Alfalfa to get back into planetary boundaries

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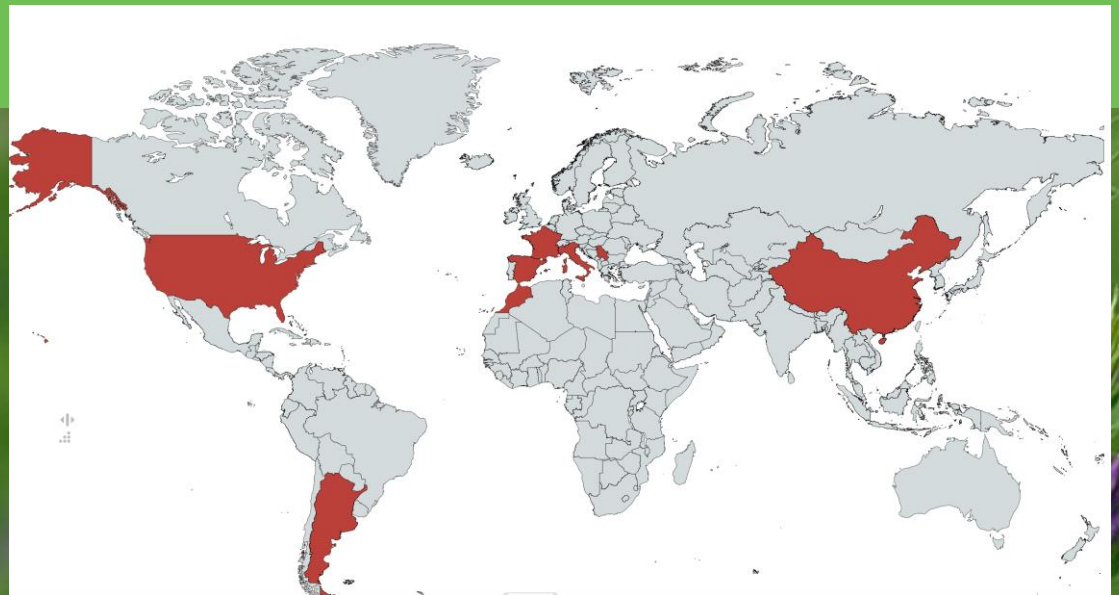
Planetary boundaries as a framework to think the role of alfalfa in future agri-food systems and to define research and innovation priorities

C. Huyghe, M. Brun, C. Brummer, S. Jézéquel, B. Julier, H. Labanca, N. Liu, J. Lloveras, A. Odorizzi, A. Palmonari, D. Sokolovic, C. Tabel, I. Thami Alami.

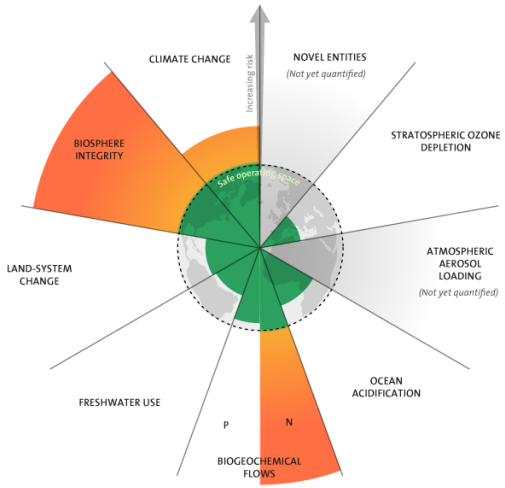
All members of the Scientific Committee of World Alfalfa Conference 2025



FROM 03 TO 06 nov. 2025

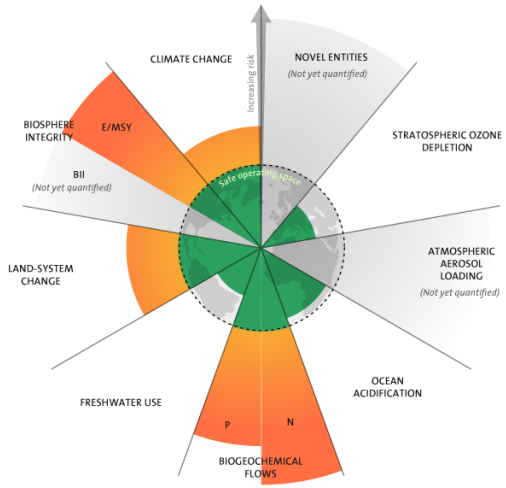
Human activities broke the planetary boundaries (Johan Rockström (2009))

2009



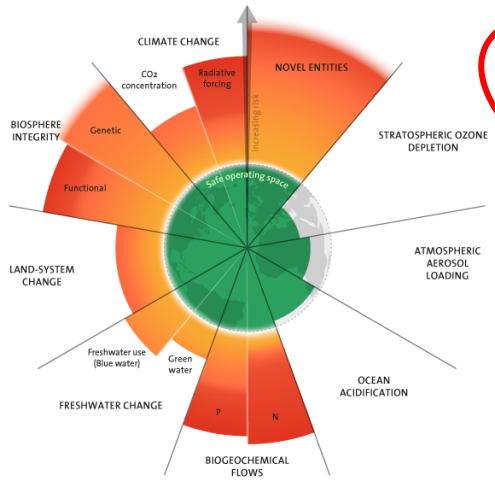
7 boundaries assessed,
3 crossed

2015



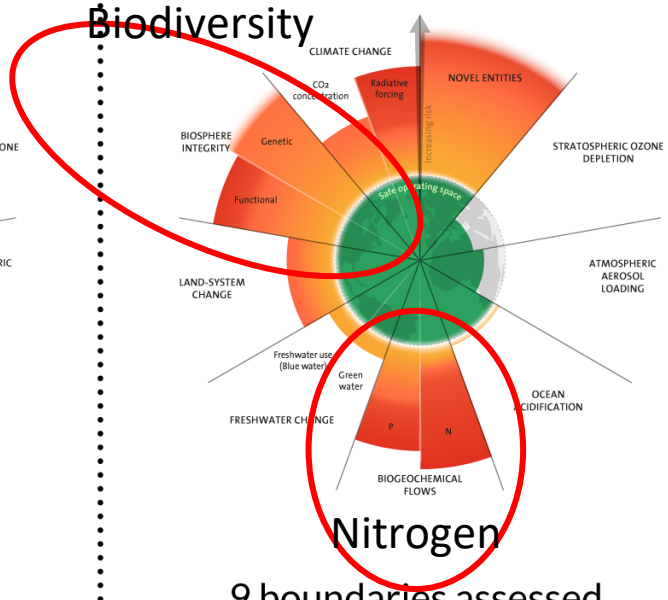
7 boundaries assessed,
4 crossed

2023



9 boundaries assessed,
6 crossed

2025



9 boundaries assessed,
7 crossed

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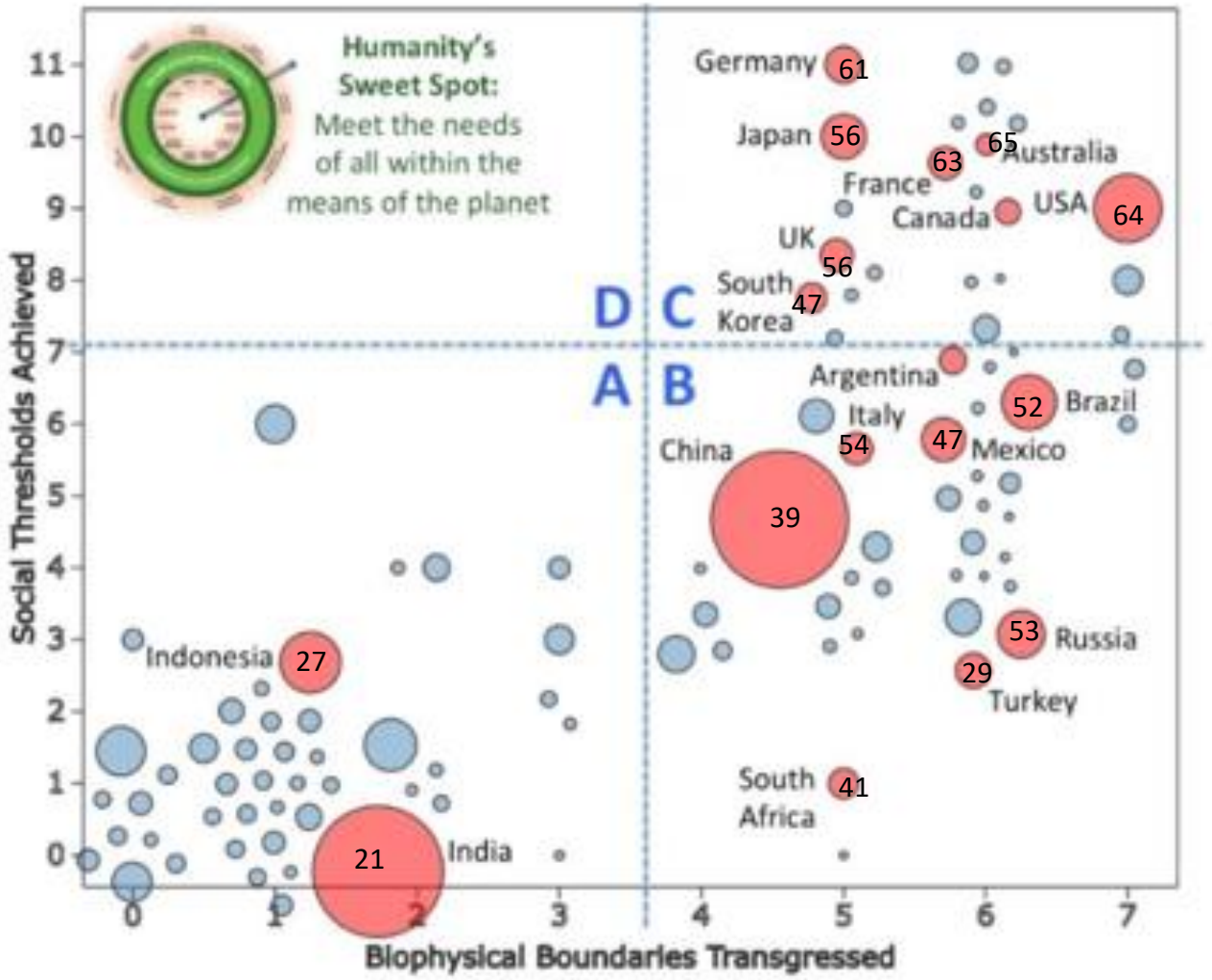
- Social equity at the price of a high share of animal proteins?
- Agricultural transition and food transition are intimately linked
- Food processing industries and consumers contribute to the sociotechnic lock-in

JUST: Meet the needs of social well-being

% animal proteins



SAFE: biophysical boundaries

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Biodiversity

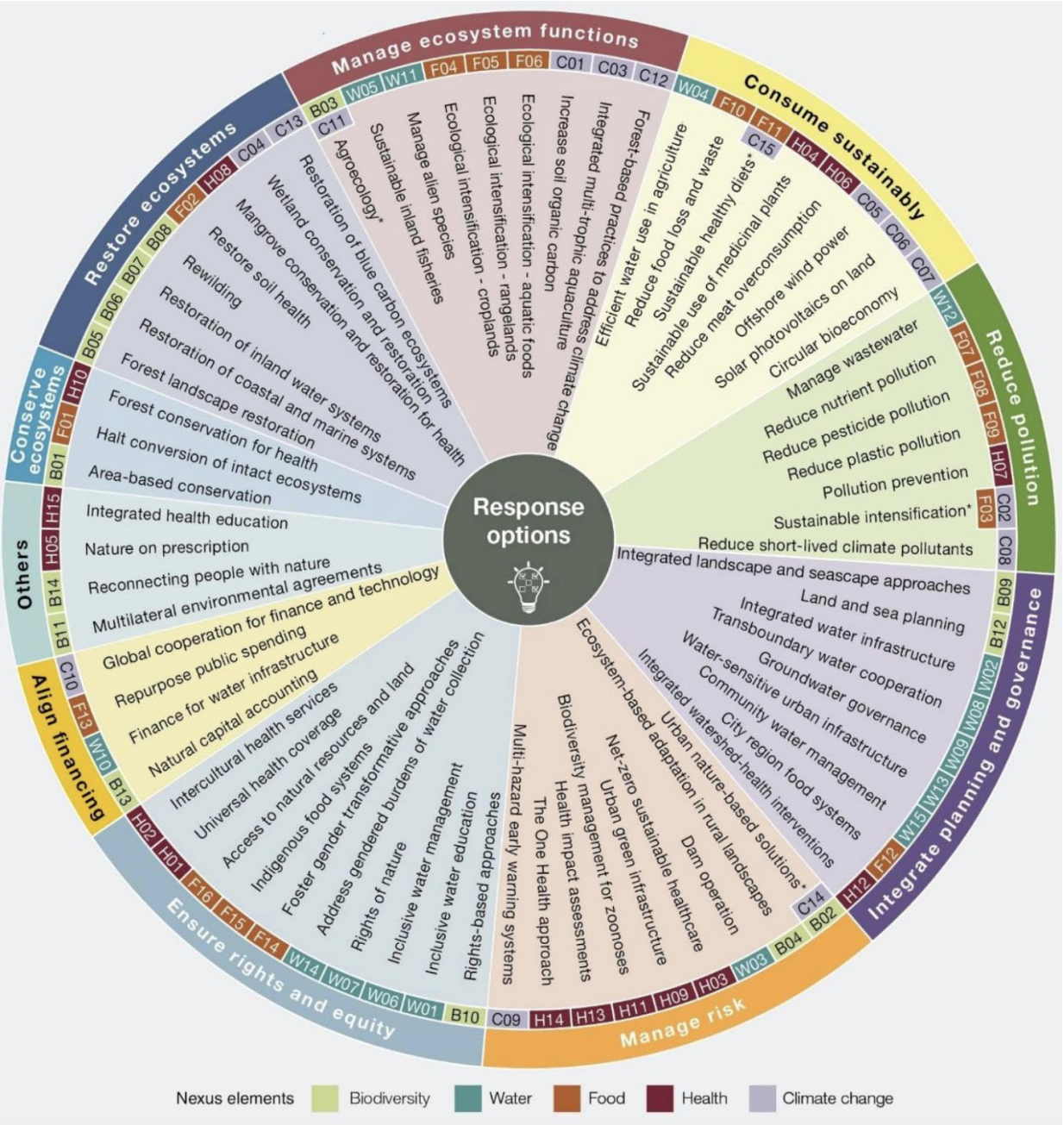
The 2024 IPBES report showed the links between biodiversity, water, food, health and climate

IPBES elaborated 6 scenarios (nexus): what are the expected impacts?

	Biodiversity	Water	Food	Health	Climate
Nature-oriented	▲▲▲	▲▲	▲	▲	▲
Balanced	▲	▲	▲▲	▲▲	▲
Biodiversity conservation first	▲▲	≈	▼▼	≈	▲
Climate first	▼	≈	▼▼	▲	▲▲
Food first	▼▼	▼	▲▲	▲	▼▼
Nature overexploitation	▼▼	≈	▼▼	▼	▼▼

▲: favourable
≈ : variable
▼: unfavourable

The possible answers under the « Balanced » scenario



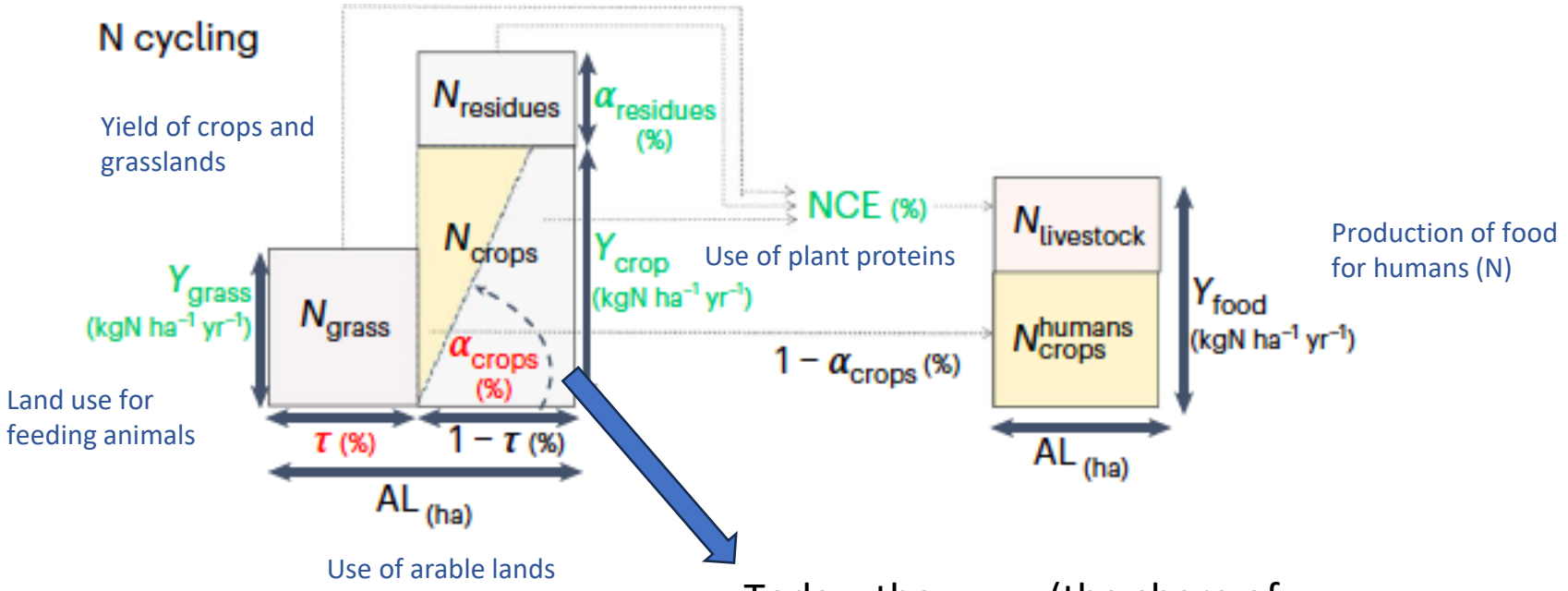
The relevant ones for alfalfa-based production systems

- Conserve ecosystems
  - ~~0-conversion of intact ecosystems~~
- Restore ecosystem
  - ~~Restore soil health~~
- Manage ecosystem functions
  - ~~Ecological intensification~~
  - ~~Agroecology~~
- Consume sustainably
  - ~~Efficient water use in agriculture~~
  - ~~Reduce wastes and losses~~
  - ~~Sustainable and healthy diets (including less meat)~~
- Reduce pollution
  - ~~Reduce nutrient and pesticide pollution~~
  - ~~Sustainable intensification~~
- Integrate planning and governance
  - ~~Integrated landscape approaches~~
  - ~~City region food systems~~
- Ensure rights and equity
  - ~~Access to natural resources and water~~
- Align financing
  - ~~Repurpose public spending~~

Nitrogen and proteins

Building on a fertile foresight (Chatzimpiros and Harchaoui, 2023)

Nitrogen cycle and its components



Today, the α_{crops} (the share of annual crops used to feed animals) is 57%

Chatzimpiros et Harchaoui, 2023, Nature Food

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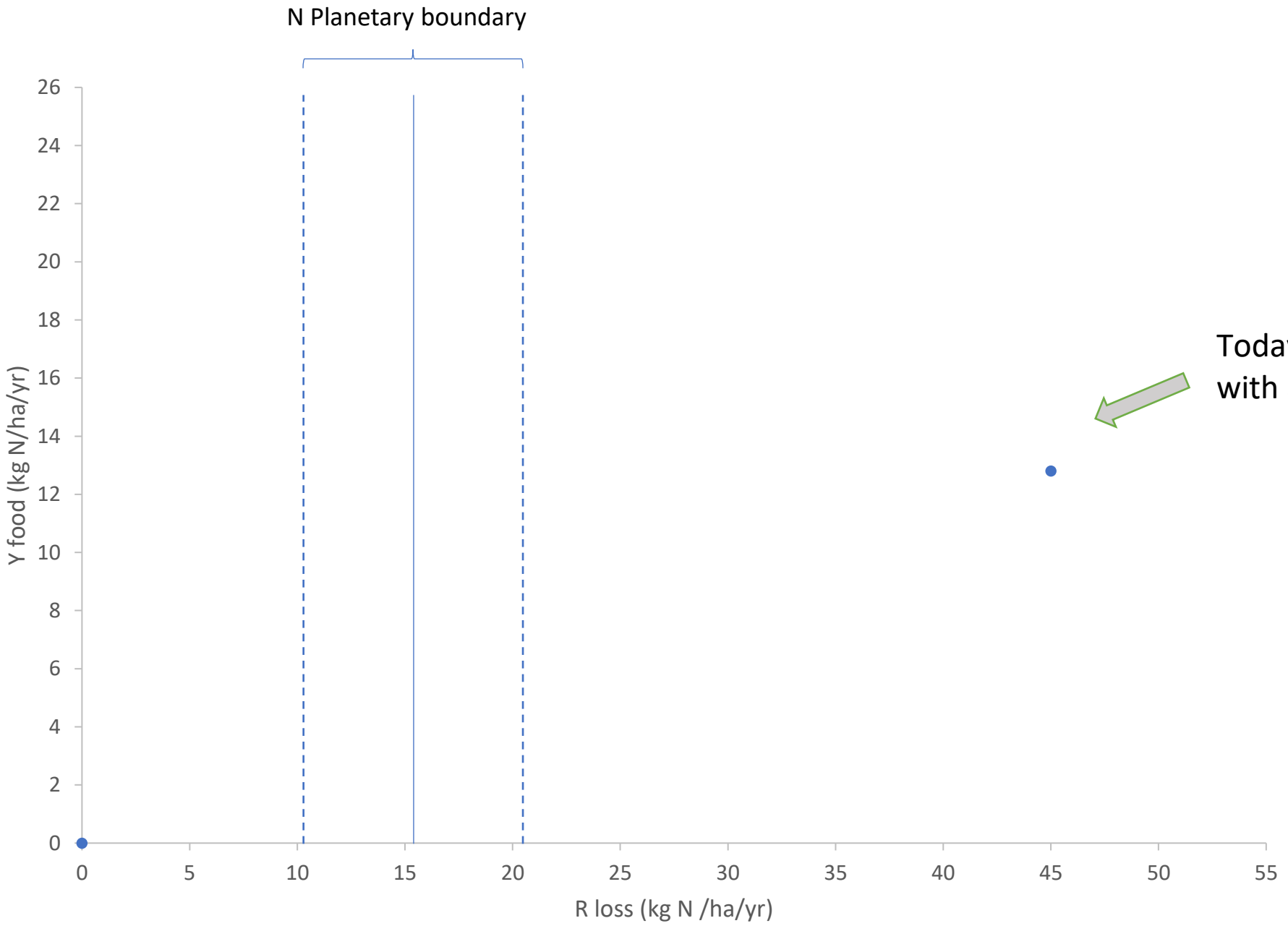

Today, we are here,
with a NUE of 20%!

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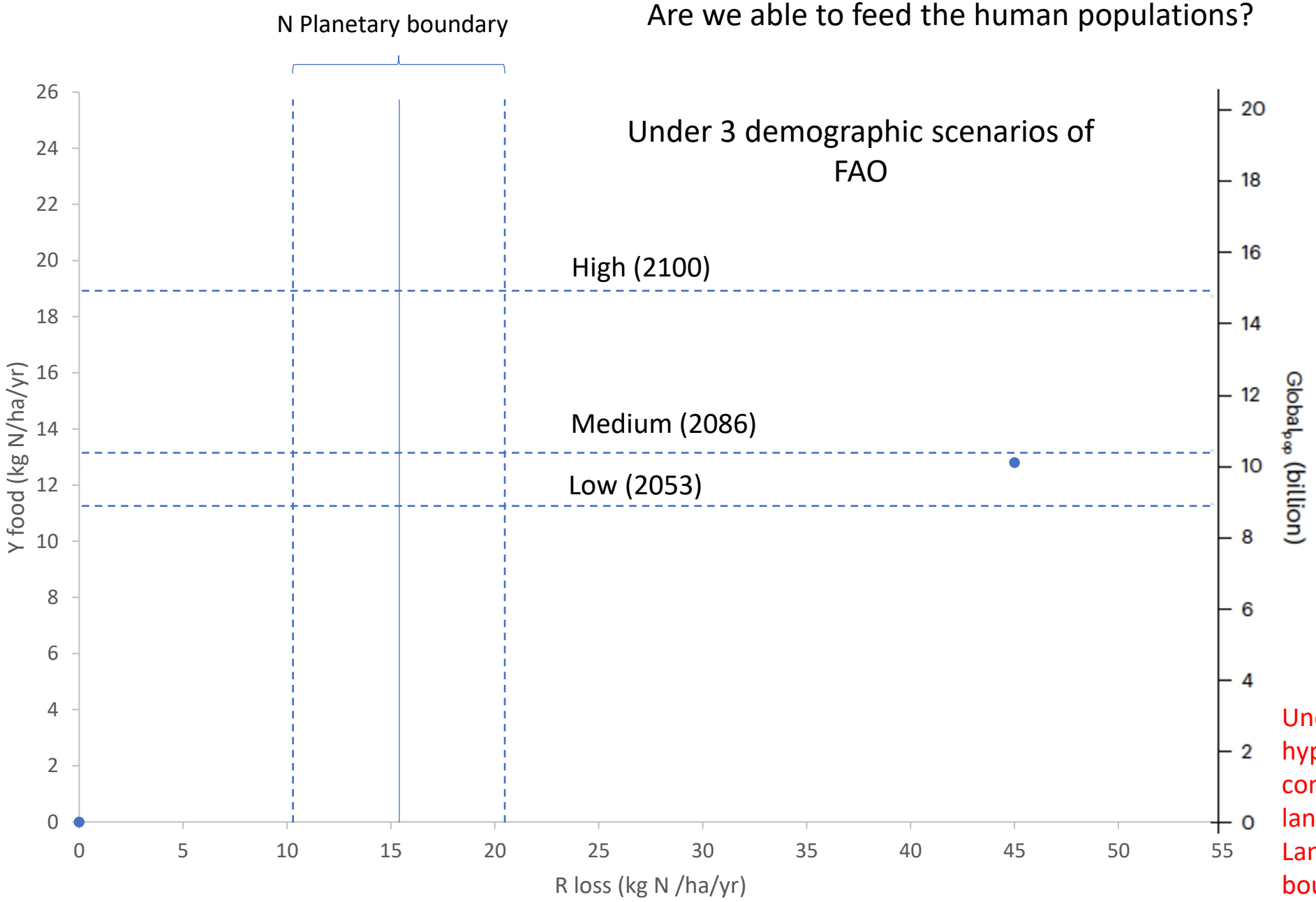
Are we able to feed the human populations?



Under the hypothesis of constant Arable land, for sake of Land Use Planetary boundary

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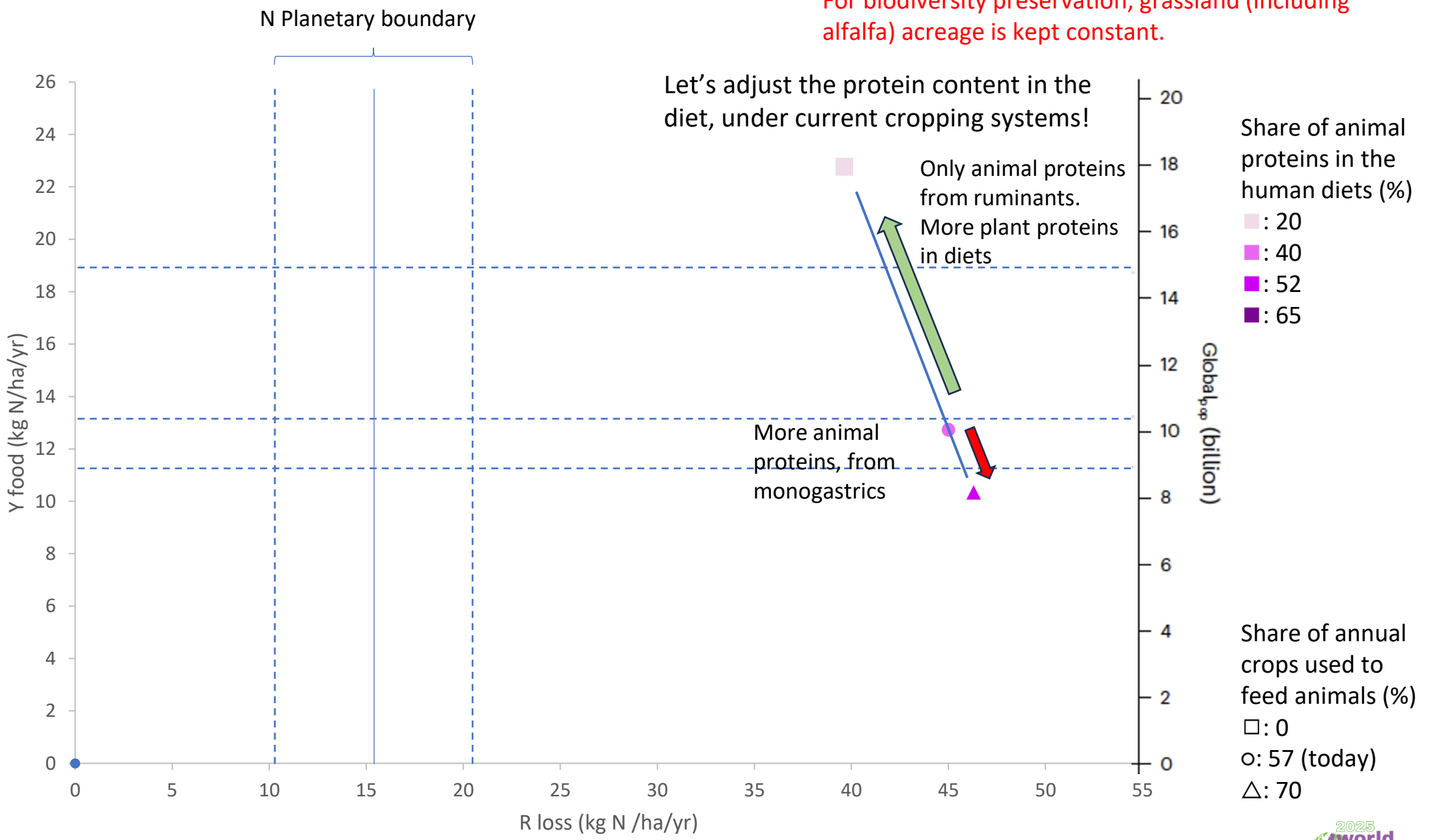
For biodiversity preservation, grassland (including alfalfa) acreage is kept constant.



Share of animal proteins in the human diets (%)
■: 20
■: 40
■: 52
■: 65

Share of annual crops used to feed animals (%)
□: 0
○: 57 (today)
△: 70

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Human diets

- A huge difference regarding the global population that can be fed
- A limited contribution to the reduction of the N losses

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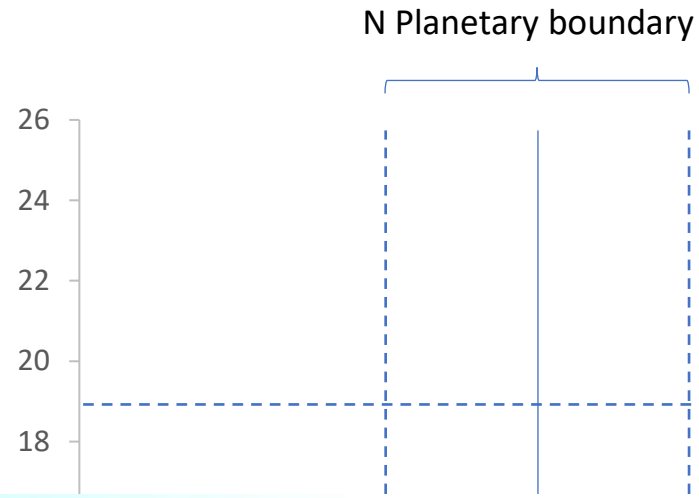
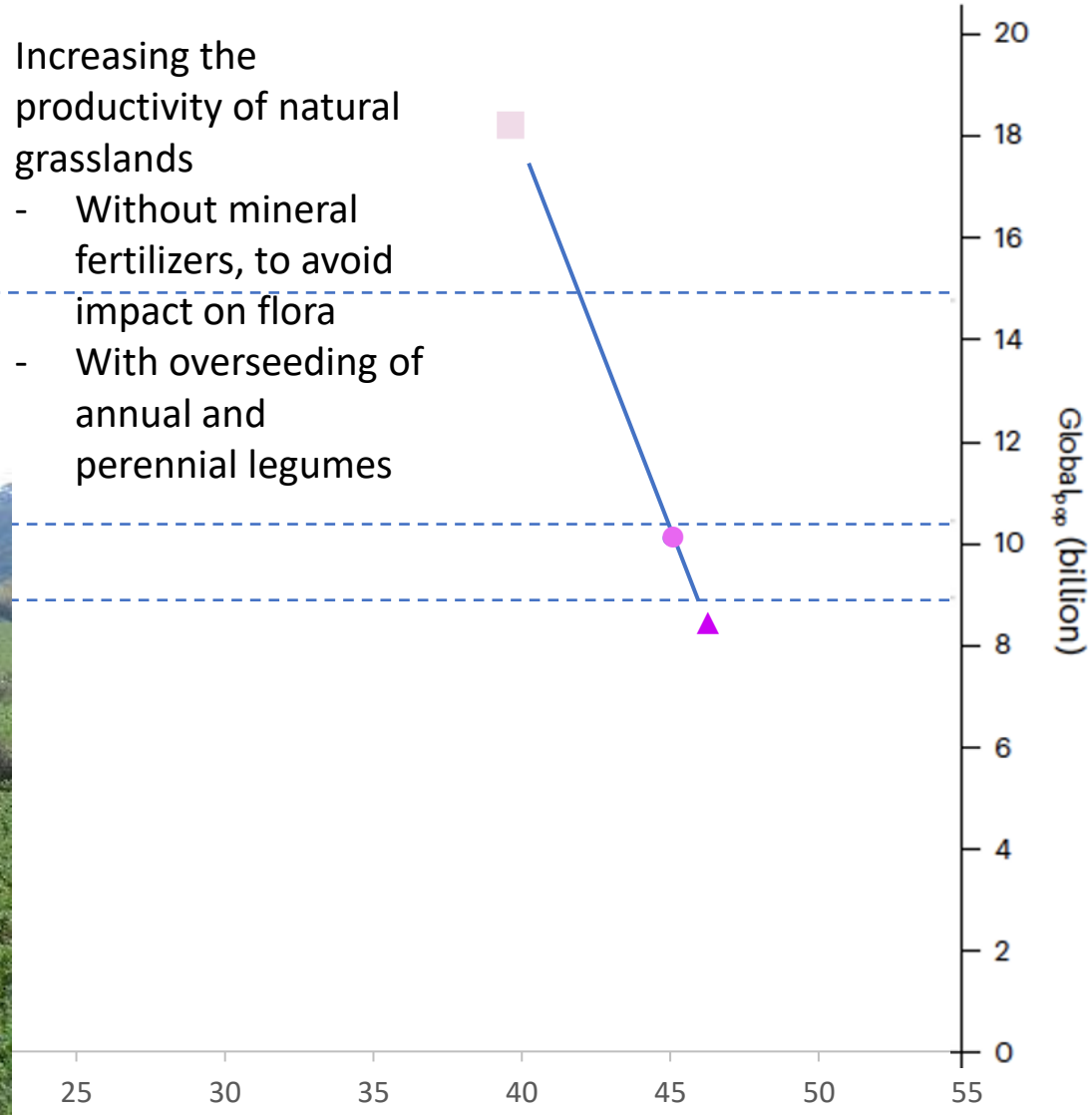


Increasing the productivity of natural grasslands

- Without mineral fertilizers, to avoid impact on flora
- With overseeding of annual and perennial legumes



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into planetary boundaries

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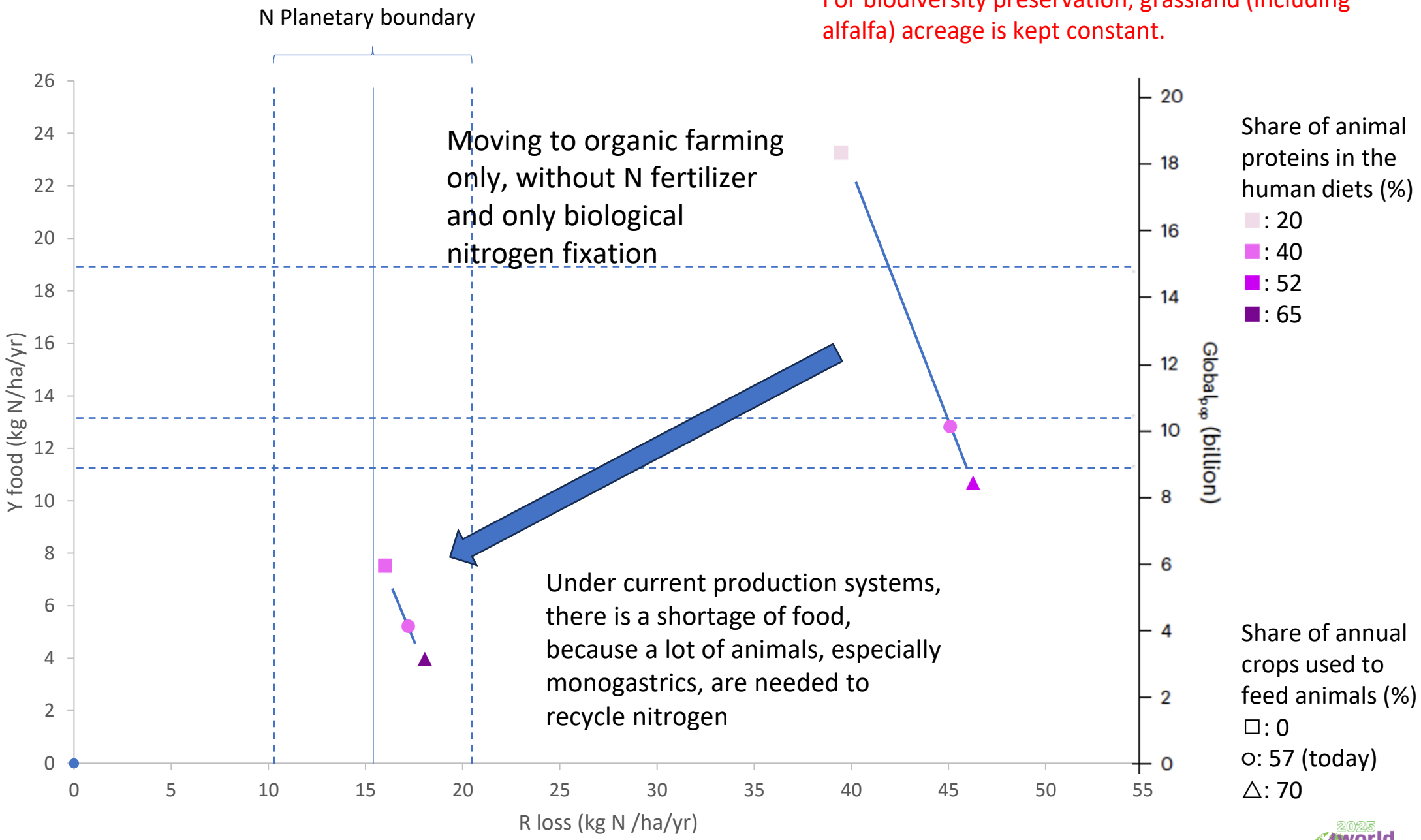

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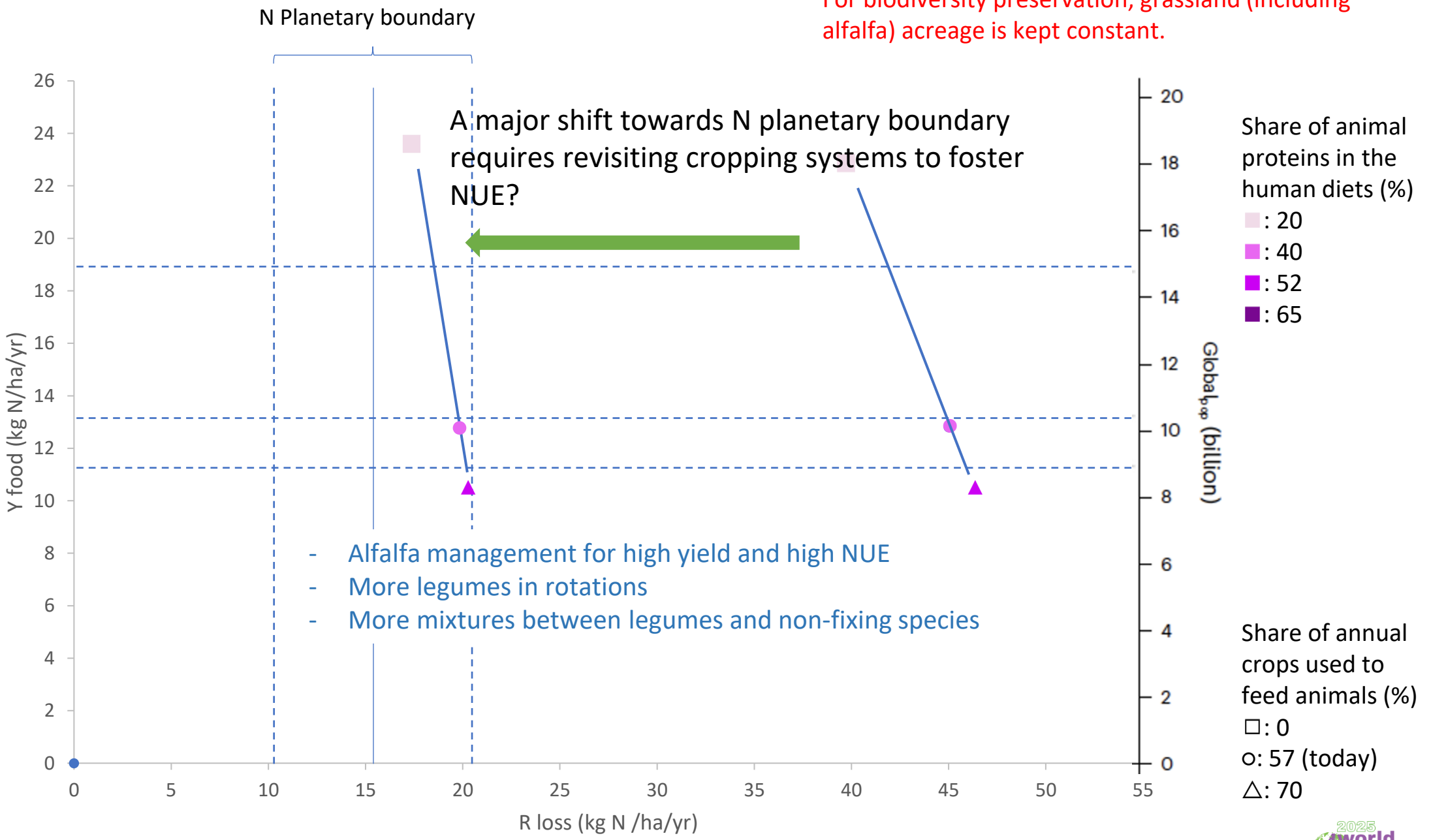

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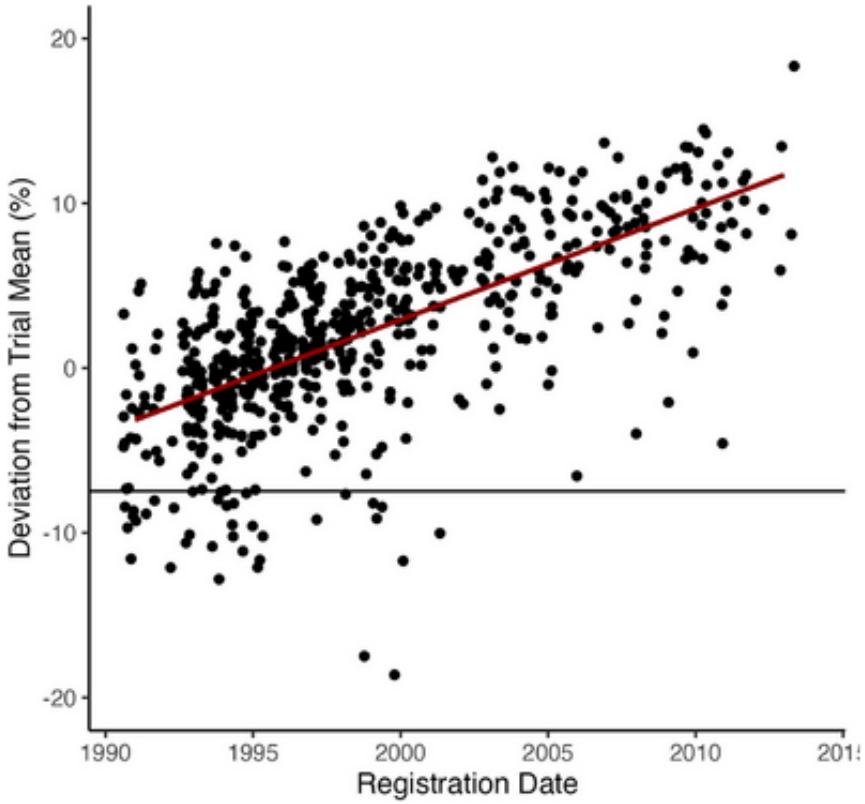
Higher NUE of crops: alfalfa management

- Increasing alfalfa yield per se (especially through plant breeding)
- Making the best out of Nitrogen symbiotic fixation
  - Protect the rhizobium populations in soils.
  - More attention has to be paid to effect of herbicides
- Irrigation and water manageme
  2018. Field Crops Research)



Tilhou and Riday, 2025. Crop Science

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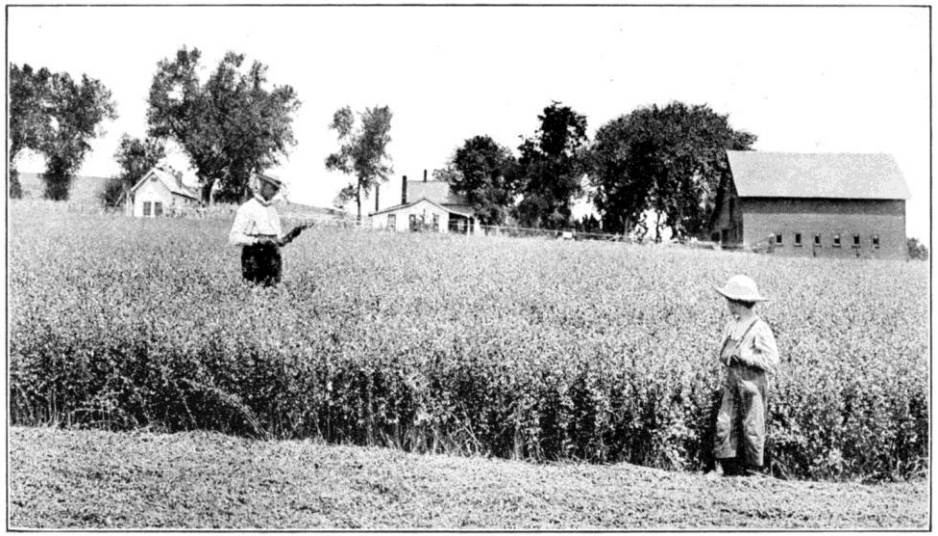
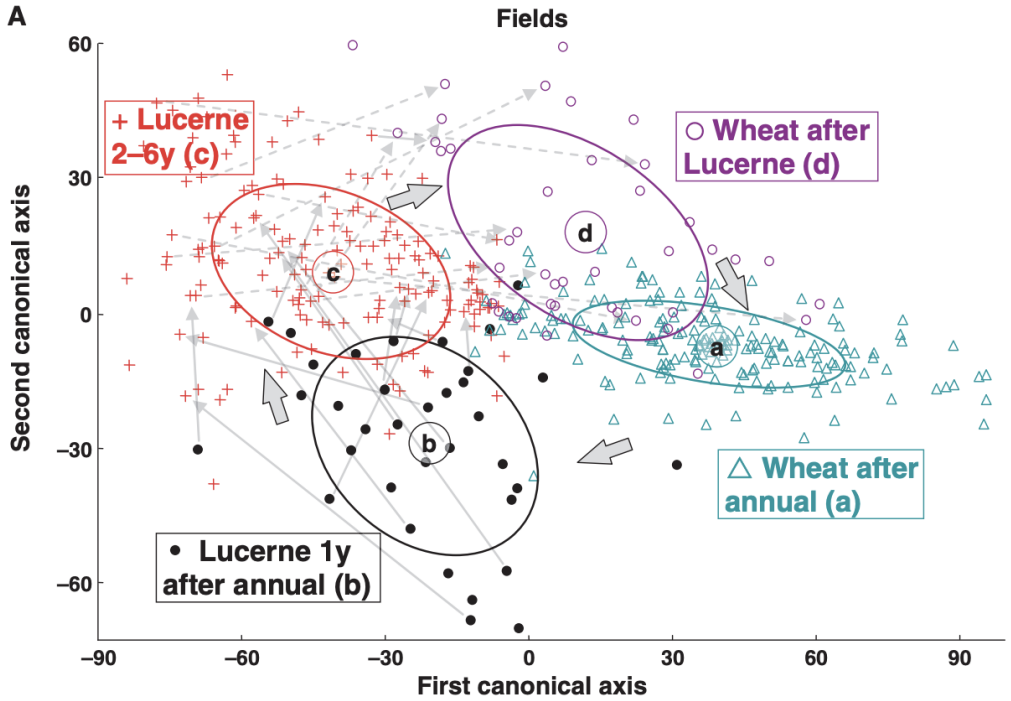
Higher NUE of crops: more legumes in the rotations

- Increasing the availability of N from legumes and symbiotic fixation for non-fixing crops in the rotations
  - Alfalfa is an excellent preceeding crop,
    - For nitrogen fixation
    - For weed suppression



The Book of Alfalfa, F.D. Coburn, 1912
(*its use as a forage and fertilizer*)



Meiss et al, 2010. Weed research

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Higher NUE of crops: crop mixtures

- Alfalfa in mixed forage swards
  - Effect on total forage yield
  - Effect on yield distribution along seasons
  - Protein content

- Alfalfa as living mulches for cereals (several papers in the conference)

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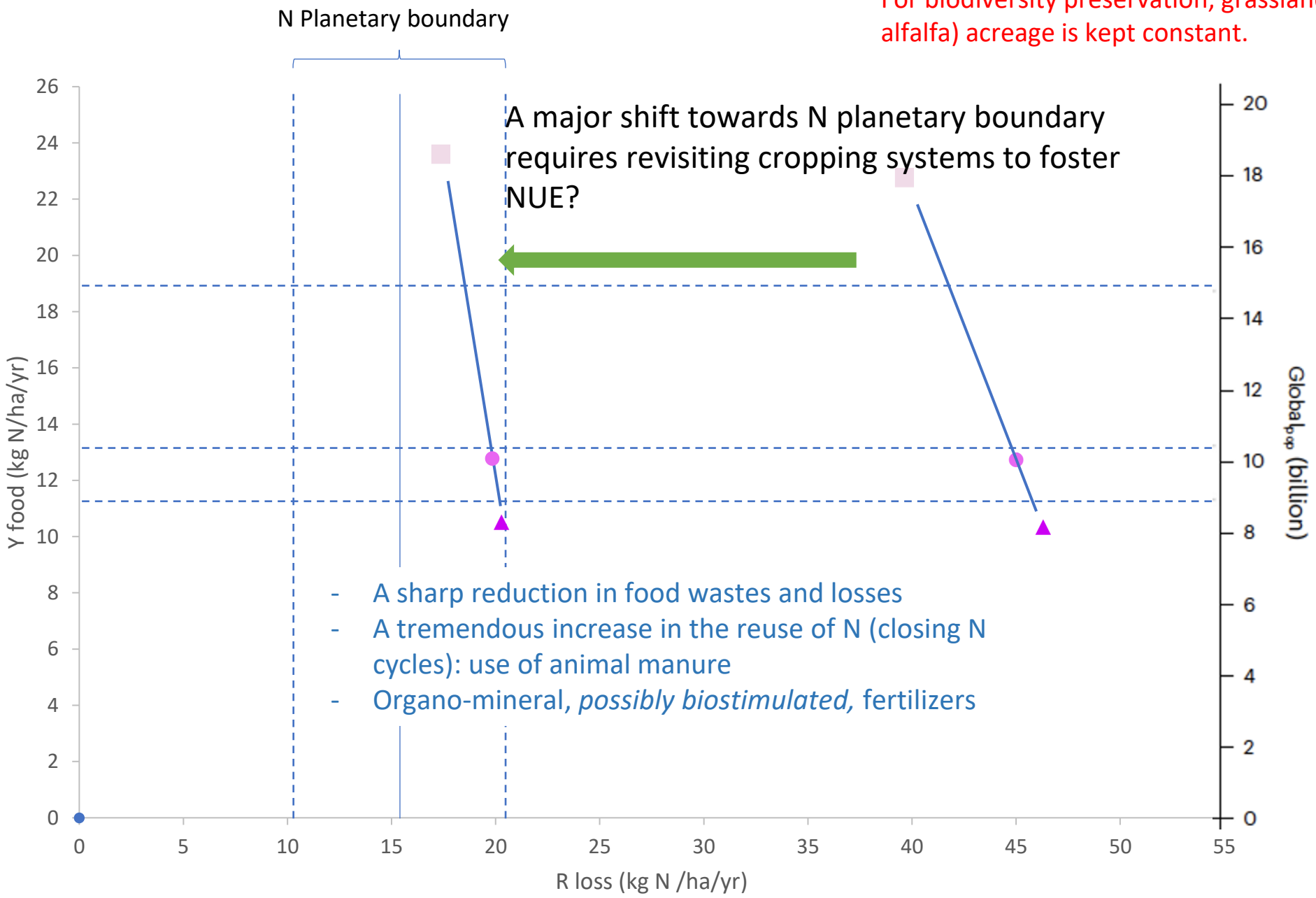

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Reducing wastes and losses

- Of the human food: 30% are lost today
  - Reducing the losses
  - Converting them to feed
  - Converting them to energy and fertilizers
- Of the animal feed
  - Losses during harvest (losses of leaf proteins, of carbohydrates during drying)
  - Losses during conservation

➢ Where dehydration is a real contribution!

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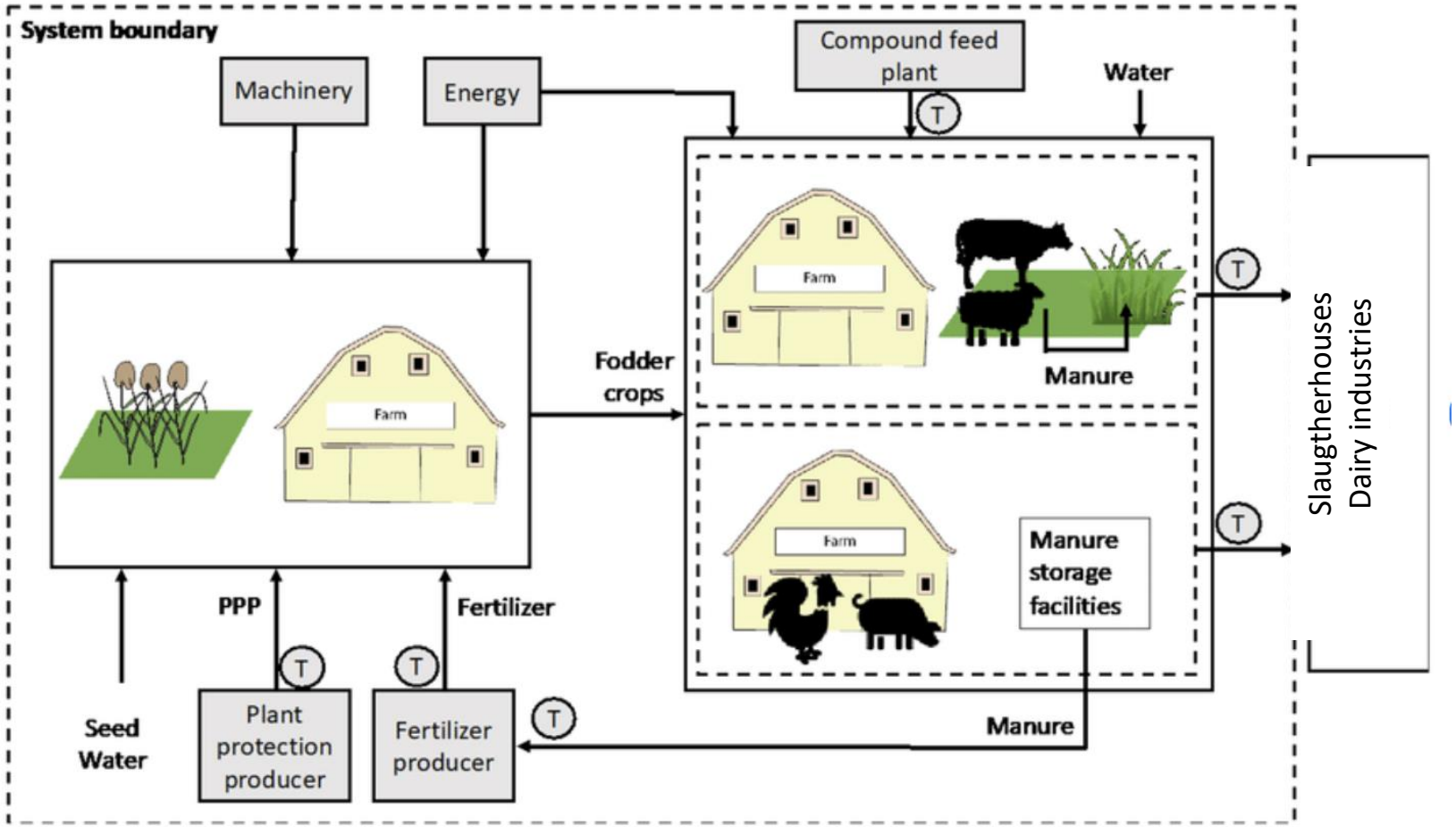
More link between animal and plant productions

When co-located



When intimately linked at the farm level

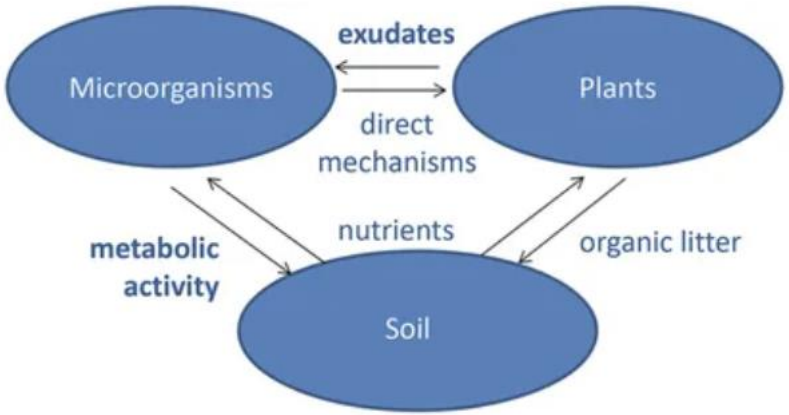
- Better use of feed (especially important for proteins that are the scarest resources)
- Less losses of N and P in manure
- Less energy costs for transport

Slurry application on alfalfa (Shi et al, 2024. Sustainability)

More link between animal and plant productions

When not co-located

- How to transport manure over long distances?
  - Terrial example in France
- N and P in manure are unbalanced. The N availability does not always fit crop needs. How to improve their agronomic value?
  - Towards organo-mineral fertilizers
- How to improve their fertilizing values and their absorption by crops?
  - Interaction with the crop root microbiota
  - *Towards biostimulated organo-mineral fertilizers?*



Jacoby et al, 2017. Frontiers in Plant Science

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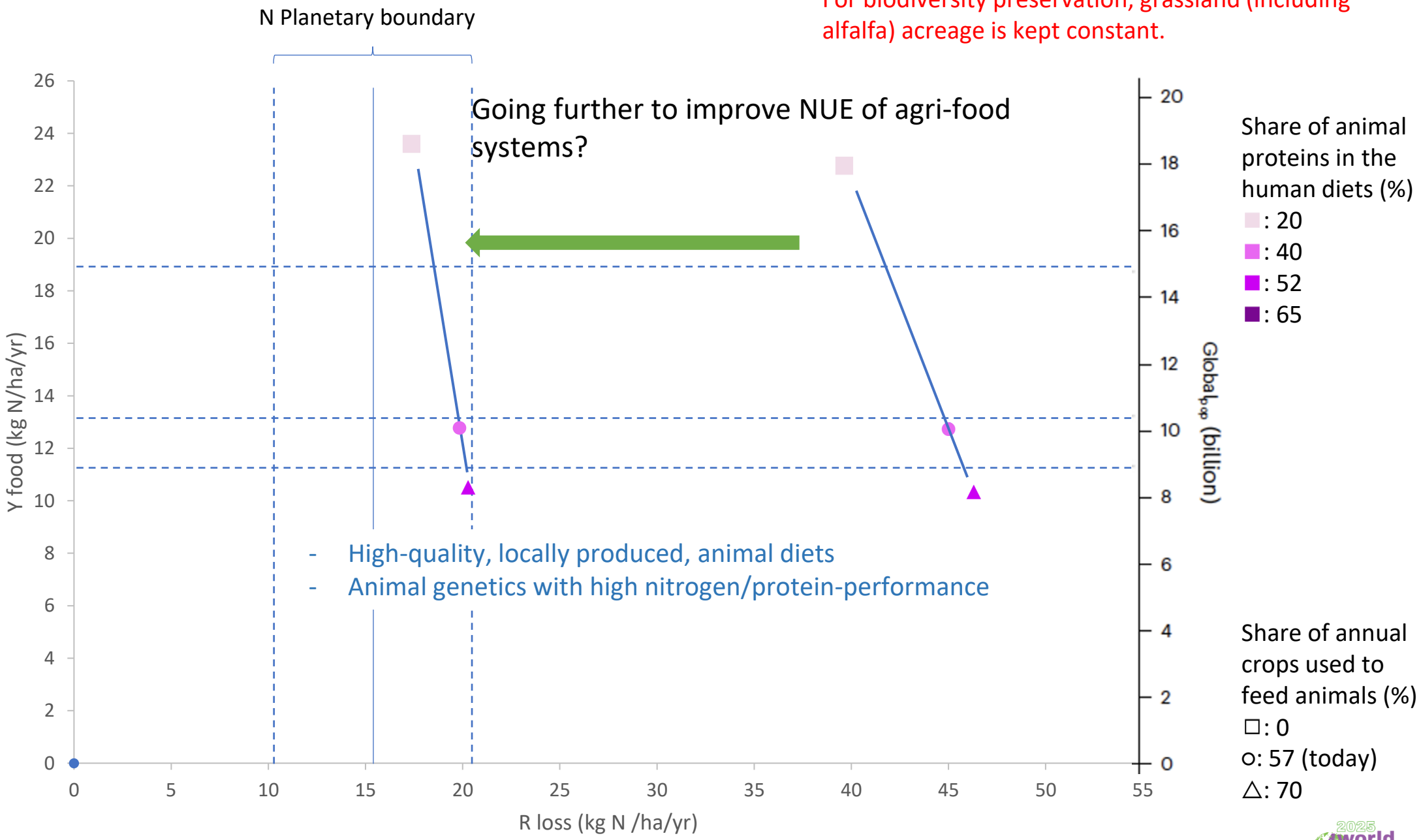

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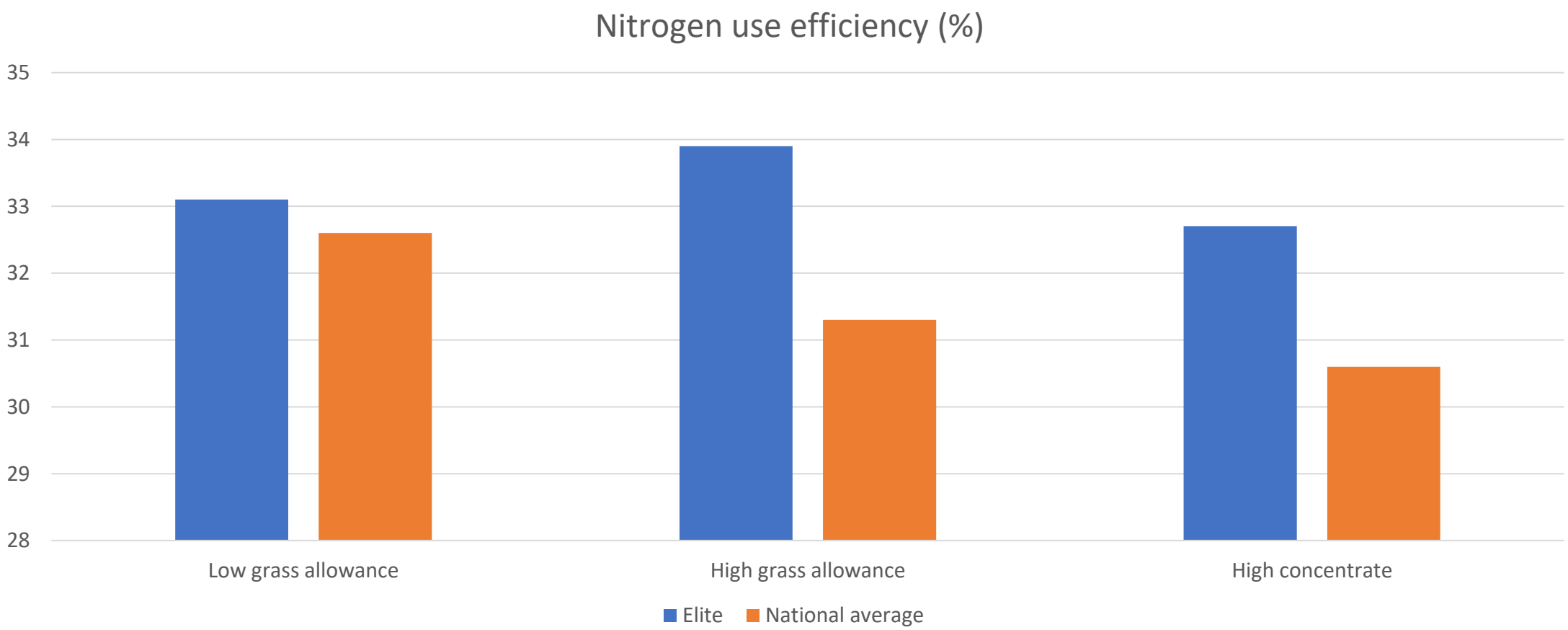
Genetic gains in Elite Holstein breeding (Lahart et al, 2021)



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N Planetary boundary

The same improvements being applied to organic farming?

- Better use of BNF
- More recycling
- Adapted animals

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Global$_{pop}$ (billion)

R loss (kg N /ha/yr)

to get back into planetary boundaries

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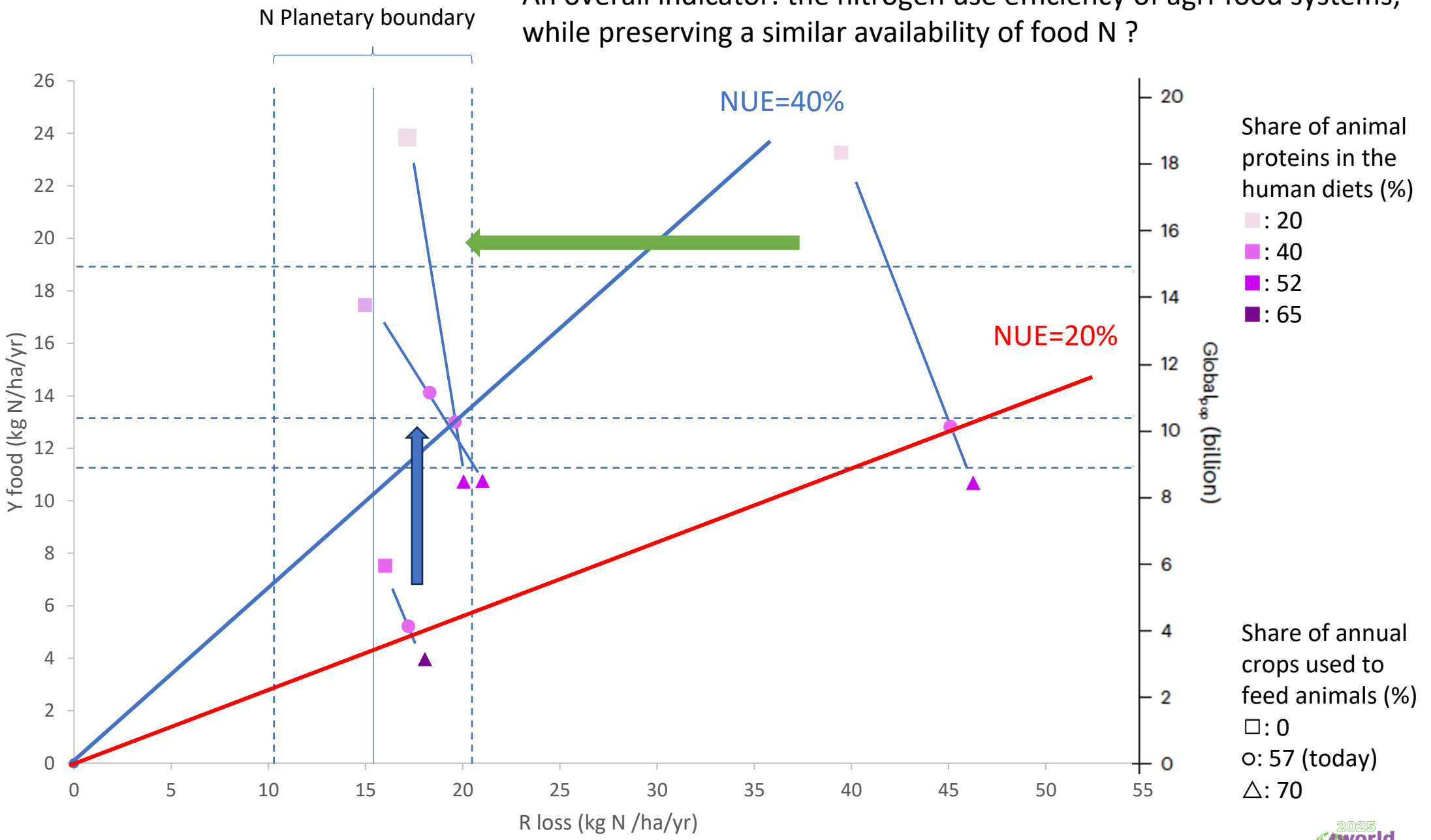
An overall indicator: the nitrogen use efficiency of agri-food systems, while preserving a similar availability of food N ?



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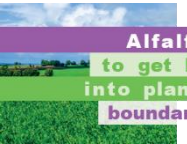
Cross-cutting issues

- The roads to get back to planetary boundaries are narrow but they exist, both in conventional and organic farming
- They require huge redesign!
- A system-thinking is compulsory
  - At the crop level
    - Mixtures of plant species
    - Associated microbiota
    - Crop rotations and spatial organisation
  - Animal-plant combined productions (Watson et al, 2019)
  - Place-based approach
    - Local use of feed and manure
    - Cooperation among farmers (Agroecosystem Living Labs approaches)
- We need the right indicators
  - NUE instead of yield or protein content alone
  - Protein-energy balance instead of protein content
- Many results will be shown during the conference to illustrate these elements

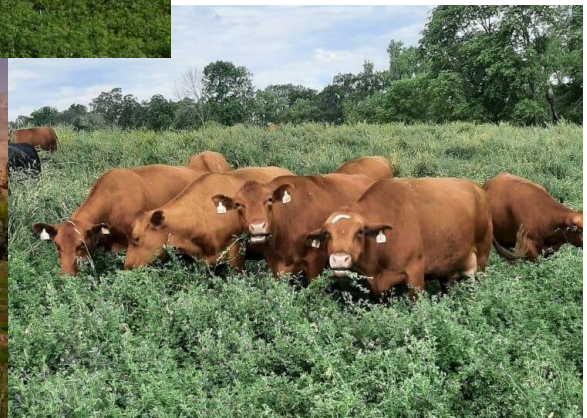
Conclusion

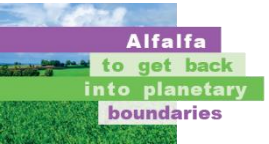
Alfalfa, the future in the making?



A way to answer this issue is to share a common representation of the future. Which one do you support?

?






Thank you for your attention