Utrecht University

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

Impacts of nutrient availability and soil microbiome on least-cost plant economy

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Introduction

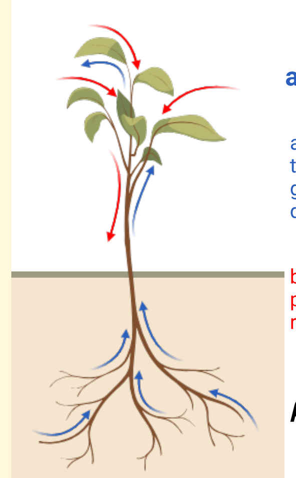
Eco-Evolutionary Optimality (EEO) approaches are proposed as a base for next generation ecosystem models. A central theorem here is the optimization of resource use and allocation to different environments.

Optimization is defined as the minimization of the summed costs of maintaining transpiration (E) and carboxylation Vcmax for a given assimilation rate A:

Costs = a*E/A + b*Vcmax/A

Within this framework, it has been found to be conceptually easier to predict the ratio of intercellular CO2 (ci) to environmental CO2 (ca), instead of stomatal conductance, with: ci : ca = χ

This research focusses on the relative cost factors *a* and *b*, the β in the model. The effects of nutrients and microbiome and their effects on whole plant scale are also studied.



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

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

$$\chi_{optimal} = \frac{\Gamma^*}{c_a} + \left(1 - \frac{\Gamma^*}{c_a}\right)\frac{\xi}{\xi + \sqrt{D}}$$

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

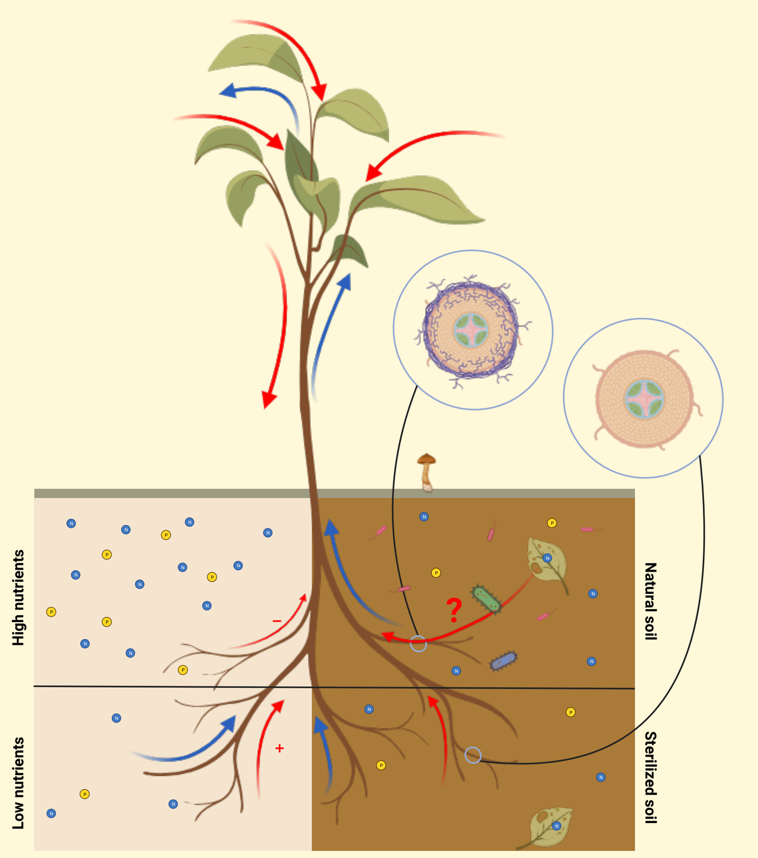
$$\xi = \sqrt{\frac{\beta(K+\Gamma^*)}{1.6\eta^*}}$$

$\beta = b/a$

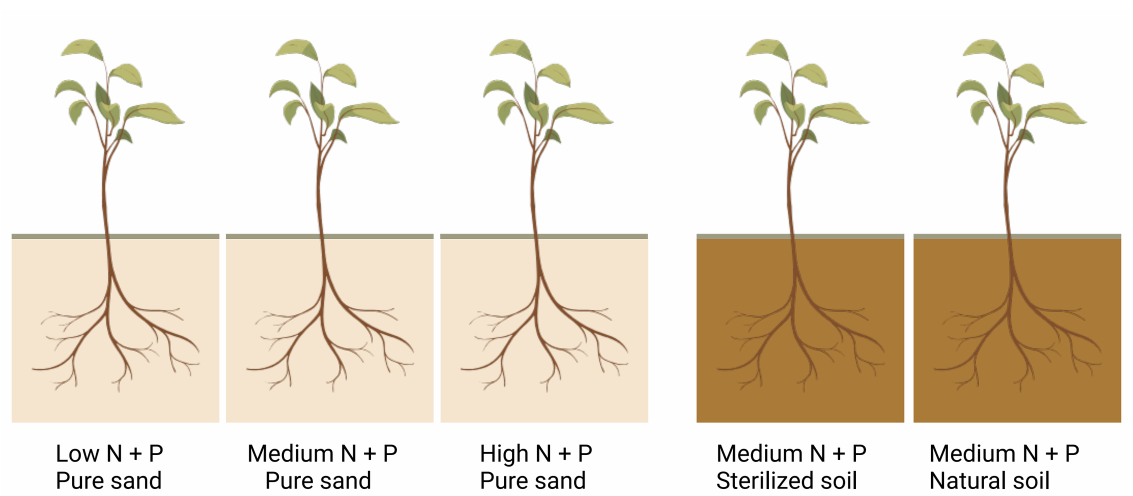
b ~~ g C in roots/whole plant g N

How do plant available nutrients impact the photosynthetic capacity and the least-cost optimization of χ?

Nutrient availability significantly affects plant growth, with low availability leading t poor performance. A symbiotic microbiome can alleviate nutrient or water stress but conversely, parasitistic or pathogenic relations decrease a plant's overall fitness. How do nutrients change optimality from a plant's perspective? And does the presence of a natural microbiome change optimality as



Methods



Substrate	Treatment
Sand	Low N+P
	Medium N+P
	High N+P
Soil	Sterilized
	Natural

Low: 26mg N + 1.75mg P
Medium: 36mg N + 2.40mg P
High: 78mg N + 5.25mg P

Both soils: 36mg N + 2.04mg P (readily available)

Two species native to the Netherlands were chosen: *Holcus lanatus* (C3, grass) and *Solanum dulcamara* (C3, forb). Per treatment combination 10 individual plants per species were planted (total n = 100).

Plants were measured for photosynthetic capacity after 7 weeks and destructively harvested after 8 weeks of treatment.

Results from leaf to plant

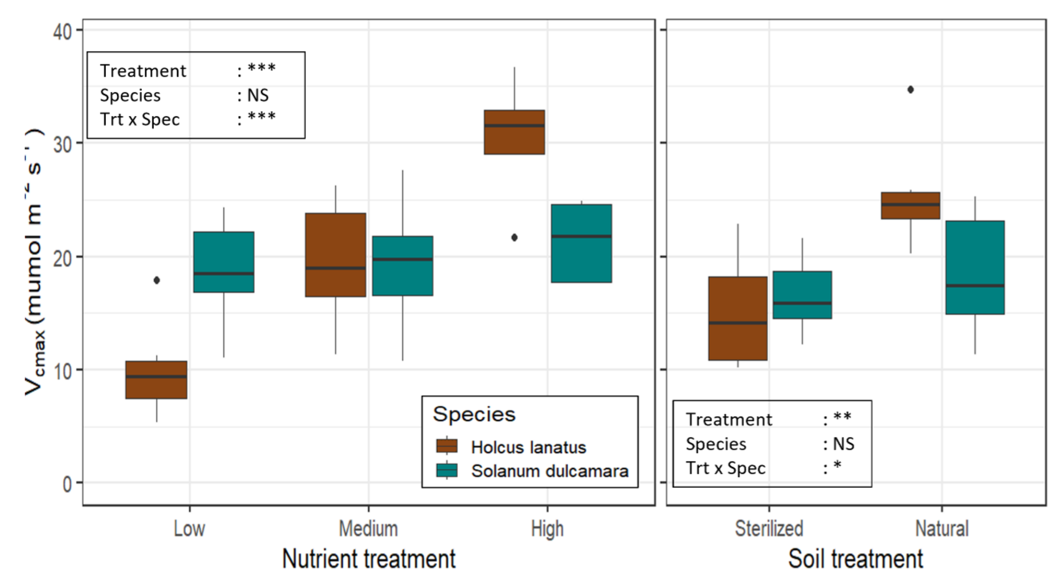


Fig. 1. Maximum rate of carboxylation (V_{cmax}, μmol CO_2 m^{-2} s^{-1}) measured 7 weeks after treatment start. n = 50. Statistical analysis: Two-way ANOVA

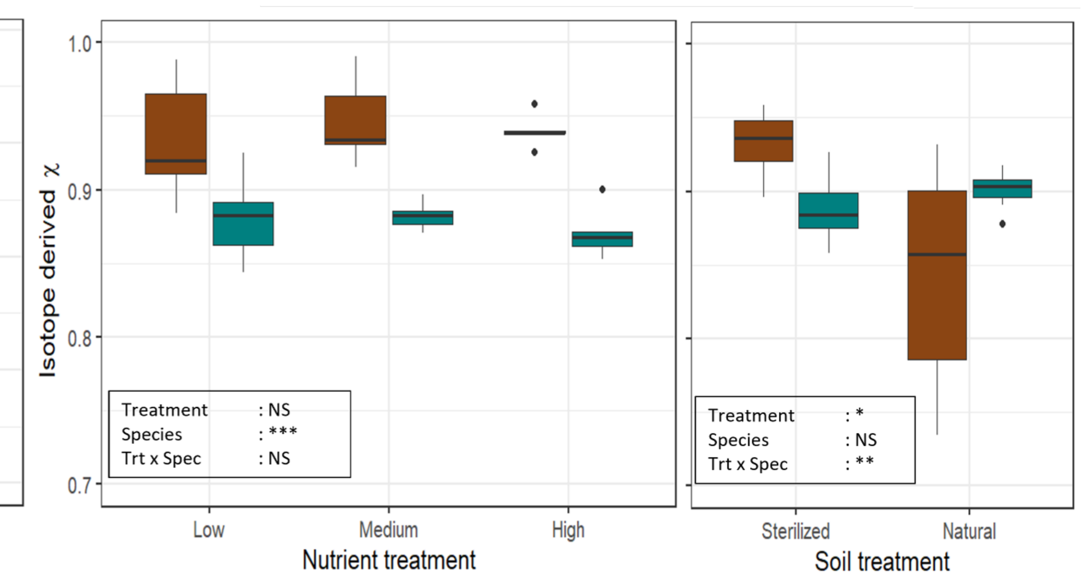


Fig. 2. δ^{13} C derived χ values. n = 73. Statistical analysis: Two-way ANOVA
Signif. codes: '***' < 0.001 '**' < 0.01 '*' < 0.05 '.' < 0.1 'NS' < 1

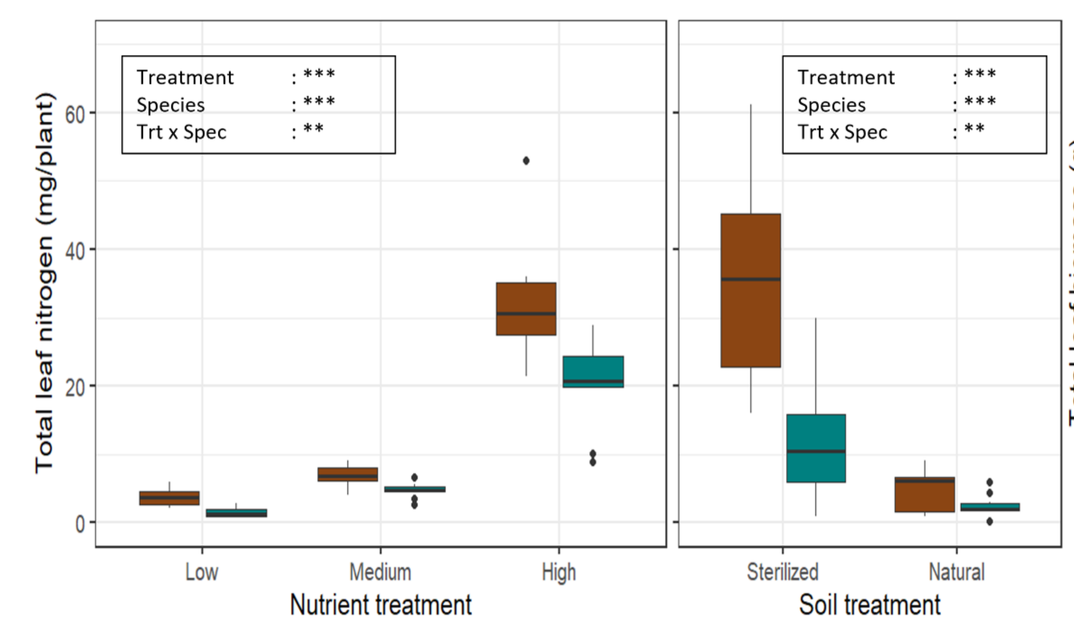


Fig. 3. Leaf nitrogen, calculated from N concentration and total leaf biomass. n = 100
Signif. codes: '***' < 0.001 '**' < 0.01 '*' < 0.05 '.' < 0.1 'NS' < 1

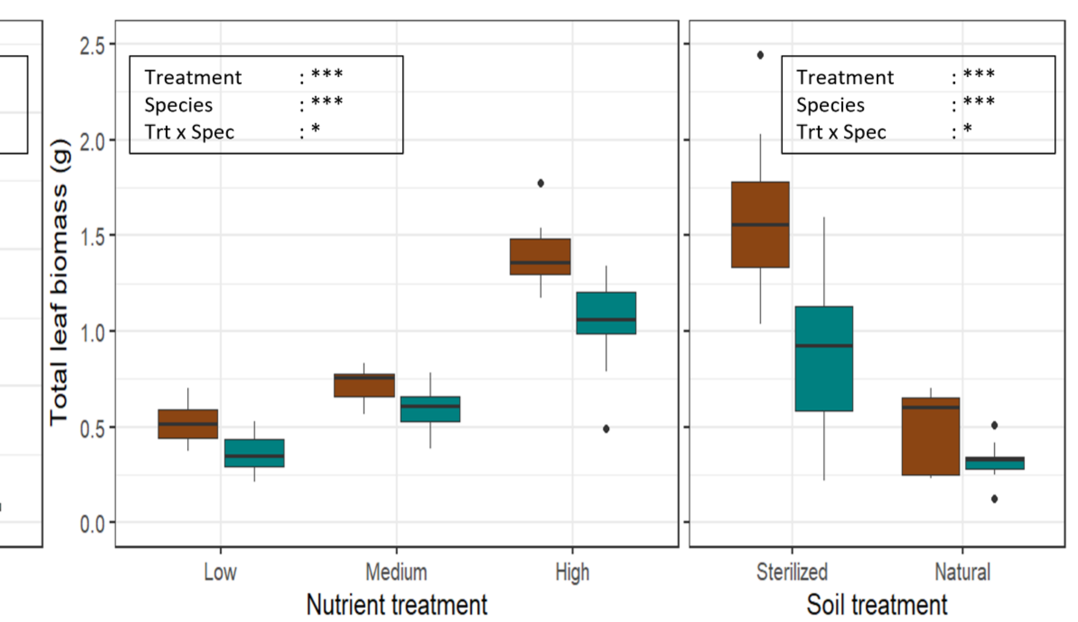


Fig. 4. Total leaf dry weight. n = 100
Signif. codes: '***' < 0.001 '**' < 0.01 '*' < 0.05 '.' < 0.1 'NS' < 1

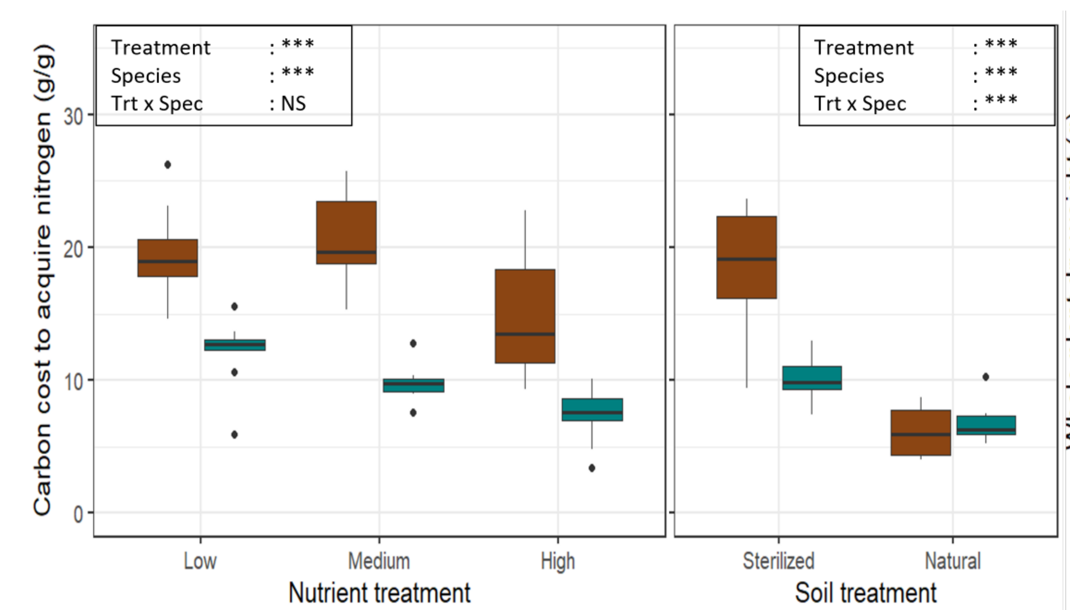


Fig. 5. Root system carbon / whole plant nitrogen (see introduction). n = 100
Signif. codes: '***' < 0.001 '**' < 0.01 '*' < 0.05 '.' < 0.1 'NS' < 1

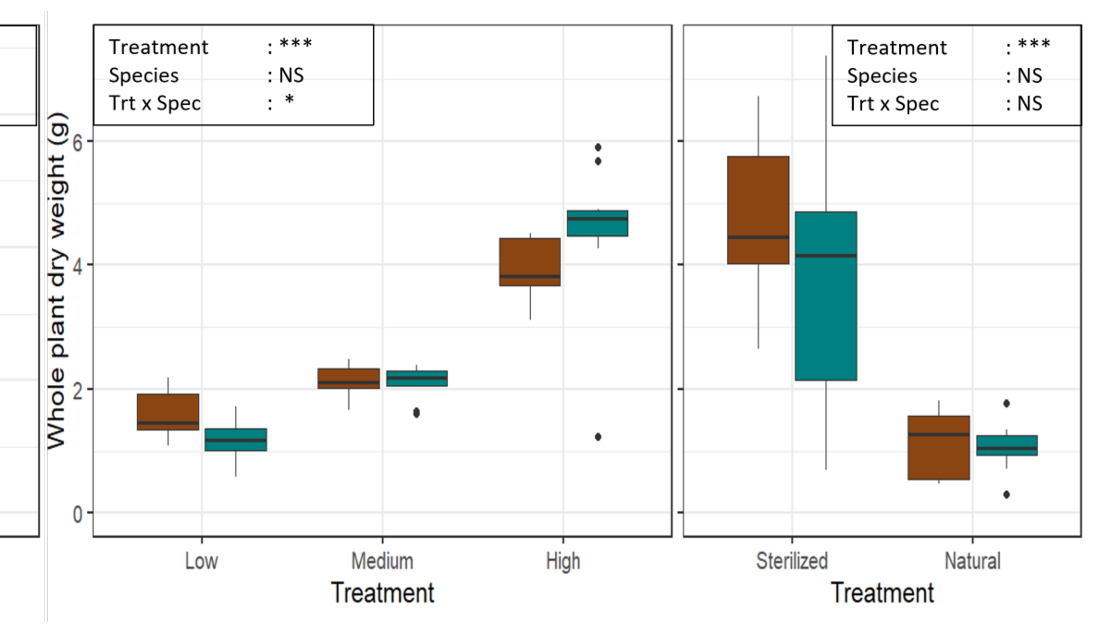


Fig. 6. Whole plant dry weight. n = 100
Signif. codes: '***' < 0.001 '**' < 0.01 '*' < 0.05 '.' < 0.1 'NS' < 1

Results

Multiple two-way ANOVAs were performed to thes the effects of species, treatment, and their interaction on the variables of interest. Due to the differences in substrate, the nutrient treatments in sand and the sterilization treatments in the natural soils were separated to prevent an unfair comparison.

The results indicated a significant effect of nutrient treatment and an interaction effect of treatment and species on the maximum rate of carboxylation (V_{cmax}). In soils the sterilization treatment and the interaction between treatment and species were found to be significant.

Only species were found te have a significant effect on isotopically derived χ for plants grown in sand. In soils the main effects are treatment and the interaction between treatment and species.

At canopy level, treatment, species, and their interaction had a significant effect on total leaf nitrogen and leaf biomass for plants grown in sand AND in soils.

At whole plant level, treatment and species have a significant effect on the carbon cost to acquire nutrients for plants grown in sand. In soils, treatment, species and the interaction is significant. Whole plant dry weight is signifcantly affected by treatment and interaction in sand. Only the sterilization of soils has a signifcant effect on plant dry weight.

Conclusion & discussion

We explored the effects of nutrients on sand and the effects of microbiome in soils plant performance in EEO theory. While the nutrient treatments did affect the photosynthetic capacity significantly, it did not affect the isotope derived χ, supporting EEO theory[1,2]. This means that the cost of maintaining transpiration relative to the cost of procuring and using nitrogen (β) did not change. In soils a similar pattern can be seen, with a change in photosynthetic capacity, but a relatively constant χ value. Only *Holcus lanatus* grown on the natural soils .

At canopy level, addition of nutrients in sand shows an increase in total leaf nitrogen, as would be expected from an increase in photosynthetic capacity at leaf level. In soils, the opposite is visible. While plants in natural soils had significantly higher V_{cmax} the total leaf nitrogen is lower. This is also visible in leaf biomass, with significantly lower leaf biomassin natural soils than in sterilized soils.

These results support EEO theory by showing the relative insensitivity of χ to nutrients and microbial influences. It also shows that plants grown on sand with added nutrients behave relatively predictably, but that but it also shows that the microbial influences can induce unexpected results. The consequences for EEO theory testing could be that the soil microbial community induces a relatively poorly understood effect of below-ground processes influencing the translation of robust leaf-level optimality to whole plant/ecosystem functioning.

Outlook

Another iteration of this experiment is being analysed. Similar results are observed in the photosynthetic capacity, but overall plant performance was higher in the second run. Data of whole plant nitrogen partitioning will be analysed. An extensive dataset of the two experimental runs with various undiscussed measurements from soil to leaf will be made available for the whole LEMONTREE team.

Literature

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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.*

Acknowledgements

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