Alfalfa to get back into planetary boundaries

2025 world alfalfa congress
FRANCE REIMS-CHÂLONS

Session 5: Alfalfa-based cropping systems in a sustainable land-use for livestock production

Session chair(s): Liu N. & Labanca H.

Parallel session

FROM 03 › TO 06
nov. 2025

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Legume introduction enhances productivity and soil carbon sequestration in degraded grasslands: Decadal insights into the role of phosphorus fertilization

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FROM 03 › TO 06 nov. 2025

Overview of Presentation

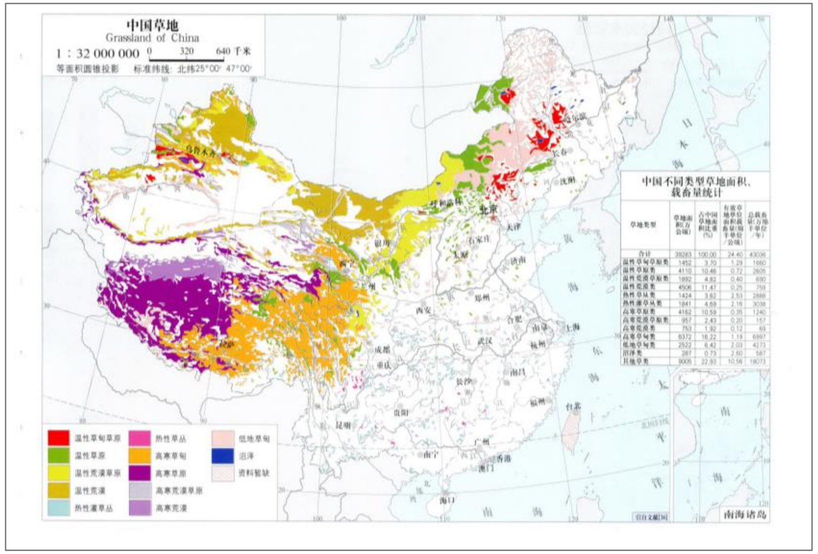
01 Introduction & Context

02 Study Site & Experimental Design

03 Research Findings

04 Conclusions & Implication

Introduction—The Current State of Grasslands in China

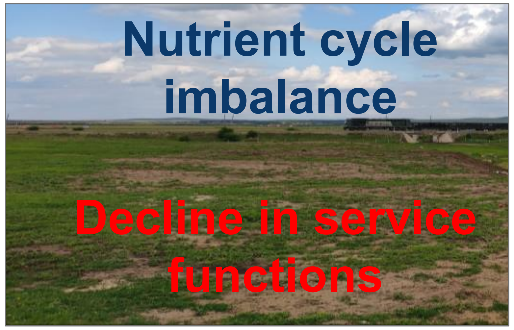


- The proportion of **high-quality forage** in natural grasslands has declined.

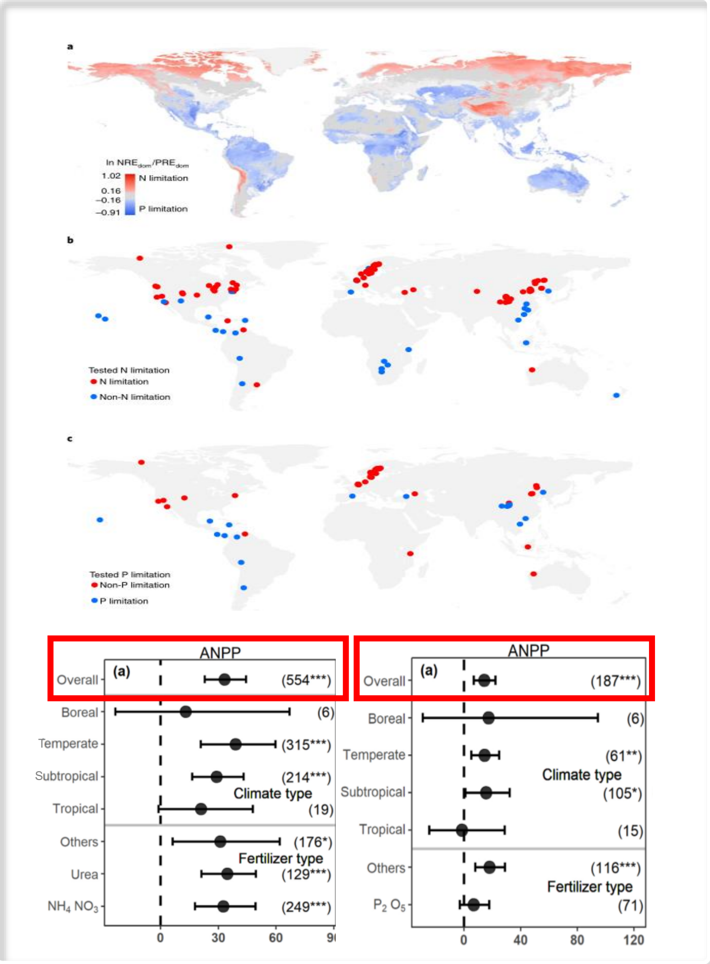
Undegraded Grasslands

70%~90%

Degraded Grasslands



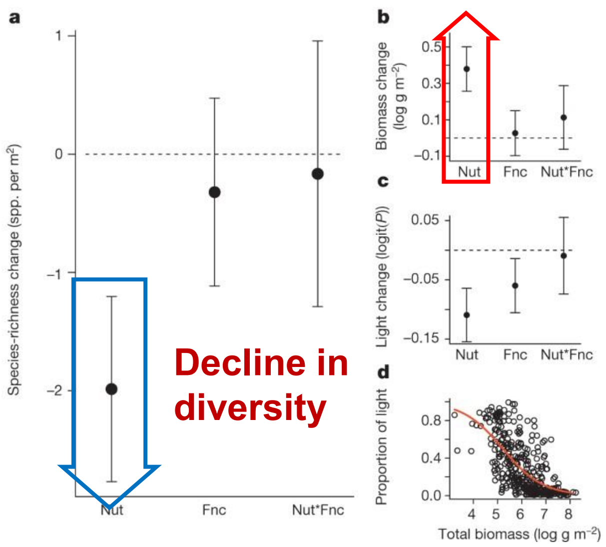
- **Fertilization to Improve Degraded Grasslands**

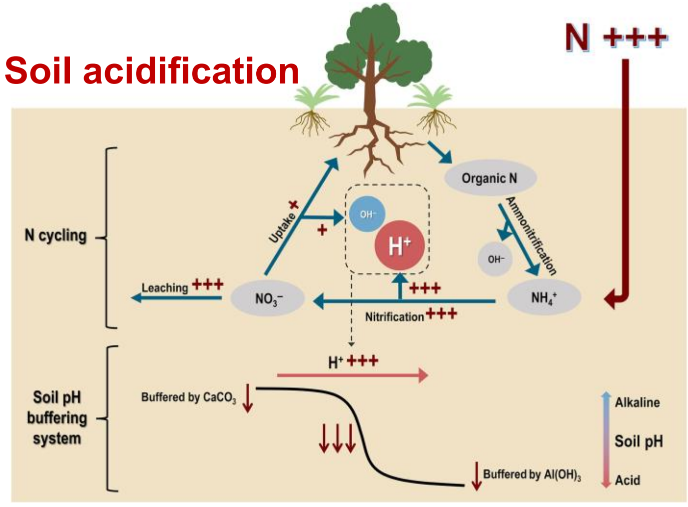


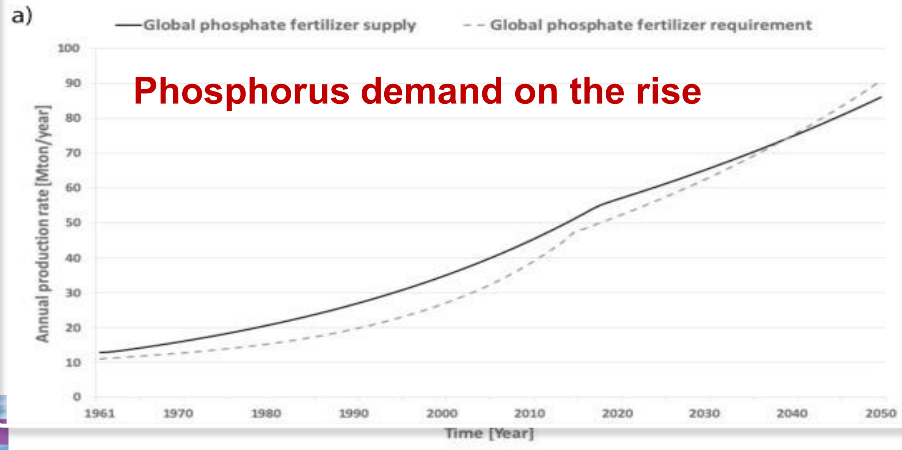
Elser et al., 2007; Li et al., 2022

Introduction—The Current State of Grasslands in China

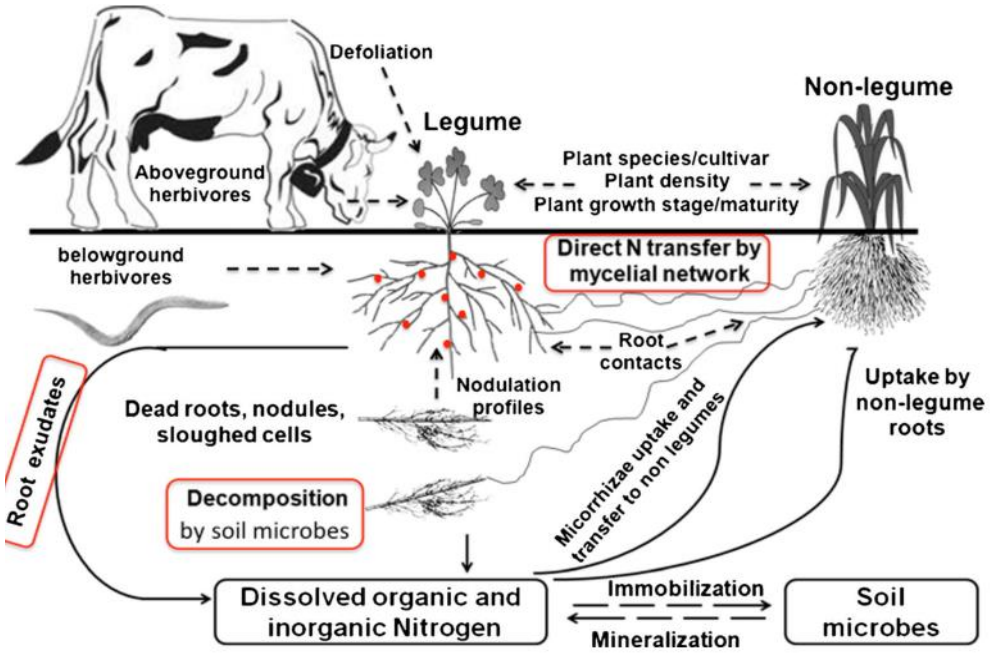
Fertilization leads to unsustainability







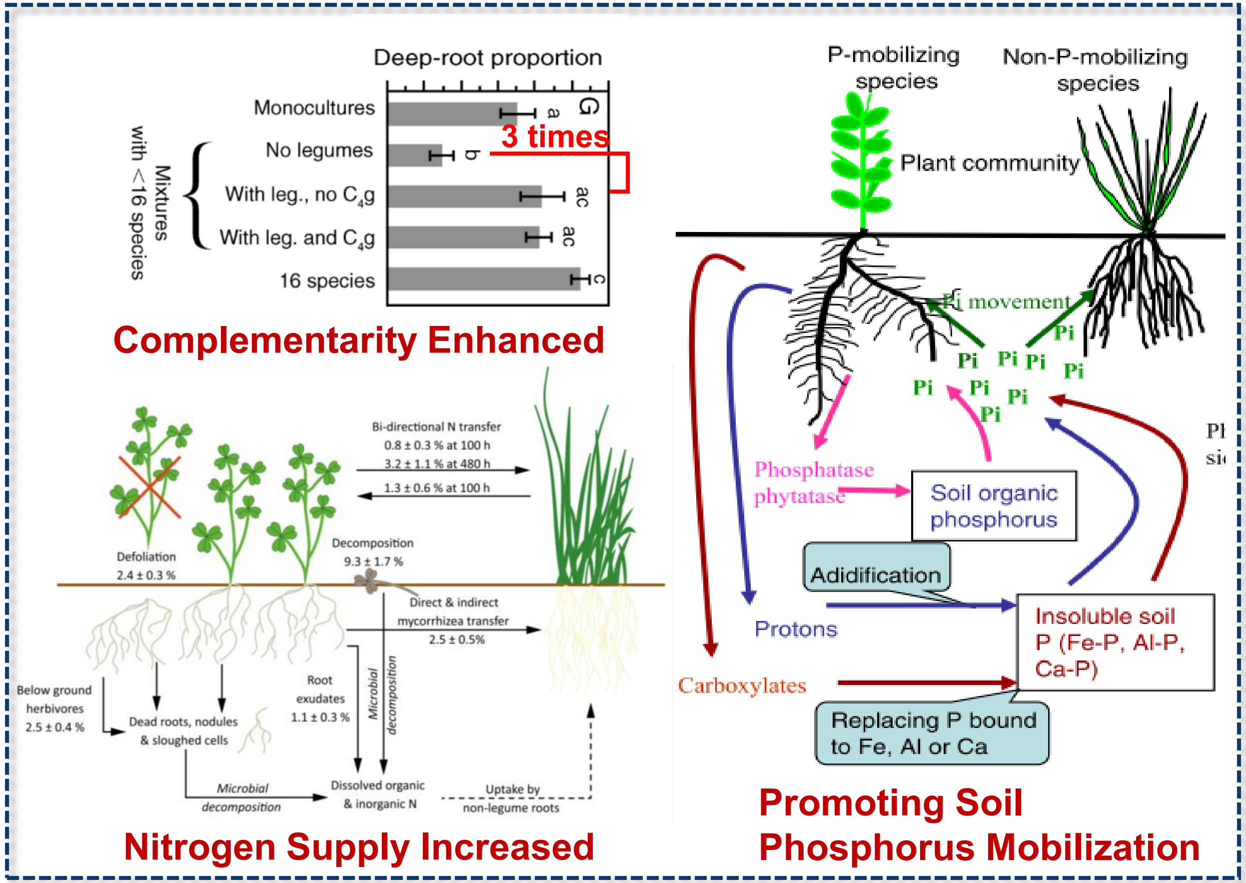
Sustainable grassland management practices are needed to restore degraded grasslands

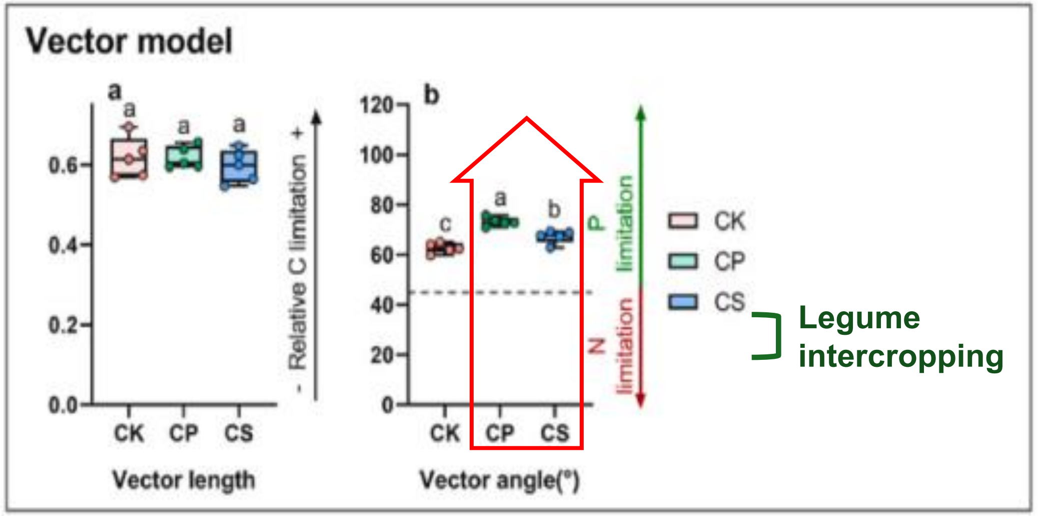


Legume introduction contributes to sustainable agricultural production

Borer et al. 2014; Chen et al., 2022; Nedelciu et al., 2020; Thilakarathna et al. 2016

Introduction—Legume enhances nutrient uptake in cropland





➤ **Biological nitrogen fixation by legumes exacerbates phosphorus limitation!**

Q: How does legume introduction into natural grassland affect the productivity and carbon sequestration, and to what extent is this effect modulated by phosphorus availability?

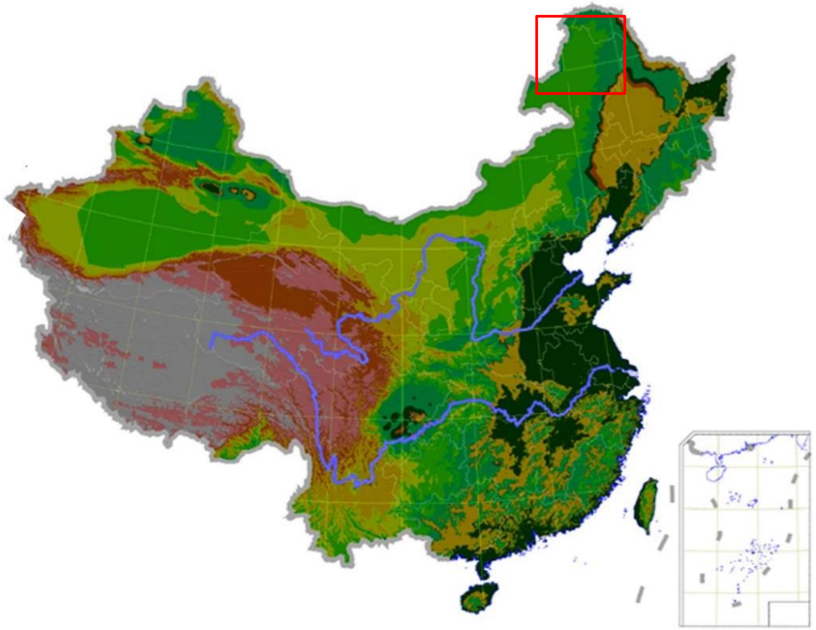
Mueller et al. 2013; Li et al. 2014; Reay et al. 2022; Xu et al., 2023

Study demonstration—Legume reseeding experiment in Inner Mongolia

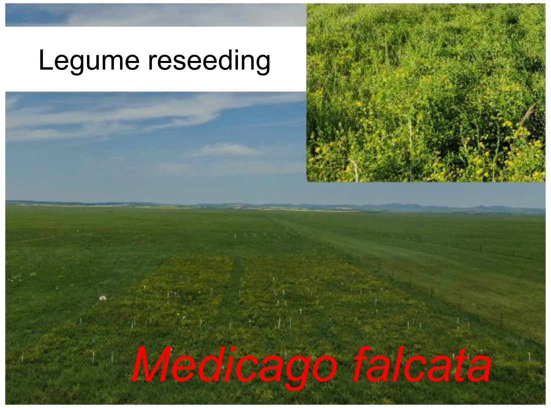
- **The experiment initiated in 2013**

Legume reseeding experiment in Inner Mongolia

➢ Site Characteristics



- **Ecosystem:** Moderately degraded grassland
- **Initial State:** Low legume abundance (< 6% cover)
- **Soil Type:** Chestnut soil (WRB classification)
- **Key Properties:** pH: ~7.0 ; Organic Matter: 54.0 g/kg; Available N: 13.5 mg/kg ; Olsen-P: 3.38 mg/kg



Treatment	Legume	Phosphorus
CK	0	0
P	0	1
L (YCK)	1	0
LP (YP)	1	1

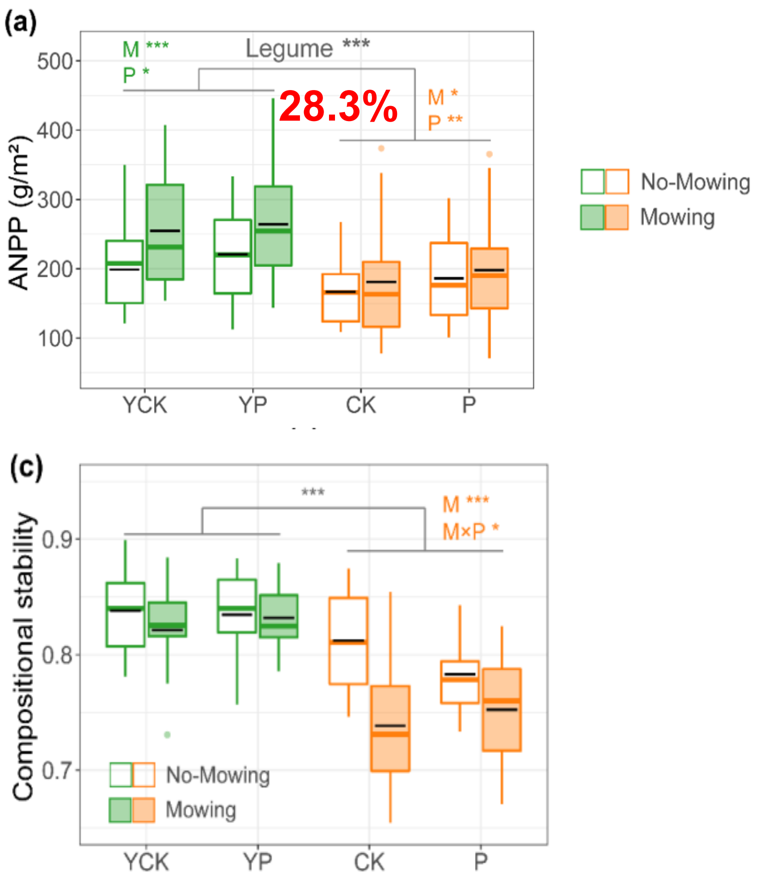
Levels：

Legume introduction: 15 kg ha^{-1}, 30 cm row spacing

Phosphorus fertilization: 32 kg P ha^{-1} year^{-1}

Results—Effects of Legume Introduction on Grassland Productivity

➢ An analysis of plant data from 2017 to 2020



Following mowing:

Legume increased ANPP by 23.7%, whereas naturally restoration only increase by 7.4%

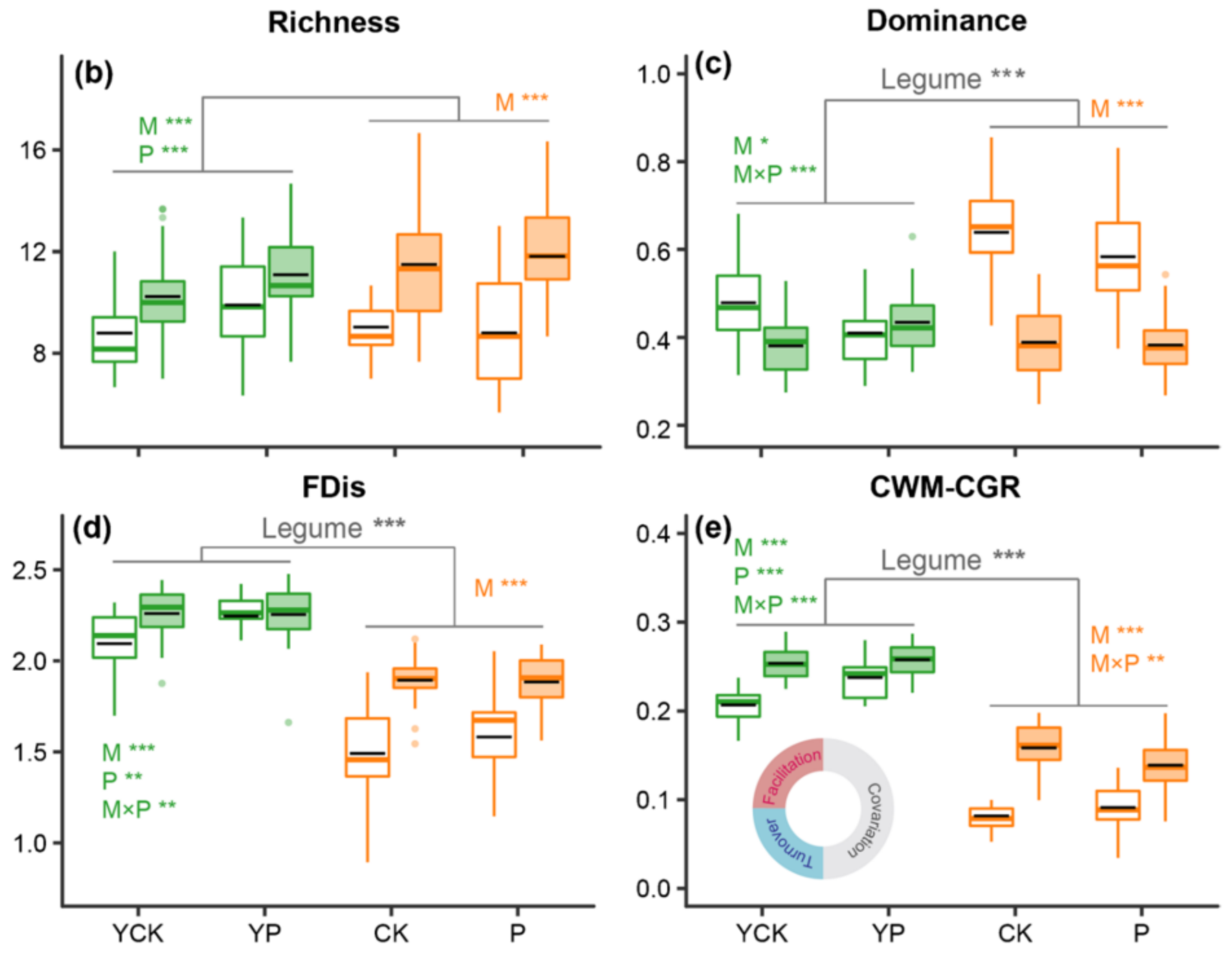
Following P fertilization:

Legume increased ANPP by 7.0%, whereas naturally restoration increase by 10.4%

Legume enhanced plant compositional stability significantly!

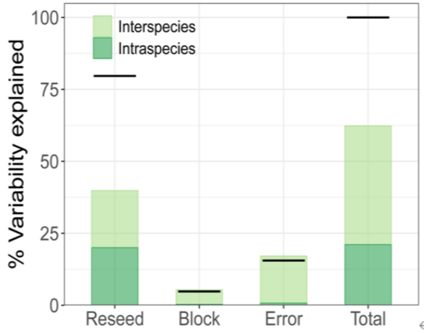
Effects of Legume Introduction on Grassland Productivity

➢ Plant Community Properties



Legume Introduction：

Species Richness	Dominance ↓
Functional Dispersion ↑	Community-weighted mean compensatory growth rate ↑

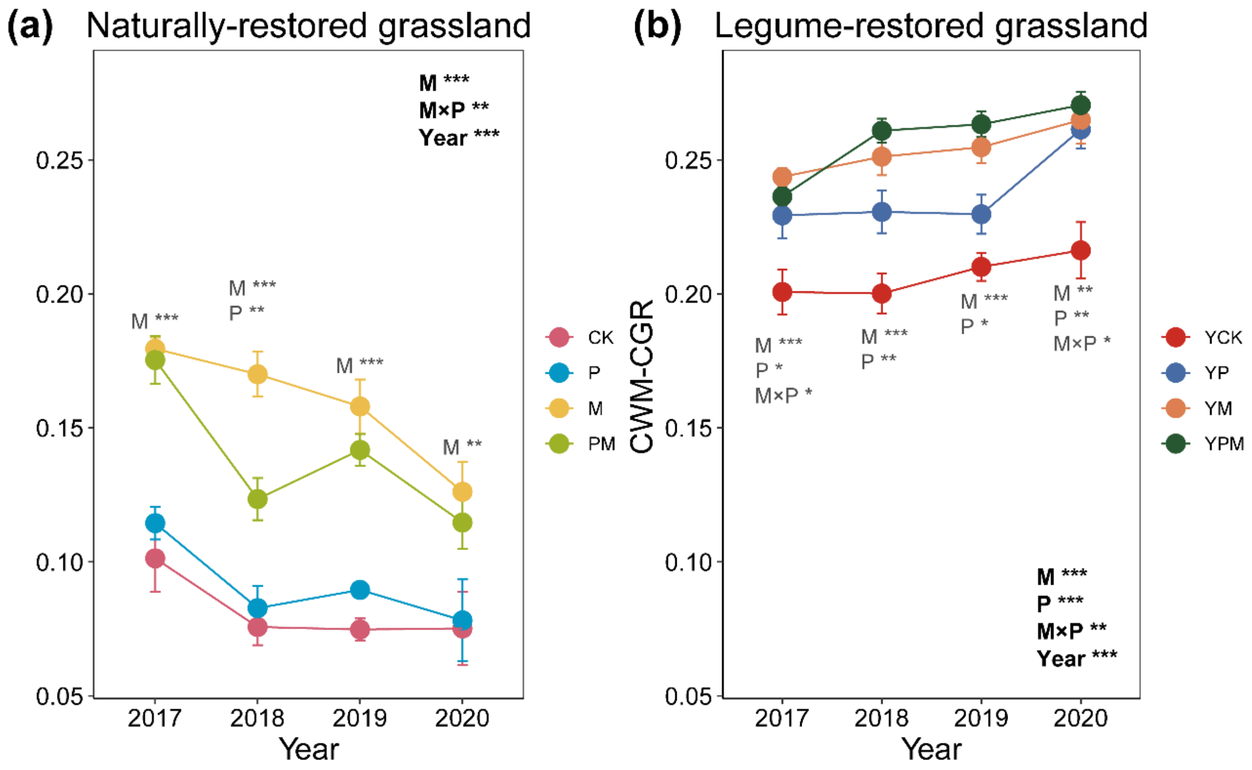


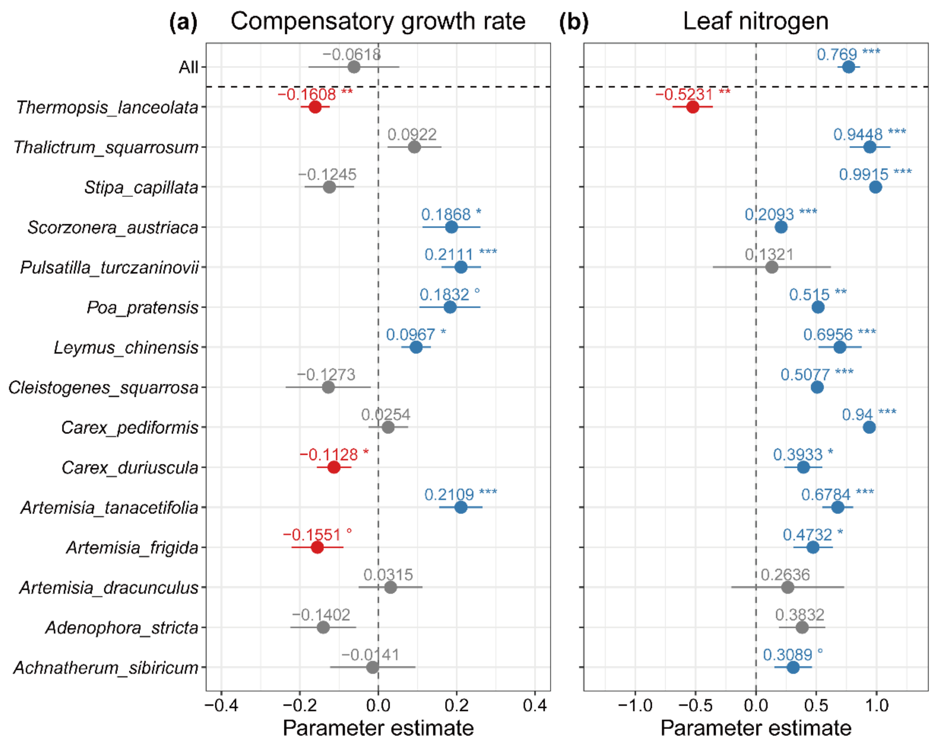
Species turnover：19.82 %

Facilitation：20.01%

Effects of Legume Introduction on Grassland Productivity

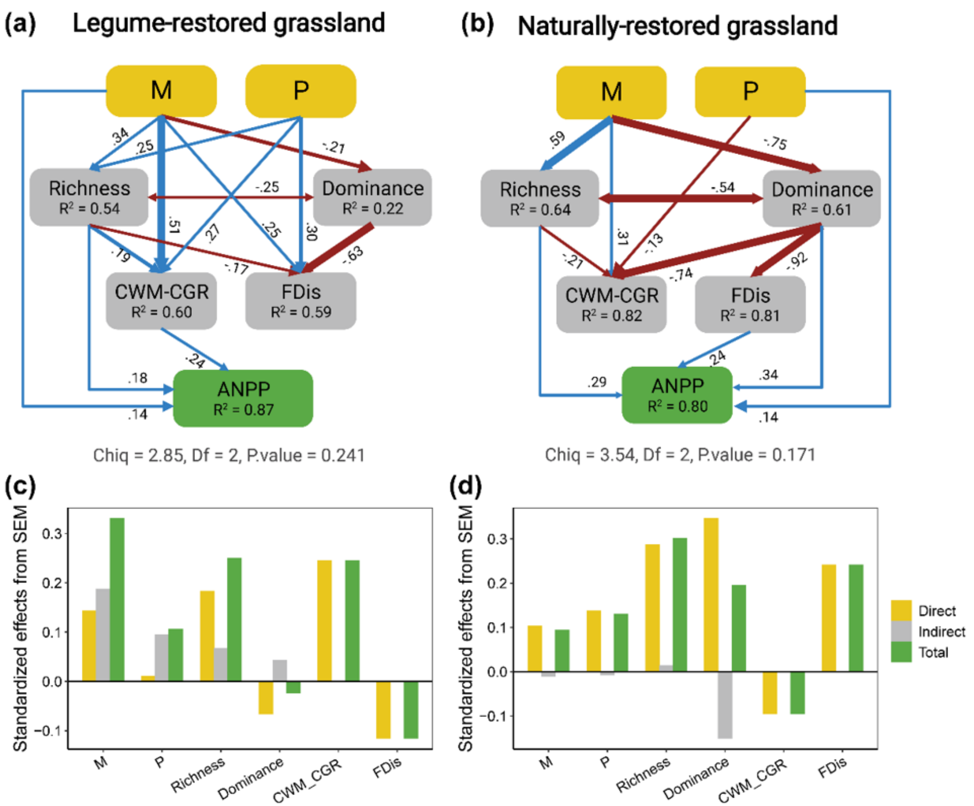
➢ Plant Compensatory Growth Rate





Effects of Legume Introduction on Grassland Productivity

➢ Pathways of management practice affecting aboveground biomass



Legume-introduced grasslands achieve higher ecological efficiency through the **dual mechanisms** of key functional species-driven effects and resource complementarity.

Implication:

Legume introduction can sustainably increase plant compensatory growth rates of natural grassland. This highlights the effectiveness of restoring legumes in enhancing biomass production sustainably and mitigating degradation in grasslands suffering from prolonged or intense defoliation.

Guo et al., 2024, *Agronomy for Sustainable Development*

Effects of Legume Introduction on Soil Organic Carbon

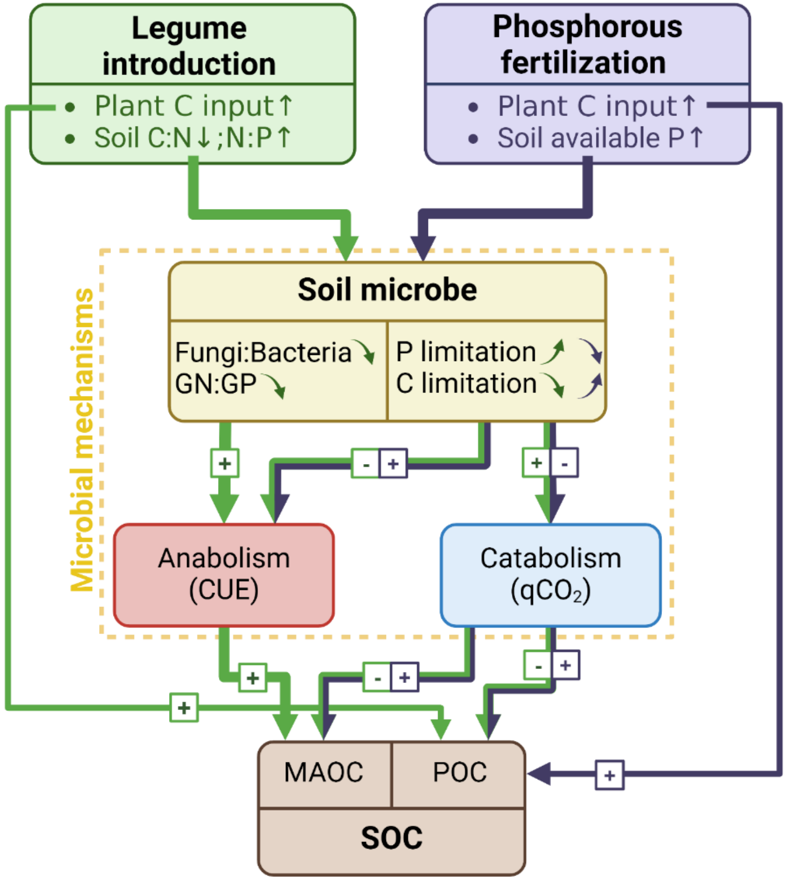
➢ one-time sampling based on a ten-year field experiment

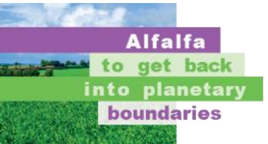
Measured Parameters

Plant Community and Soil Physicochemical Properties	Microorganisms
ANPP, BNPP, and vegetation community composition	Microbial biomass C, N, P (MBC/N/P)
Soil Organic Carbon (SOC) and its physical fractions	Microbial community composition (PLFA)
Soil available nutrient contents	Extracellular enzyme activities (C/N/P-acquiring, oxidative enzymes)
Soil pH, bulk density	Soil respiration rate

Calculated Metrics

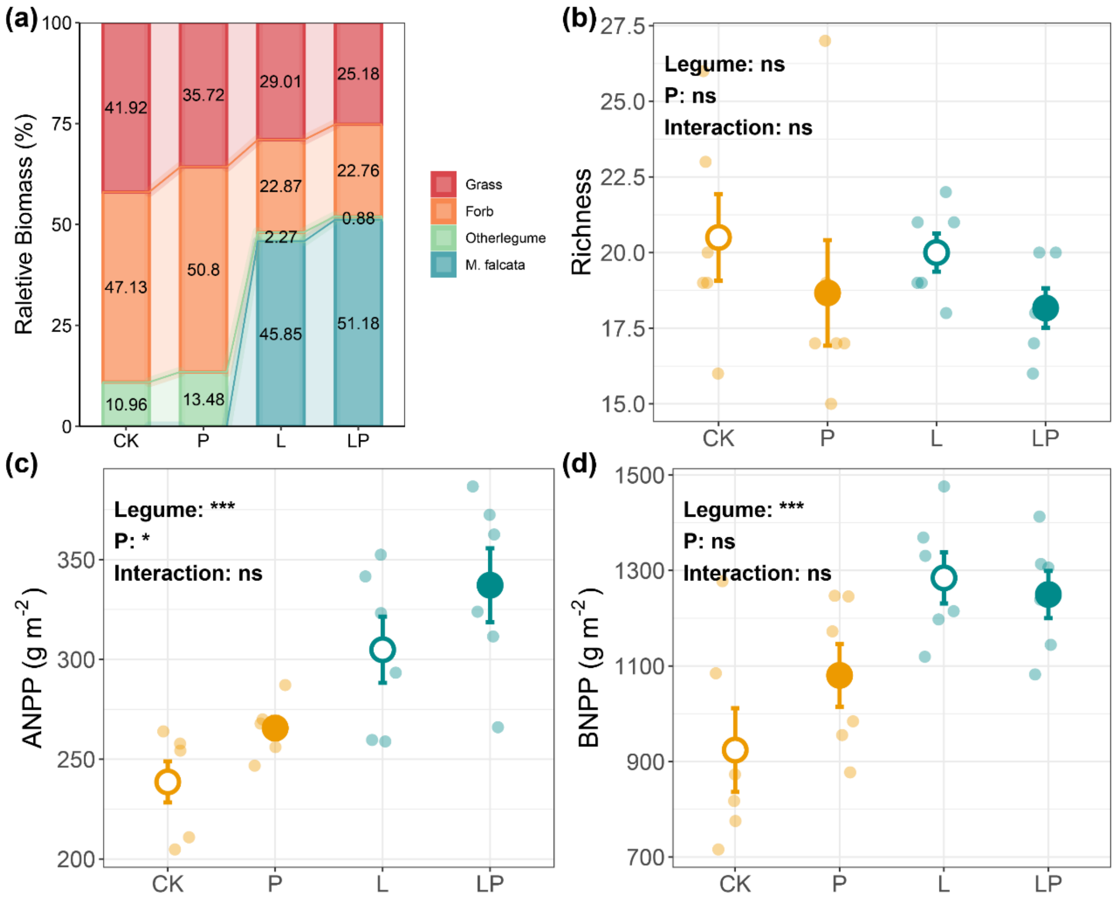
- Stoichiometry of soil available substrates
- Microbial nutrient limitation, microbial biomass stoichiometry, microbial metabolic efficiency





Effects of Legume Introduction on Soil Organic Carbon

➢ Plant Community Properties

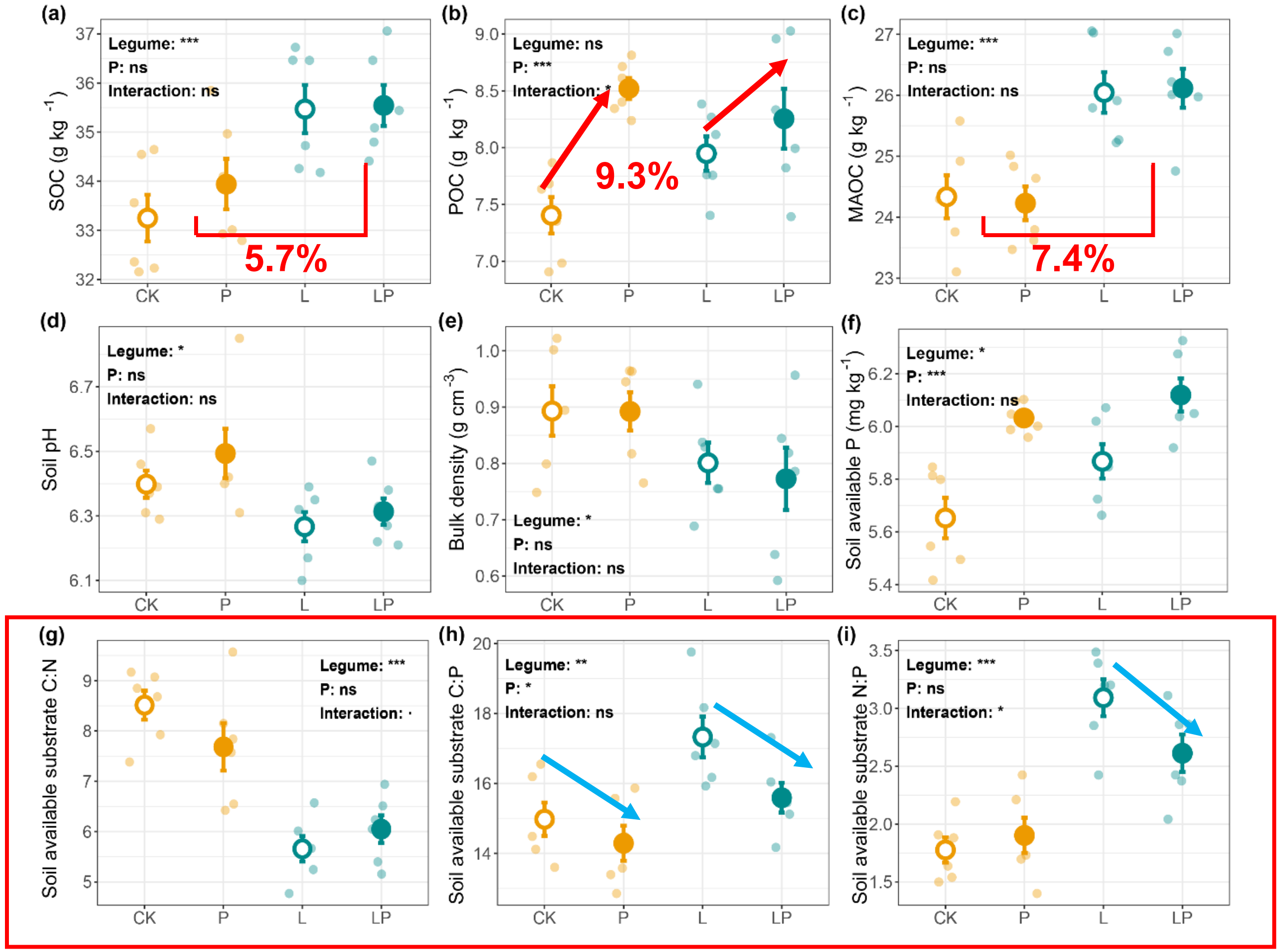


➢ **Successful establishment:** Legume introduction increased the relative abundance of legumes to ~50% (vs. 12% in control plots).

➢ While plant richness remained unaffected, both legume introduction and P addition boosted **ANPP** and **BNPP**.

Effects of Legume Introduction on Soil Organic Carbon

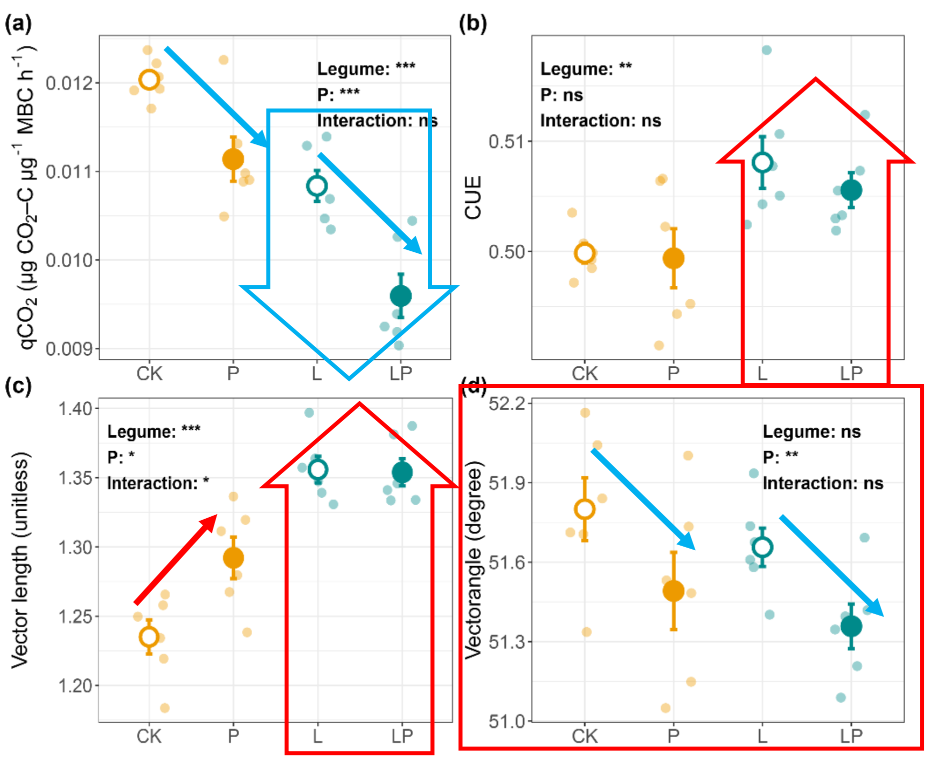
➢ Soil Organic Carbon Fractions and Physicochemical Properties



- **Legumes drove SOC sequestration:** Legume introduction increased SOC by 5.7%, primarily by boosting MAOC by 7.4%
- **P fertilization increased POC** by 9.3% without affecting SOC
- Legume introduction weakened the positive effect of phosphorus on POC (antagonistic interaction)
- Legume introduction improved **soil substrate quality**

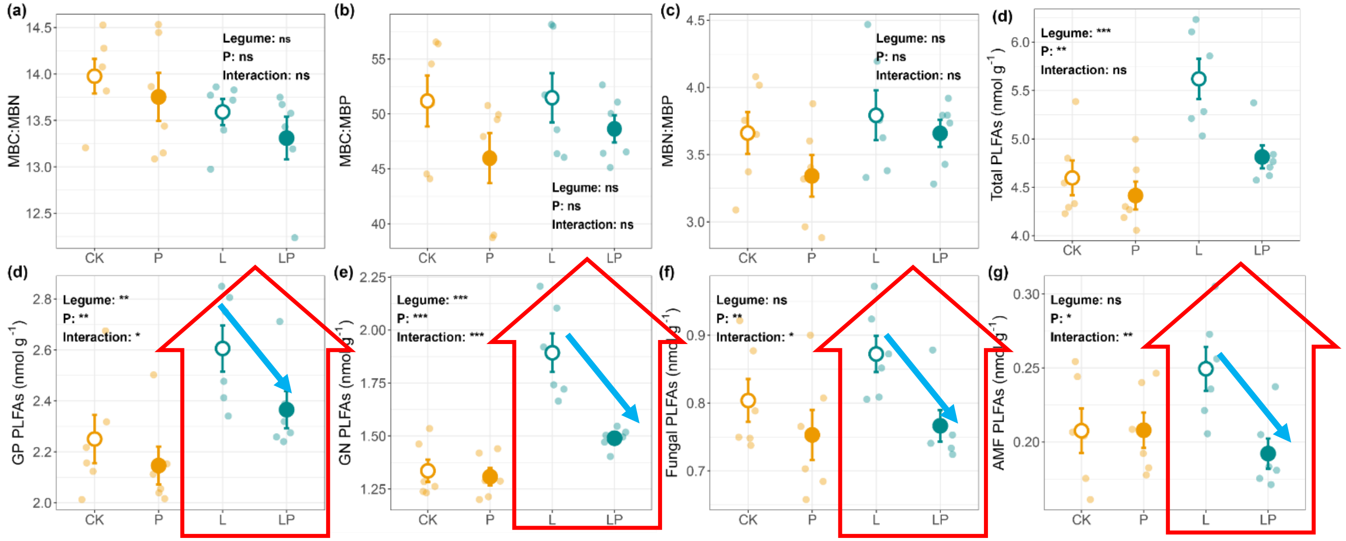
Effects of Legume Introduction on Soil Organic Carbon

➢ Microbial Metabolism & Nutrient Limitation



- Legume introduction decreased qCO_2 and increased CUE
- Phosphorus fertilization decreased qCO_2; did not affect CUE

➢ Microbial C:N:P Stoichiometry & Community Composition



- Legume increased C limitation, did not affect P limitation
- P fertilization reduced P limitation, but increased C limitation in naturally recovered grassland
- Legume introduction increased PLFA; P fertilization decreased PLFA in legume-introduced grassland.

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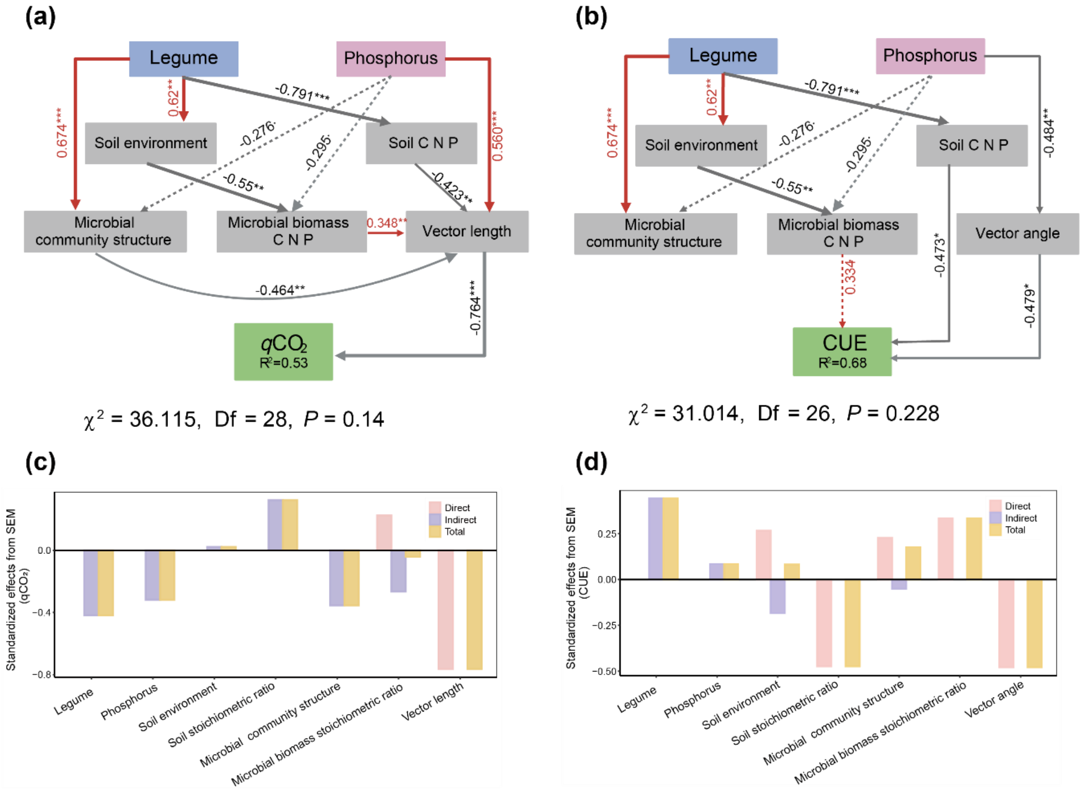
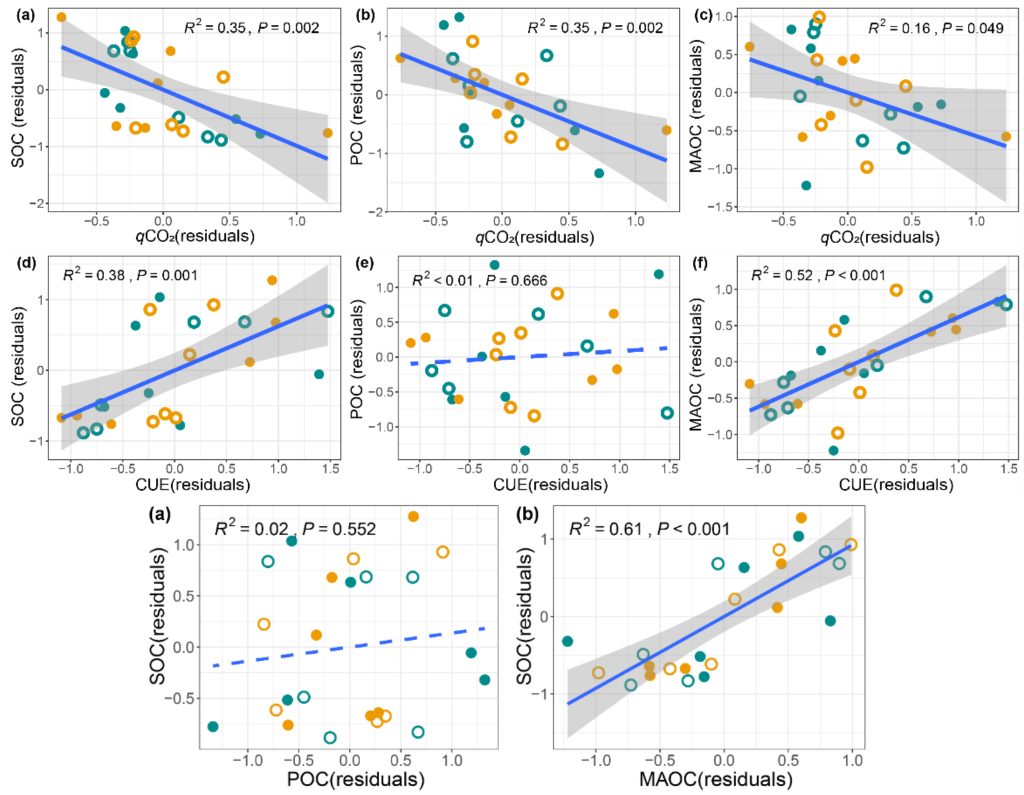
Effects of Legume Introduction on Soil Organic Carbon

➢ Pathways of legume introduction and P fertilization affecting SOC



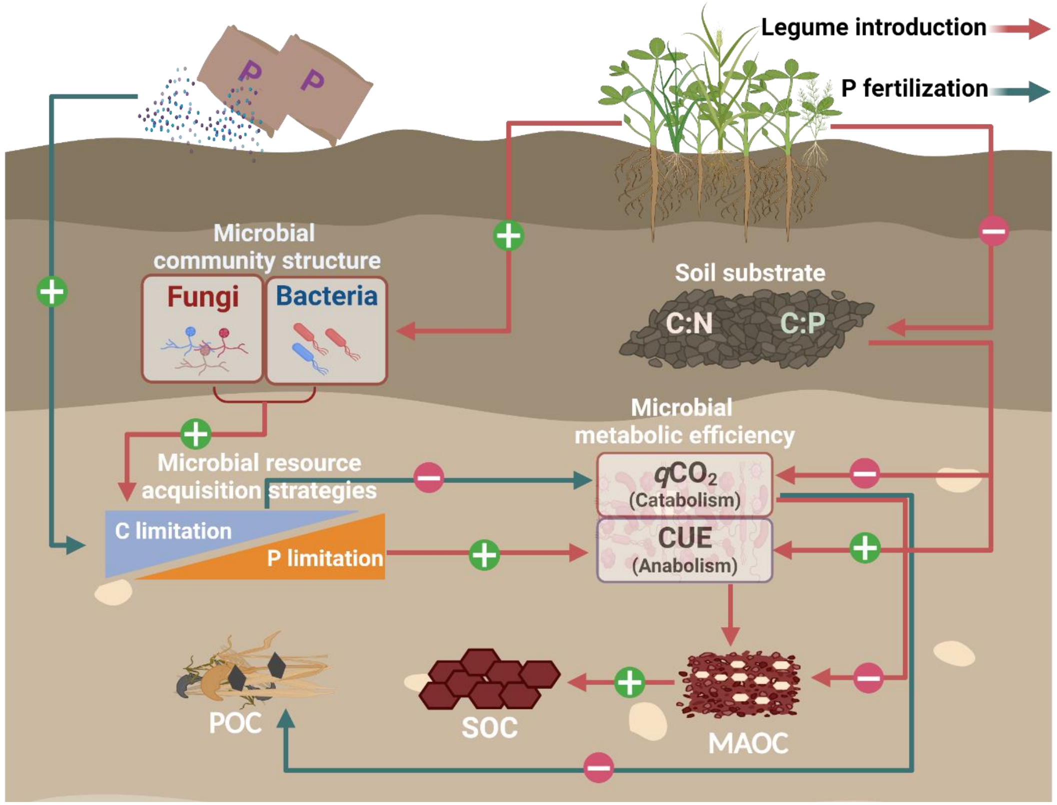


Soil substrate quality and **microbial nutrient limitation** are key factors governing microbial C metabolism efficiency

Key Finding:

SOC showed a much stronger association with MAOC than with POC

Effects of Legume Introduction on Soil Organic Carbon



- **Legume introduction boosts SOC**

Promotes microbial anabolism by improving soil substrate quality & intensifies microbial C limitation

- **P Fertilization failed to increase SOC**

Reduced overall microbial activity

Implication

For Land Managers:

Prioritize Legume Introduction: An effective, biologically-driven approach to restore soil carbon

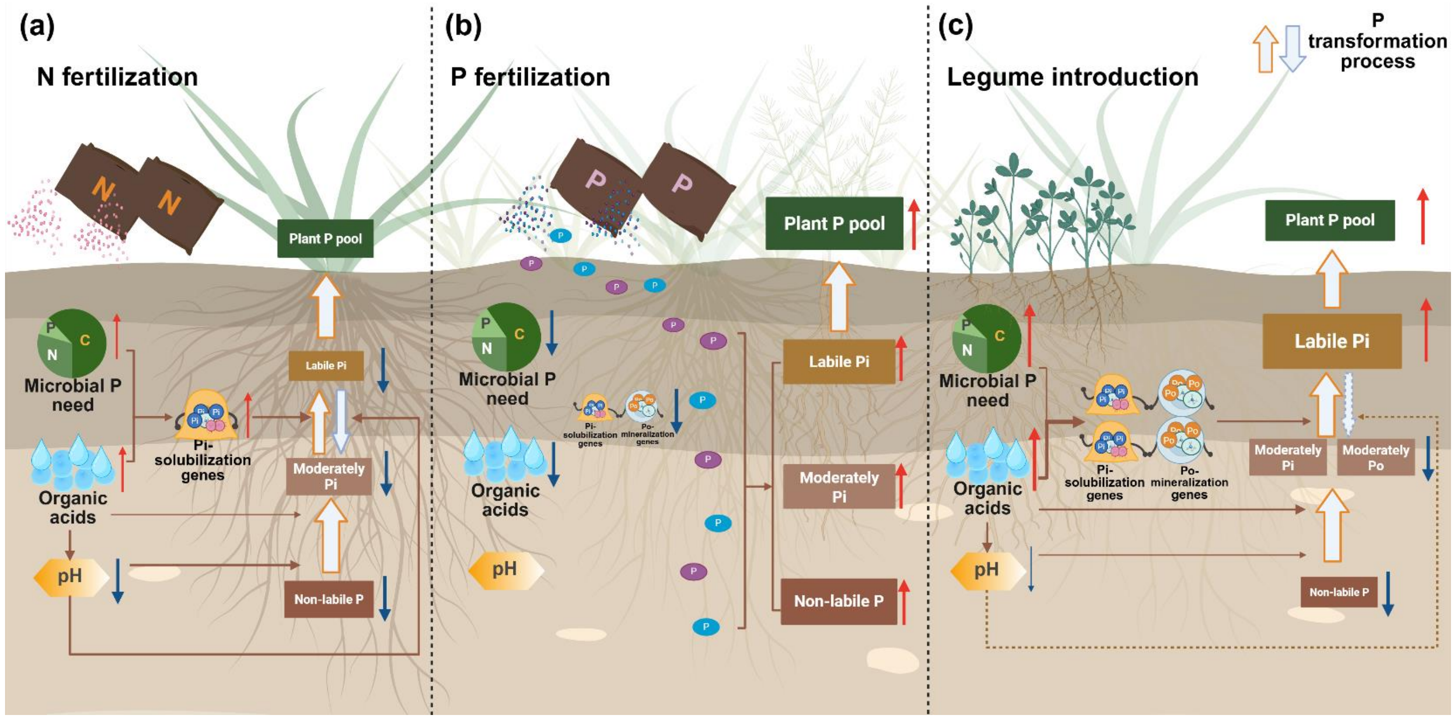
For Policymakers:

Support Integrated Strategies: Our findings provide a scientific basis for policies that move beyond simple fertilization.

Goal: Promote sustainable management for long-term C sequestration in degraded grasslands

Guo et al., 2025, *Geoderma*

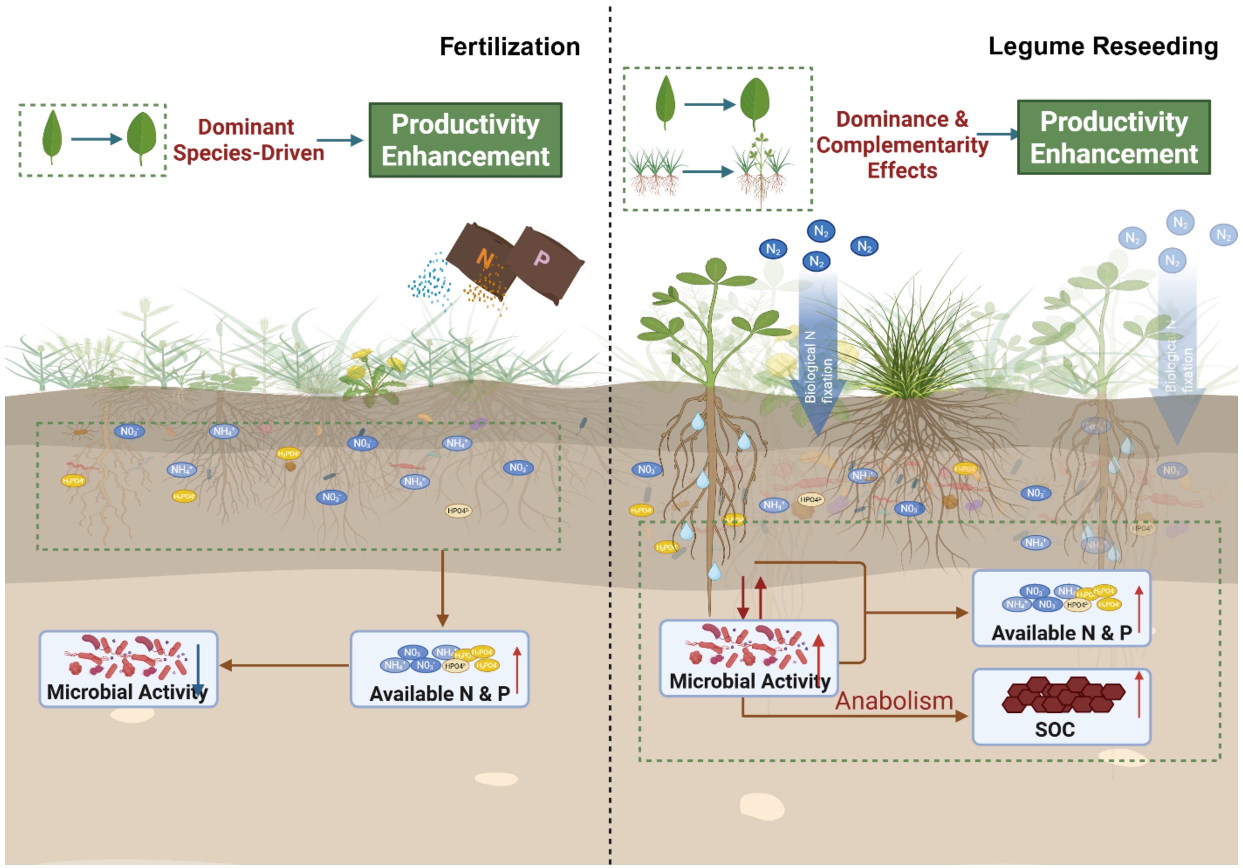
Effects of Legume Introduction on Soil Phosphorus Transformation



Implication: Legumes can activate microbial functions, reduce reliance on chemical fertilizers, and promote the sustainable development of grassland.

- **N fertilization** increases the mobilization of stable P but exacerbates the depletion of available P.
- **P fertilization** increases the content of most P fractions in the soil, but inhibits the microbial mobilization of soil P.
- **Legume introduction** increases organic acid exudation to directly stimulate the dissolution of non-labile P; organic acids also indirectly promote the transformation of moderately labile P to labile inorganic P by increasing microbial transformation.

Effects of Legume Introduction on Soil Phosphorus Transformation



Legume introduction fosters a self-sustaining system

Optimizing plant community traits
(Optimize resource use)
Enhancing positive plant-microbe interactions
(e.g., efficient C-sequestration & P-mobilization)

Fertilization creates a dependent, fragile system

While it increases short-term productivity,
it ultimately:
Degrades essential microbial functions
Disrupts soil nutrient homeostasis
Increases reliance on external nutrient inputs to maintain productivity

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Thanks

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