Universiteit Utrecht

The effect of soil nutrient content on leaf-level optimality and plant-level allocation

LEMONTREE
Land Ecosystem Models based On New Theory, obseRvations and ExperimEnts

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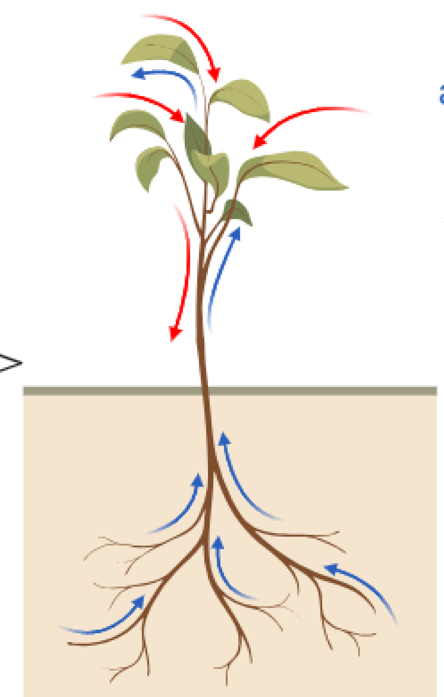
INTRODUCTION

- Natural selection favors the organs/plants/ecosystems optimally adapted to their environment, driving both **acclimation** and **adaptation.**
- **Eco-evolutionary optimality (EEO)** theory: Plants optimize their resource uses to obtain carbon (**A**ssimilation) at a lowest total cost.
- The **P-model** is based on EEO theory → Optimization is simplified to maximize **A** at the lowest summed cost for water (**E**vapotranspiration) and nitrogen (**Vcmax**, ~ photosynthetic capacity)
- Costs = a*E/A + b*Vcmax/A
- Promising use on leaf level optimization, but plant level optimality is not incorporated.

Leaf level optimization

- Optimizing costs for maximum leaf level assimilation
- Only dependent on climatic influences



$$a*\delta(E/A)/\delta\chi + b(V_{cmax}/A)/\delta\chi = 0$$

a : C cost of maintaining transpiration for a given A (average daytime conditions)

b : C cost of maintaining photosynthetic proteins required for the same A

χ : the ratio Ci:Ca (leaf intercellular CO2 : atmospheric CO2)

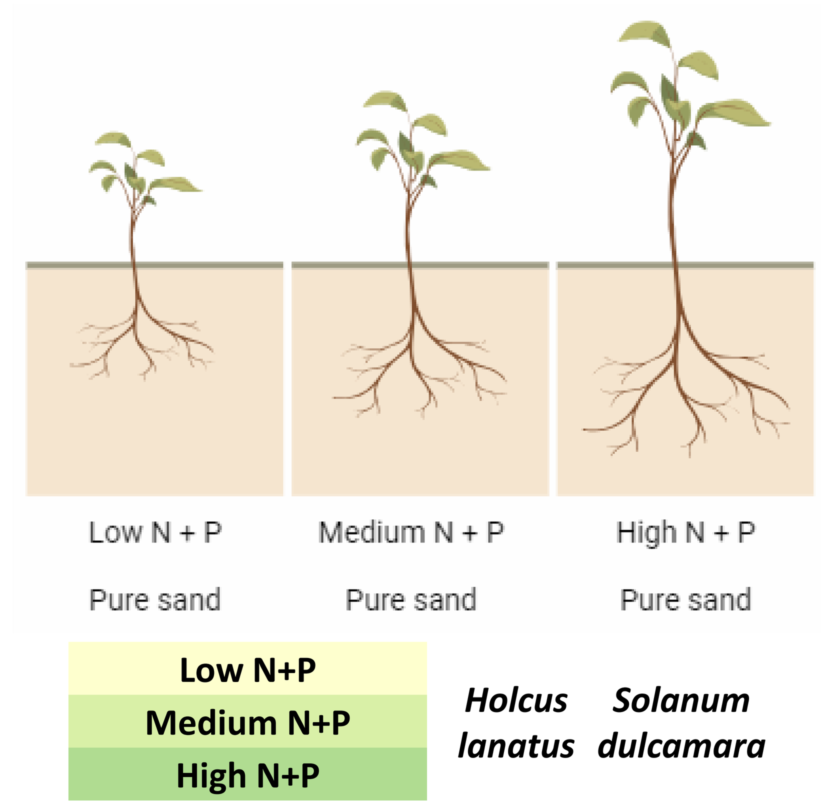
$\beta = b/a$

Plant level optimization?

- Optimizing resource costs for maximum NPP?
- Dependent on climatic and soil influences

METHODS

Greenhouse experiment
- Two species native to the Netherlands
- Three nutrient treatments



Preliminary results

Leaf level

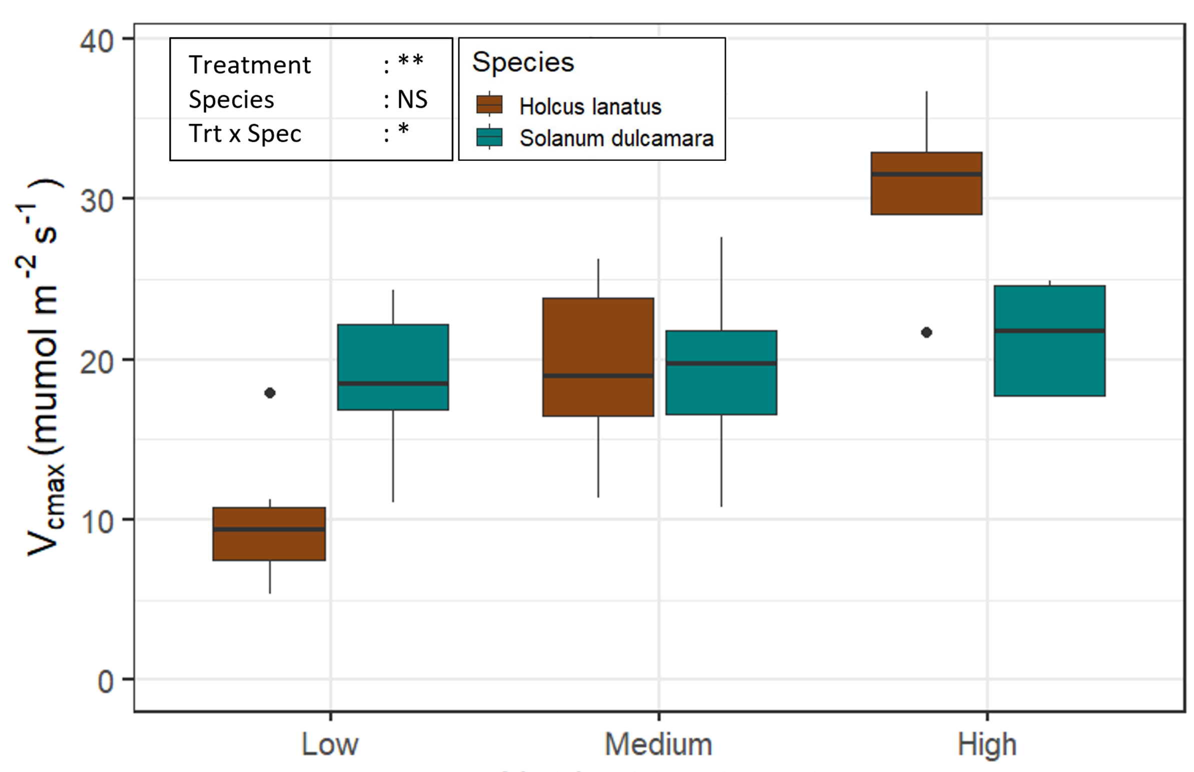


Fig. 1. Maximum rate of carboxylation (Vcmax, μmol CO2 m−2 s−1) measured 7 weeks after treatment start. n = 50. Statistical analysis: Two-way ANOVA

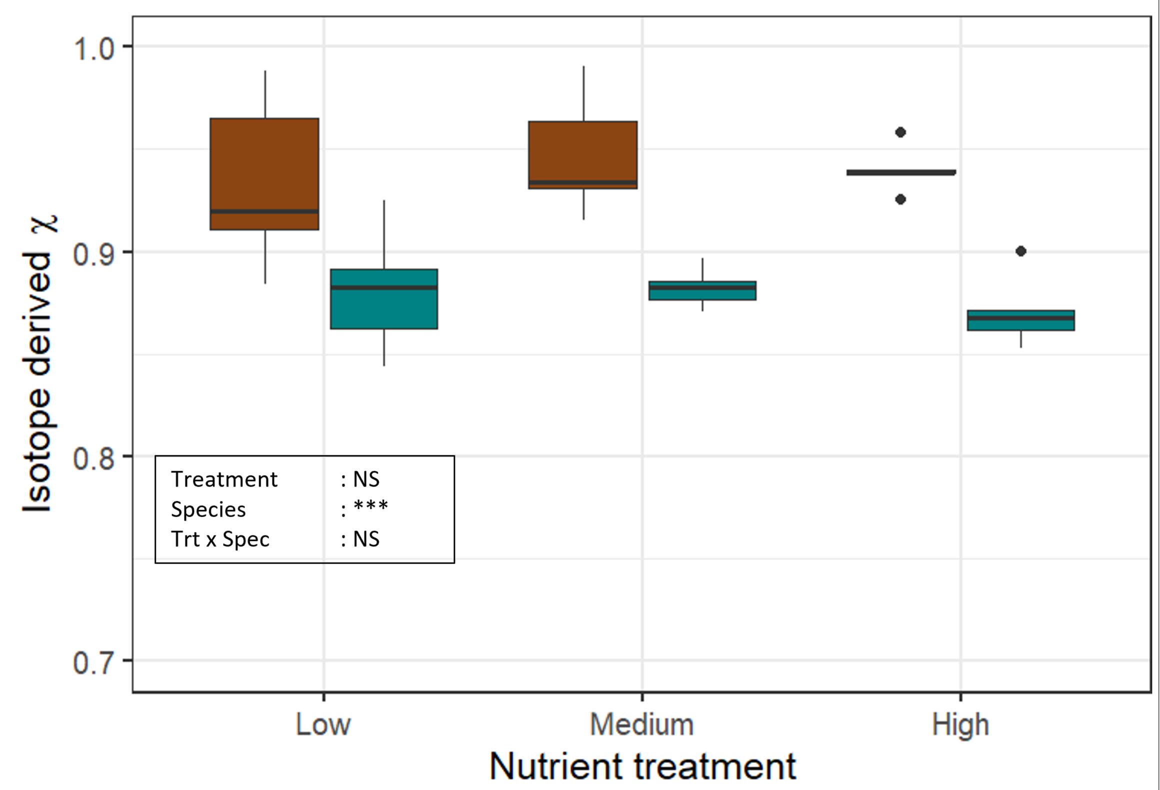


Fig. 2. δ^{13}C derived χ values. n = 73. Statistical analysis: Two-way ANOVA
Signif. codes: '***' < 0.001 '**' < 0.01 '*' < 0.05 '.' < 0.1 'NS' < 1

Plant level

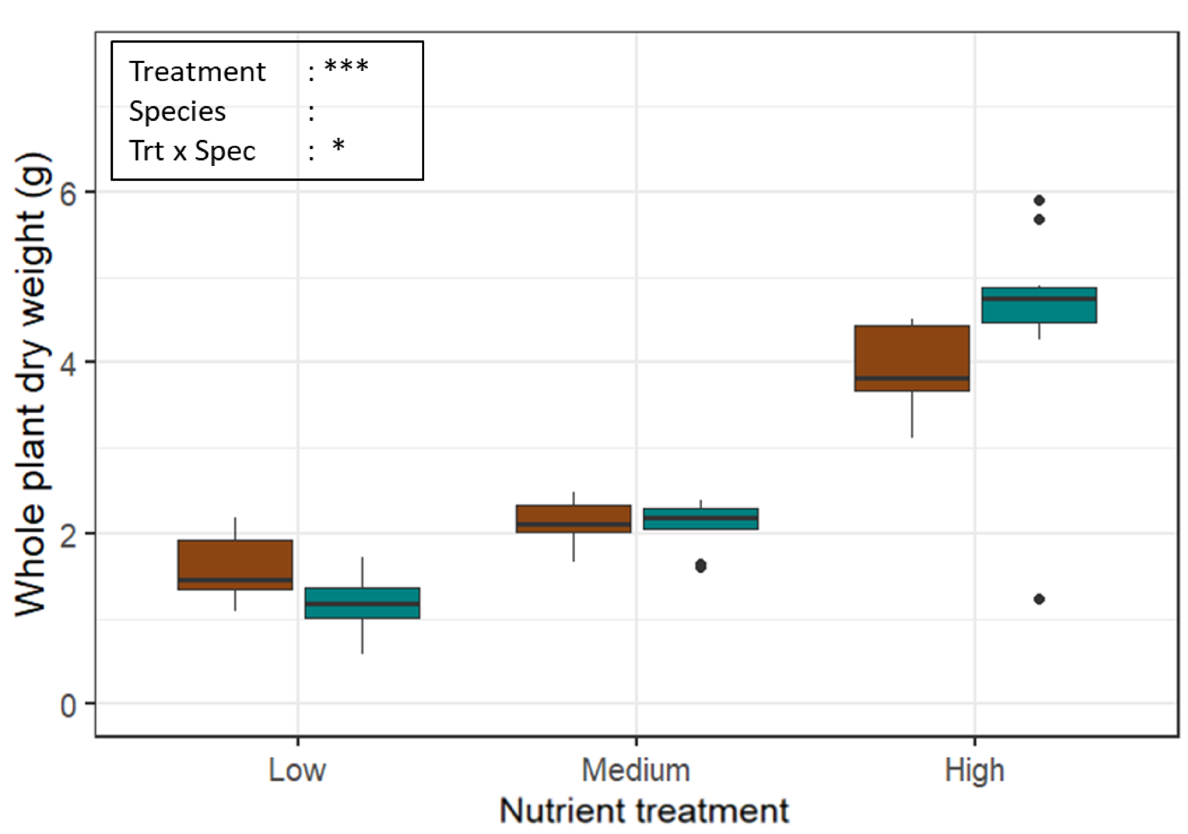


Fig. 3 Whole plant dry weight. n = 100
Signif. codes: '***' < 0.001 '**' < 0.01 '*' < 0.05 '.' < 0.1 'NS' < 1

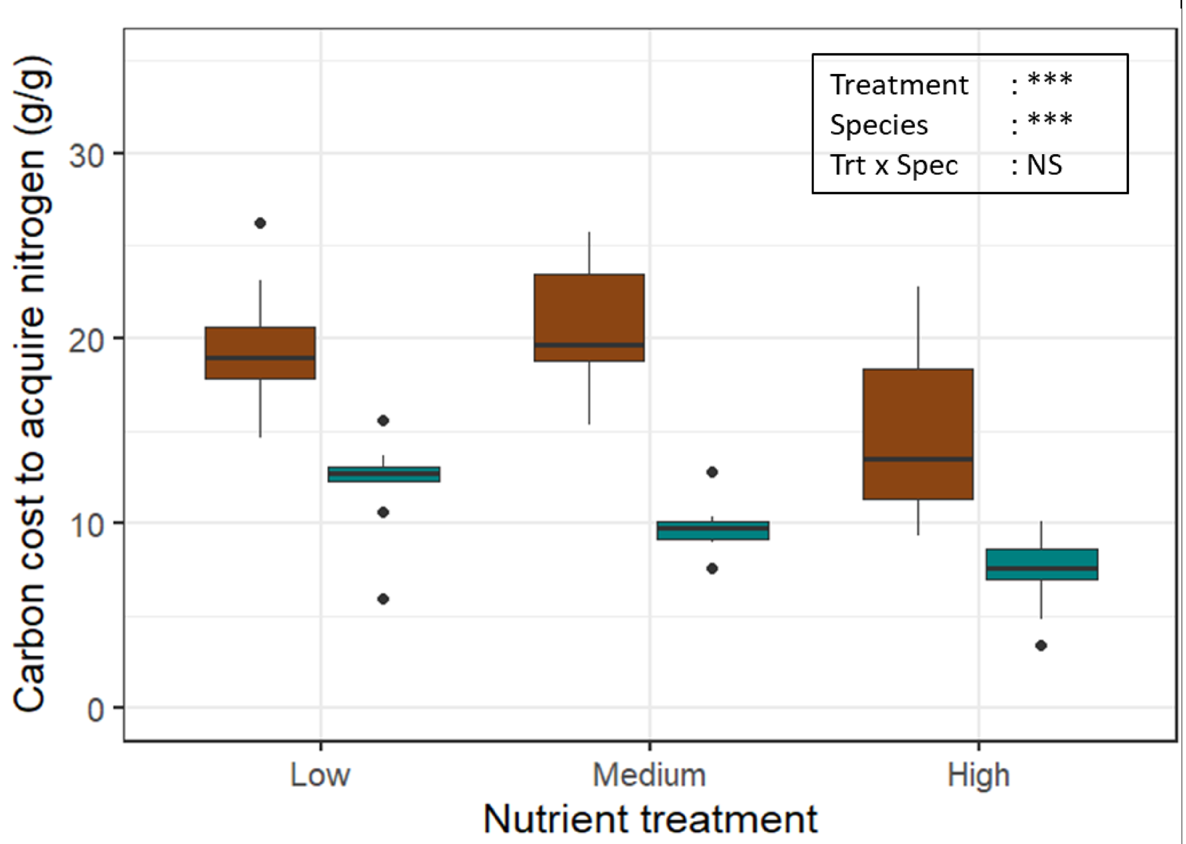


Fig. 5. Root system carbon / whole plant nitrogen. n = 100
Signif. codes: '***' < 0.001 '**' < 0.01 '*' < 0.05 '.' < 0.1 'NS' < 1

Conclusion

- Nutrients affected leaf level photosynthetic capacity, indicating a higher **total cost** for **b** with more available nutrients.
- Nutrients did not affect the isotope-derived **χ** value, indicating that while costs associated with **b** increased, costs associated with **a** increased similarly.
- Leaf-level optimality, defined as the maximization of assimilation with the lowest total costs, is not influenced by soil available nutrients.
- Leaf-level photosynthetic capacity is constrained by soil available nutrients.
- Plant growth is directly influenced by soil available nutrients.
- Resource allocation shifts towards the uptake pathway of the most limiting resource, as carbon costs to acquire nutrients are decreasing with increasing nutrient availability.

Discussion & outlook

These results support EEO theory by showing the insensitivity of χ to nutrients. While optimality indeed predicts no variation in χ for plants grown in similar climatic conditions, the absolute photosynthetic capacity **and** the net assimilation were significantly influenced by nutrients. Optimality predicts the optimal trade-off between resources, the resource availability constrains the absolute implementation of the physiological parameters.
In addition to this nutrient experiment, we grew plants on naturally occurring soils with similar nutrient availability to the medium nutrient treatment. Soils were either sterilized or not-sterilized, to investigate the effect of a natural soil microbiome on optimality theory.

1. *Harrison, S. P., Cramer, W., Franklin, O., Prentice, I. C., Wang, H., Brännström, Å., de Boer, H., Dieckmann, U., Joshi, J., Keenan, T. F., Lavergne, A., Manzoni, S., Mengoli, G., Morfopoulos, C., Peñuelas, J., Pietsch, S., Rebel, K. T., Ryu, Y., Smith, N. G., … Wright, I. J. (2021). Eco-evolutionary optimality as a means to improve vegetation and land-surface models. In New Phytologist (Vol. 231, Issue 6, pp. 2125–2141). John Wiley and Sons Inc. https://doi.org/10.1111/nph.17558*
2. *Stocker, B. D., Wang, H., Smith, N. G., Harrison, S. P., Keenan, T. F., Sandoval, D., Davis, T., and Prentice, I. C.: P-model v1.0: an optimality-based light use efficiency model for simulating ecosystem gross primary production, Geosci. Model Dev., 13, 1545–1581, https://doi.org/10.5194/gmd-13-1545-2020, 2020.*