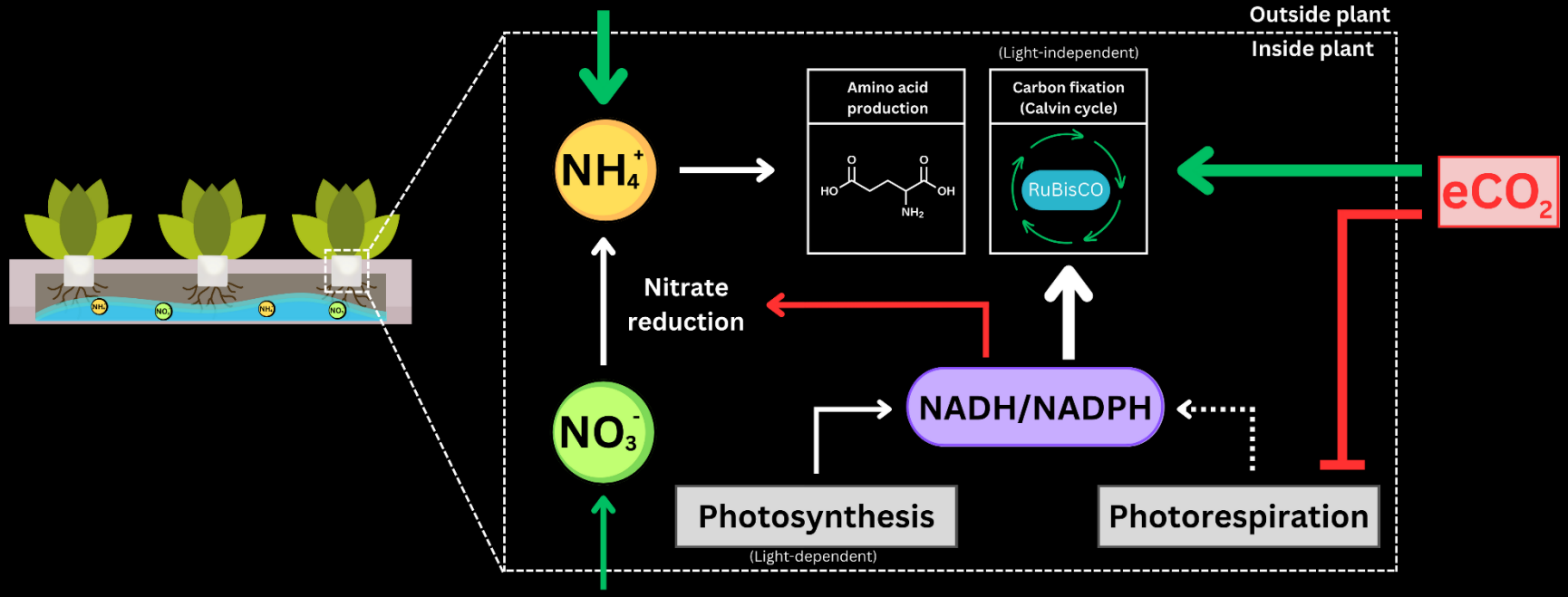


Plant growth at eCO_2 under varying N nutrition



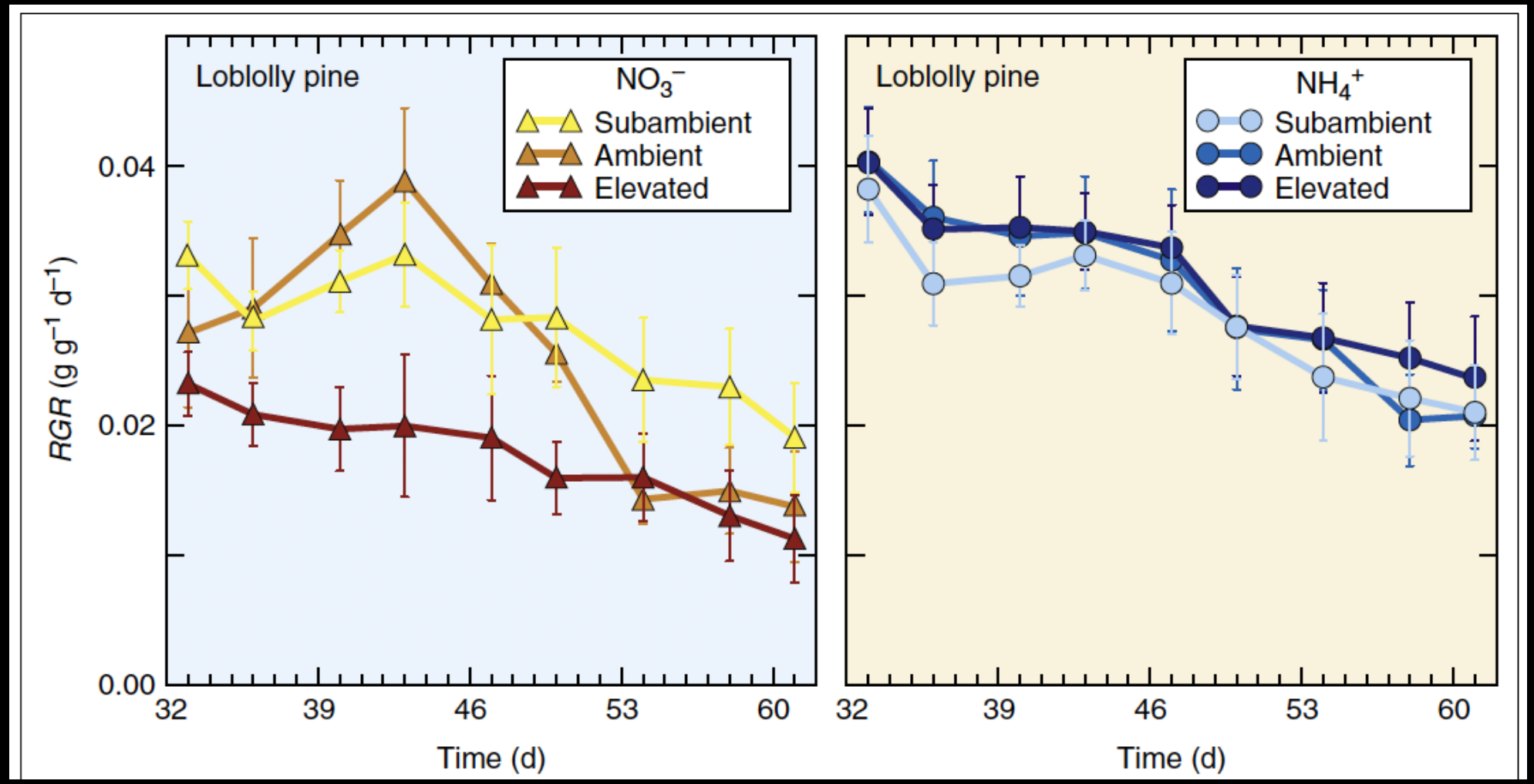
- Reductant (NADH) used during C fixation.
- Surplus reducing power available for NO_3^- reduction.

Plant growth at eCO_2 under varying N nutrition

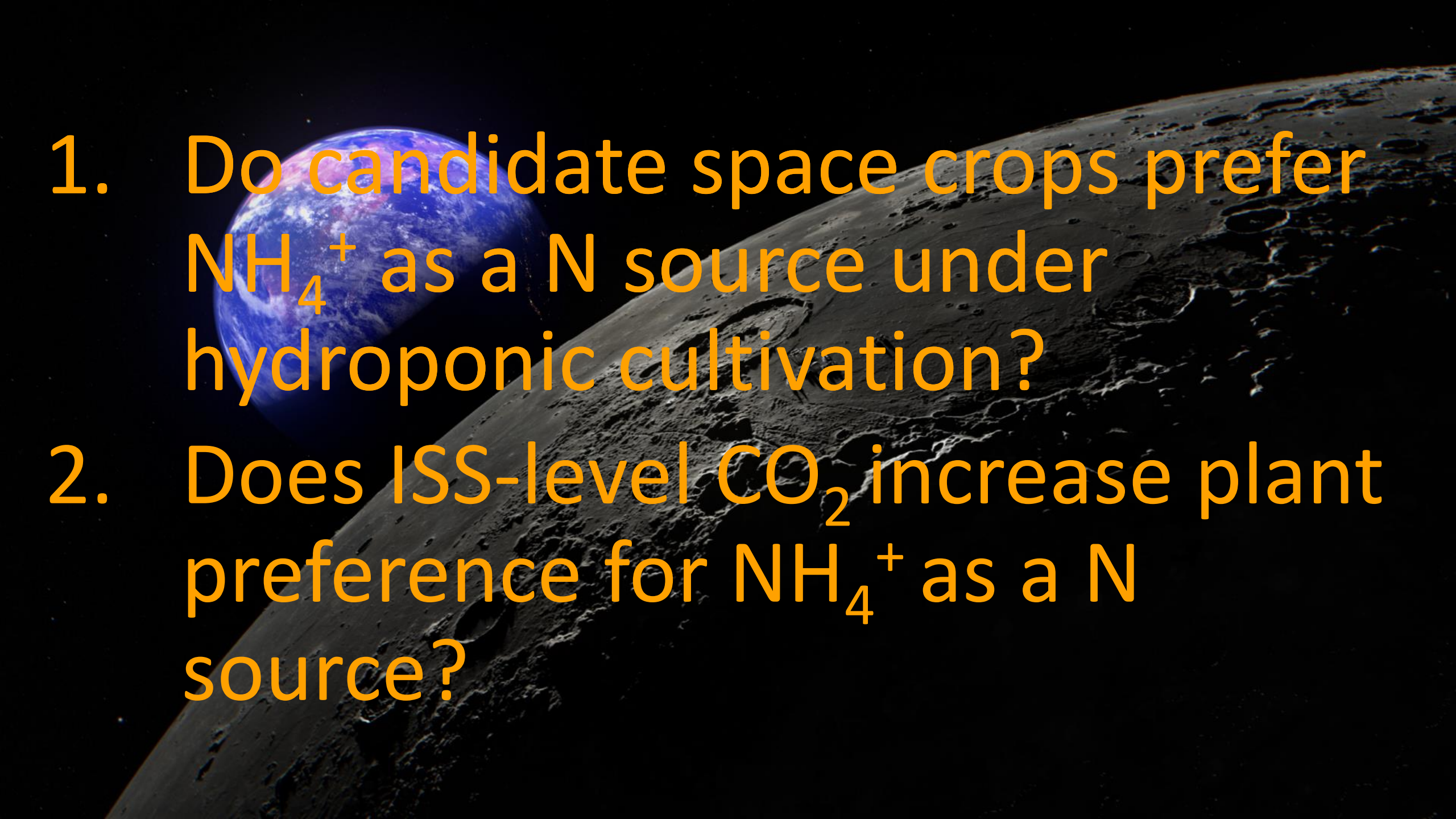


- Reducing power diverted to fix additional C.
- Inhibition of photorespiration through altered CO_2:O_2 ratio.
- Less reductant available for NO_3^- reduction.

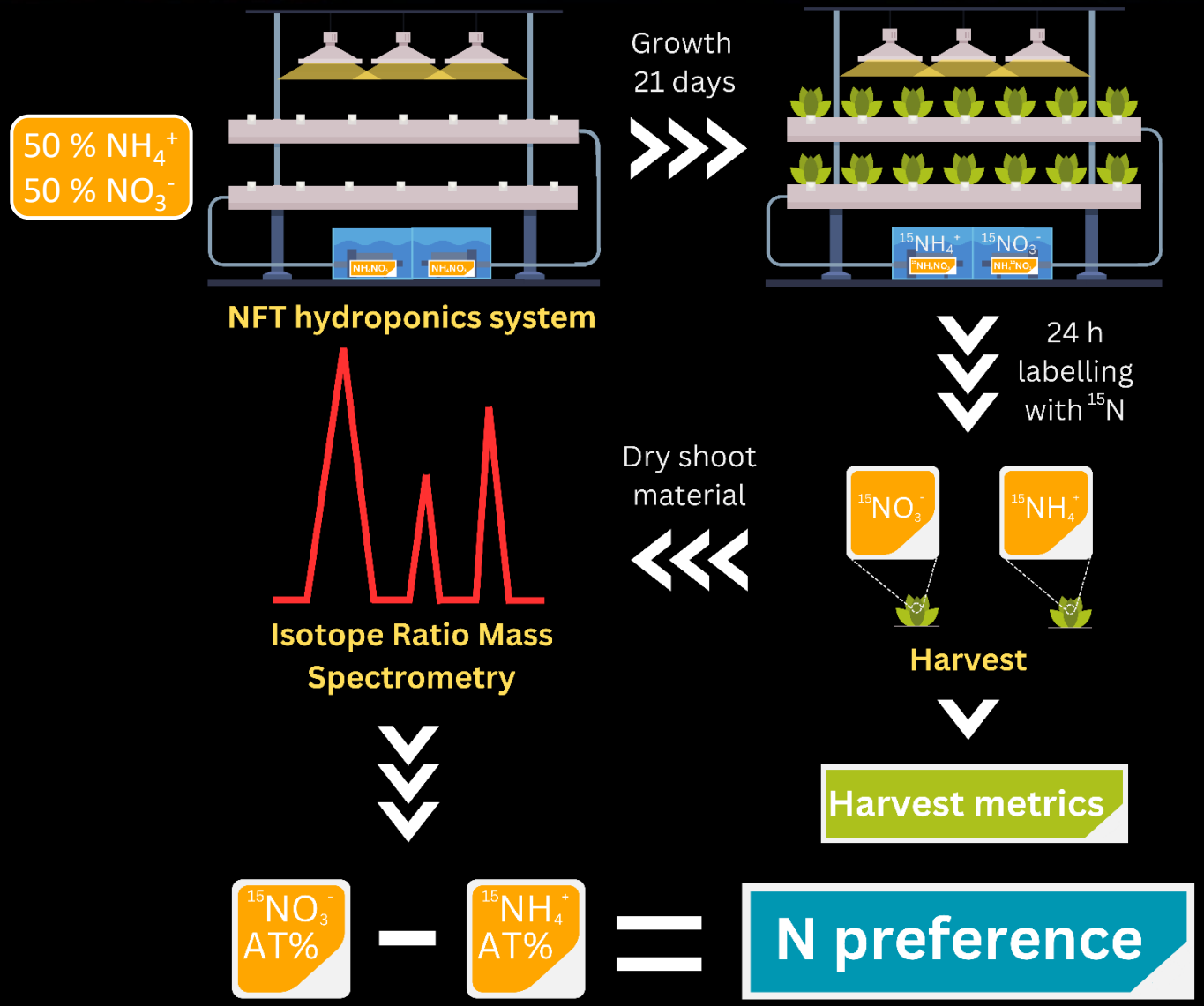
Plant growth at eCO_2



Bloom *et al.* (2012), Ecology **93**(2), pp. 355-367.


1. Do candidate space crops prefer NH_4^+ as a N source under hydroponic cultivation?
2. Does ISS-level CO_2 increase plant preference for NH_4^+ as a N source?

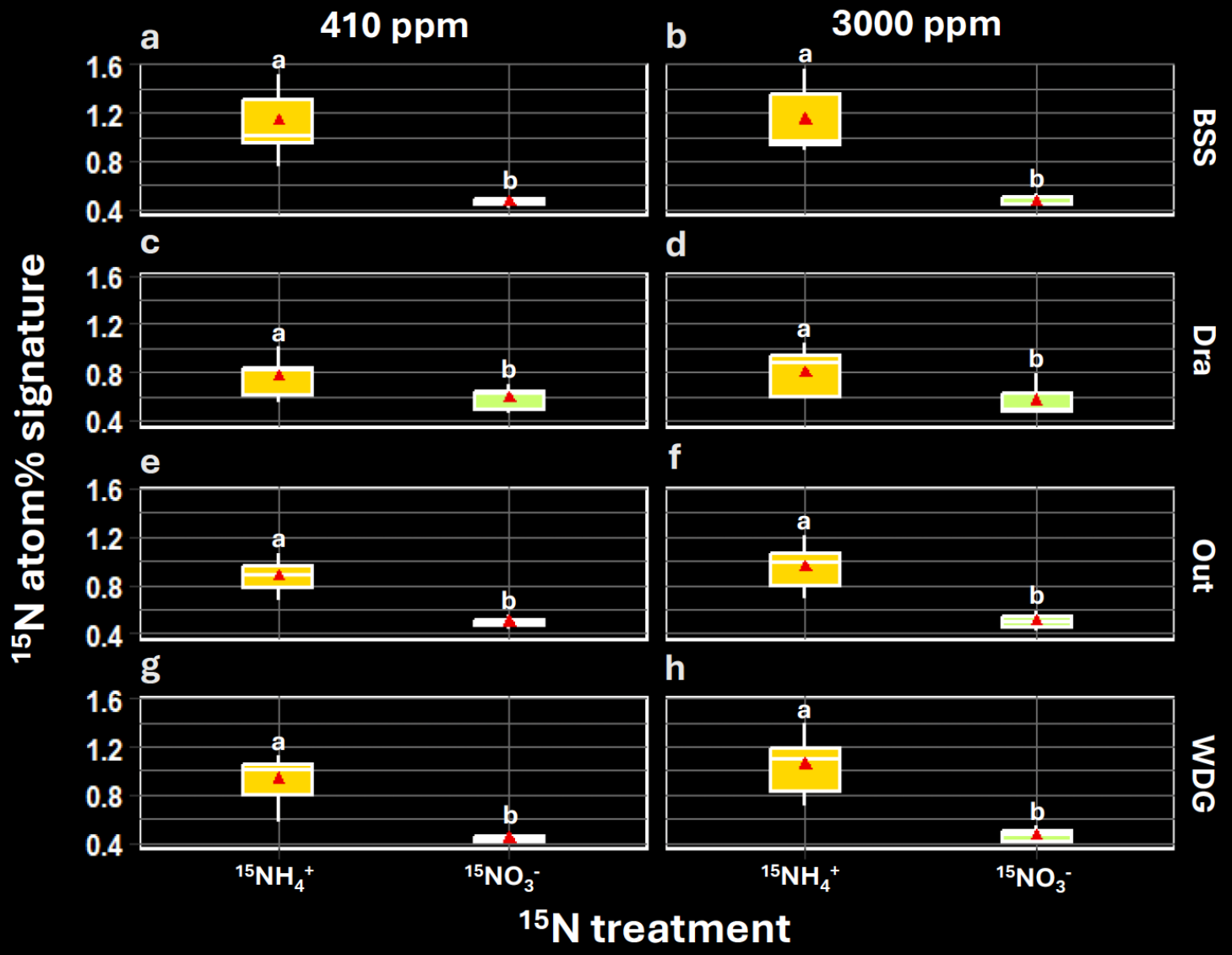
Measuring N preference using ^{15}N stable isotopes



-ve value = ammonium preference

+ve value = nitrate preference

Lettuce N preference under hydroponic cultivation

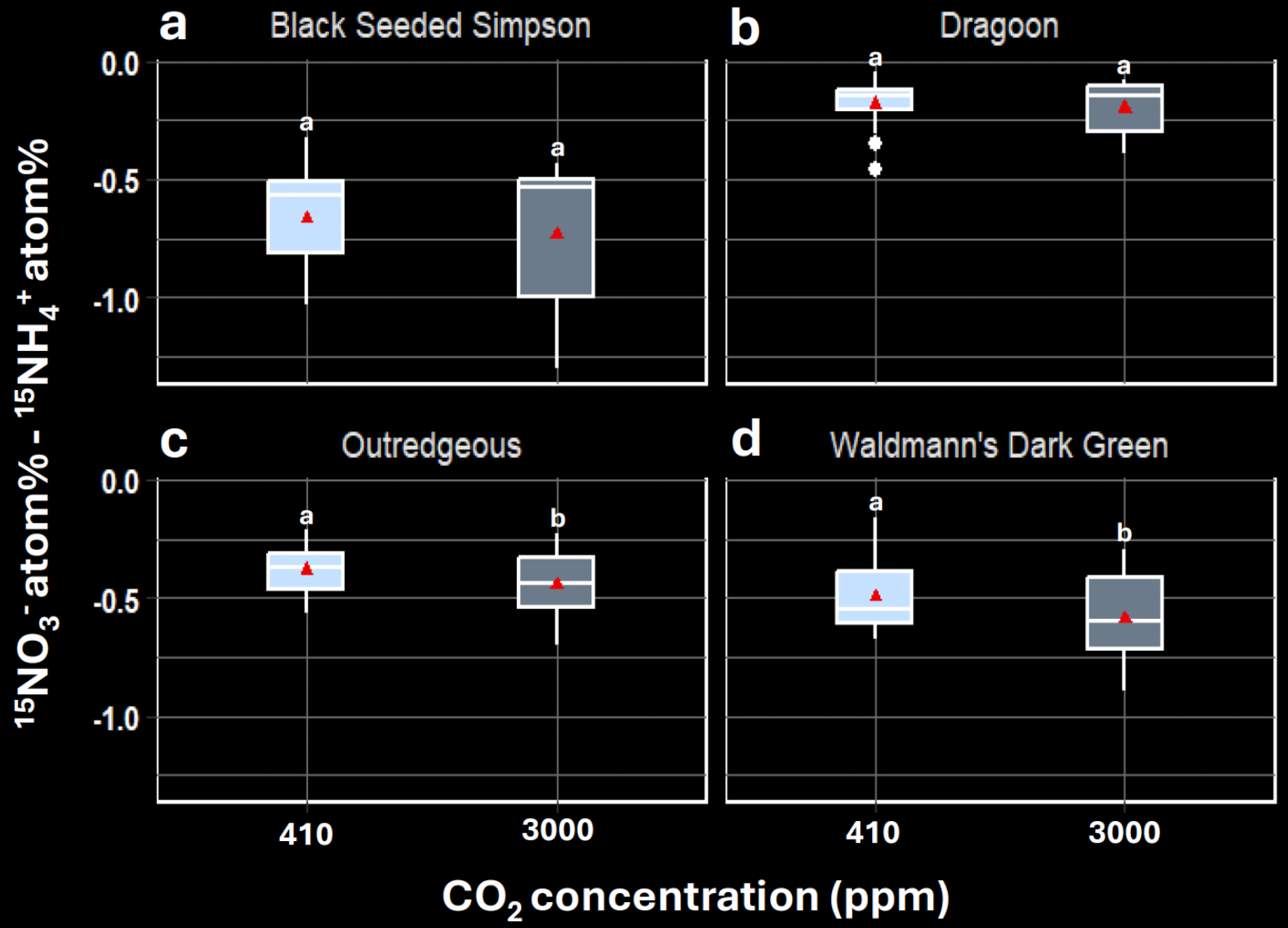


BSS – Black Seeded Simpson
Dra – Dragoon
Out – Outredgeous
WDG – Waldmann's Dark Green

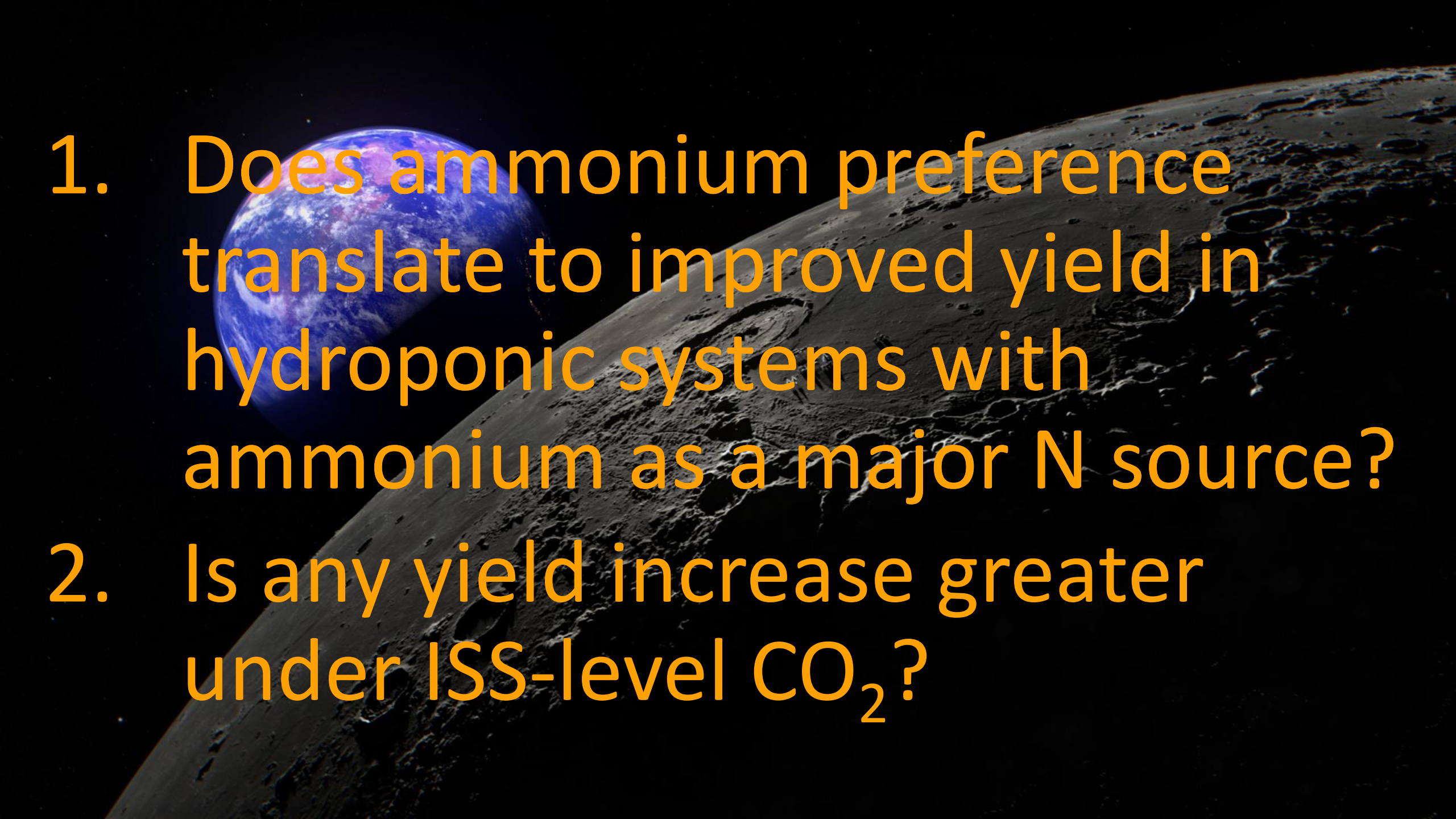
Heirloom
Grown in space

Groups not sharing a letter are significantly different ($p < 0.05$, Welch's t-test).

eCO_2 increases lettuce preference for ammonium



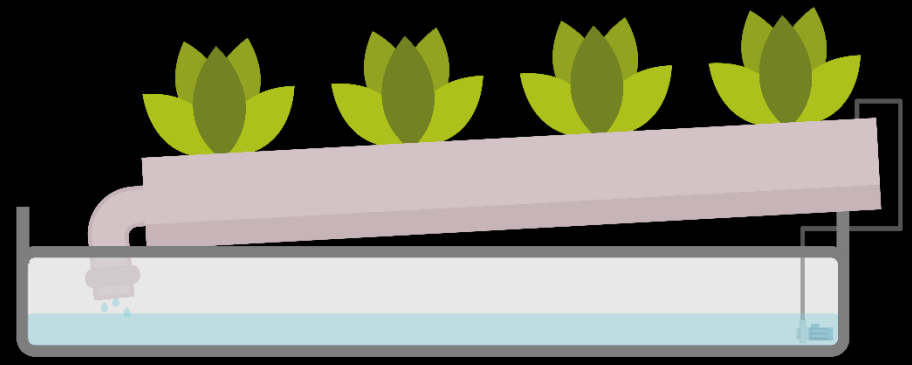
Groups not sharing a letter are significantly different ($p < 0.05$, one-way ANOVA following mixed-effects modelling).



1. Does ammonium preference translate to improved yield in hydroponic systems with ammonium as a major N source?
2. Is any yield increase greater under ISS-level CO_2?

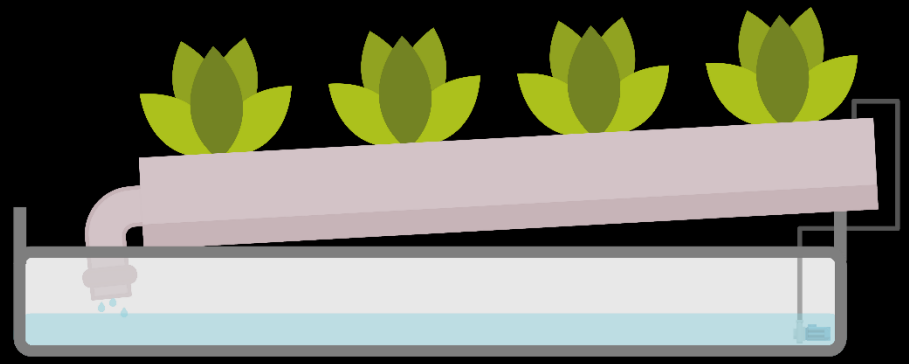
Lettuce cultivation under varying ammonium : nitrate ratios

- Two NH_4^+:NO_3^- ratios.
- Two lettuce varieties; ‘Outredgeous’ and ‘Dragoon’.
- 28 day growth cycle.
- Ambient (420 ppm) and elevated (3000 ppm) CO_2.



0% NH_4^+ : 100% NO_3^-

½ Strength Hoagland’s [control]



70% NH_4^+ : 30% NO_3^-

Results

Response variable	F statistic	P value
NH_4^+:NO_3^- ratio	6.9842	0.0106 (*)
CO_2	10.6893	0.0018 (**)
Variety	51.4308	$1.802e^{-09}$ (***)
NH_4^+:NO_3^- ratio : CO_2	0.1572	0.6932
NH_4^+:NO_3^- ratio : Variety	2.5807	0.1138
CO_2 : Variety	1.4230	0.2379
NH_4^+:NO_3^- ratio : CO_2 : Variety	0.0714	0.7903

ANOVA analysis performed in R.

NH_4^+ nutrition increases lettuce yield

- **Average yield increase of 18 % when NH_4^+ is present.**
- Trend towards higher yield increase for Dragoon (25 %) than Outredgeous (9 %), though not significant.

Response variable	F statistic	P value
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ANOVA analysis performed in R.

Elevated CO_2 increases lettuce yield

- **Average yield increase of 23 % at 3000 ppm.**
- Yield increase higher for Dragoon (26 %) than Outredgeous (16 %), though not significant.
- Difference in yield across CO_2 concentrations appears greater in 0:100 (28 %) compared to 70:30 (17 %), though not significant.

Response variable	F statistic	P value
NH_4^+:NO_3^- ratio	6.9842	0.0106 (*)
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NH_4^+:NO_3^- ratio : CO_2 : Variety	0.0714	0.7903

ANOVA analysis performed in R.

Lettuce yield varies across varieties

- **Yield ~56 % higher in Dragoon compared to Outredgeous on average.**

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NH_4^+:NO_3^- ratio	6.9842	0.0106 (*)
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Summary

- Plants take up a small baseline amount of nitrate but display significant ammonium preference when cultivated hydroponically.
- Plants with higher N demand typically source the additional N as ammonium.
- Ammonium preference may be further exacerbated by ISS-level CO_2.
- Ammonium-dominant nutrient solutions increase yield of hydroponically-grown lettuce, though this may be dependent on variety and CO_2 concentration.

Ammonium should be considered as a dominant N source for plants grown hydroponically and/or at high CO_2 in future space crop production scenarios.

Future Directions

- Determine if NH_4^+-dominant solutions increase yield in other candidate space crops.
- Explore potential use of plant N uptake strategies to:
  - Minimize nitrate accumulation in salad crops.
  - Manage pH of hydroponic nutrient solutions.

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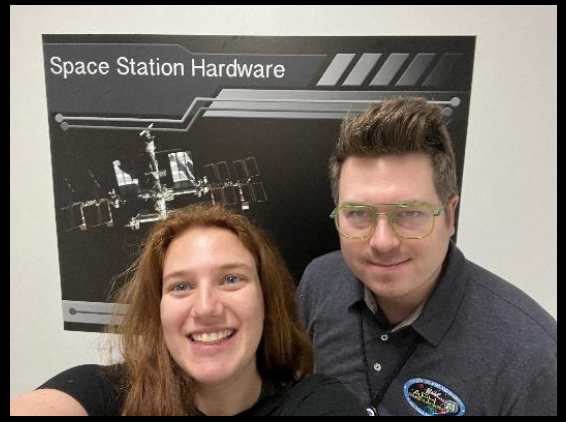

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Any questions?

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