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## **Biogeochemical Cycles: Learning From Natural and Seminatural Ecosystems to Design Sustainable Agro-Systems.**

Sébastien Fontaine, Luc Abbadie, Gaël Alvarez, Michaël Aubert, Sébastien Barot, Juliette Bloor, Delphine Derrien, Olivier Duchene, Nicolas Gross, Ludovic Henneron, et al.

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# *Biogeochemical Cycles: Learning From Natural and Semi-natural Ecosystems to Design Sustainable Agro-Systems*

Sébastien FONTAINE

With collaborations of

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# Current intensive cropping systems are not sustainable on many aspects

- Continuous degradation of soil assets:
  - - 40% of initial soil organic matter (SOM) stock within 10 years
  - Loss of « soil fertility »
- Dependency of humankind to mineral fertilizer
  - Half of world population directly depends on mineral fertilizers
  - Peak of phosphorus extraction planned for 2050
  - C-cost of ammonia production: 1,5-4 kg CO<sub>2</sub>/kg NH<sub>3</sub>
- Damage ecosystem health, water resource and climate
  - Stream, lake and coastal eutrophication
  - Agriculture contributes to 17% of global GHG



*Li et al 2019*

*Ornes 2022*

*NiD France Rapport 2020*

*FAO Report « Emissions due to agriculture 2000-2018 »*

*Lal 2003*



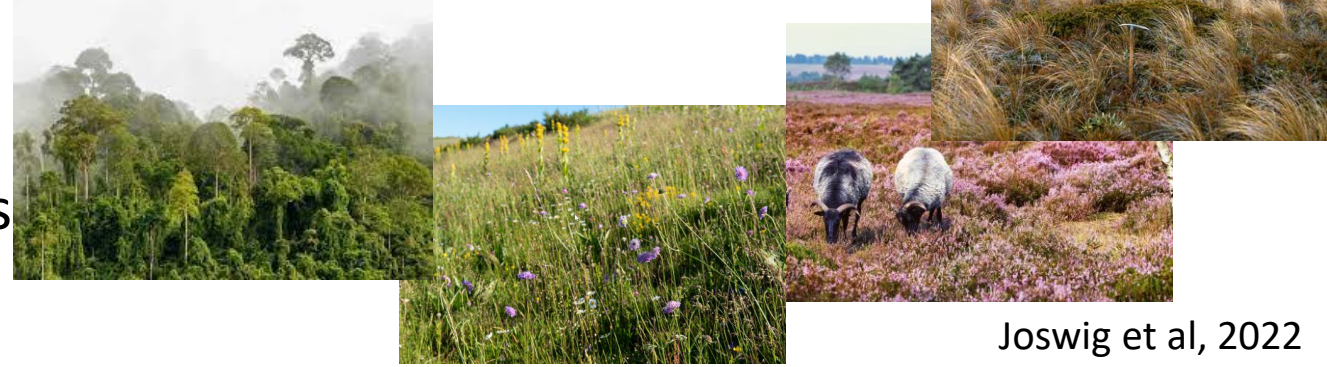
# How to develop efficient agroecological strategies ?

- Semi-natural forests and grasslands used as models
  - As productive as high-input annual crops
  - Accumulate soil C, retain nutrients, low GHG emissions
- Which aspects should be copied ? How to translate in practices?
- Current focus on:
  - General ecosystem attributes such as high diversity, root biomass, fungal biomass...
  - Improvement of specific functions such as N retention by plant roots, symbiotic N<sub>2</sub> fixation, C input to soil.



# Current difficulties/limits for agroecology development

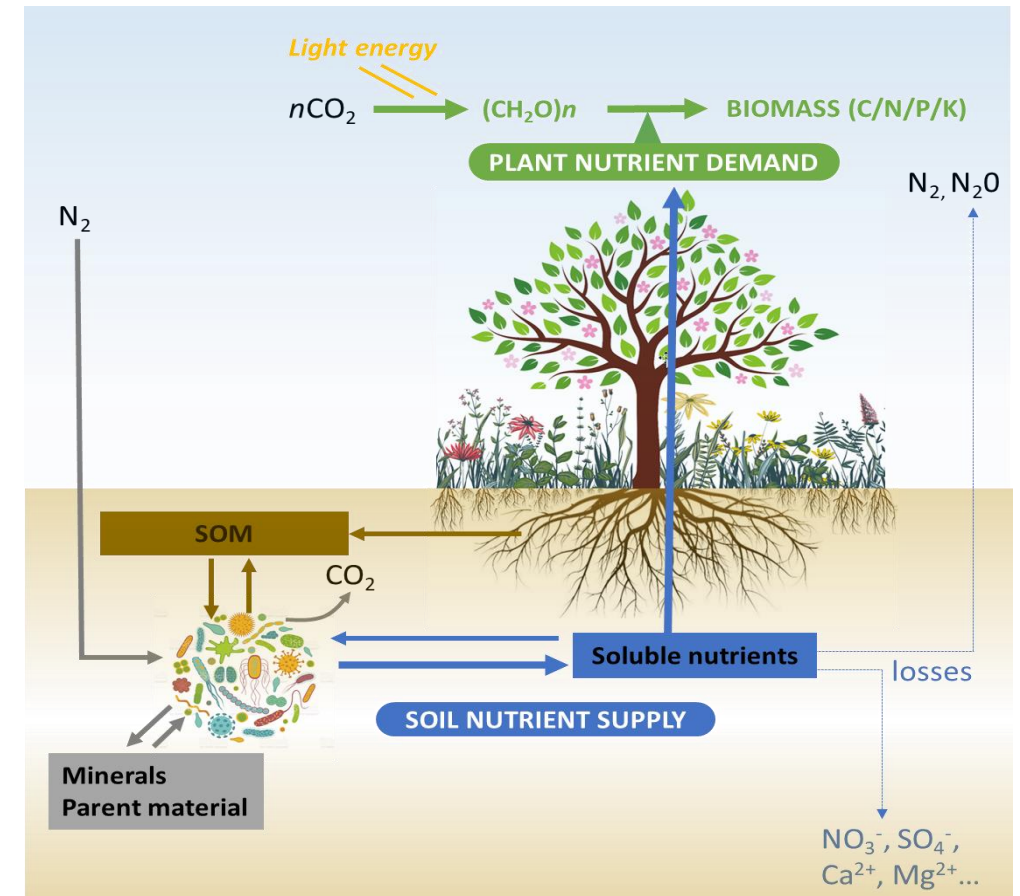
- Diversity and traits of organisms (plant, soil) are extremely variables between ecosystems



- Ecosystem functioning depends on the coupling of many plant-soil processes
  - Improvement of one process does not necessarily improve the sustainability of the whole ecosystem (e.g. legumes)

## Need of a more systemic approach considering:

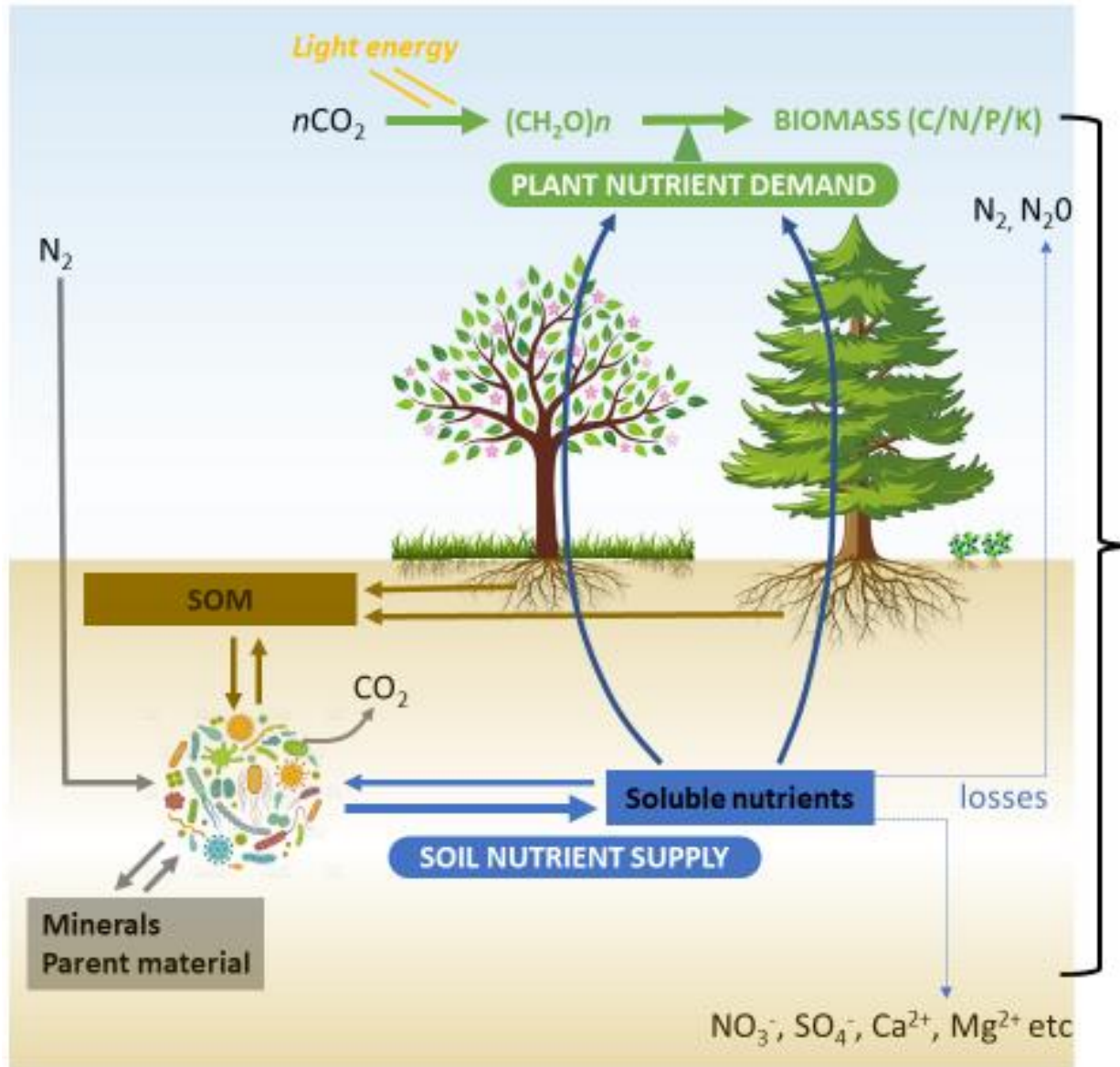
- the interactions of multiple co-occurring processes
- the adaptation of organisms/processes to pedoclimatic contexts



# Introduction of the plant-soil synchrony concept



# Ecosystem productivity & sustainability linked to the level of synchrony between plant N demand and soil supply

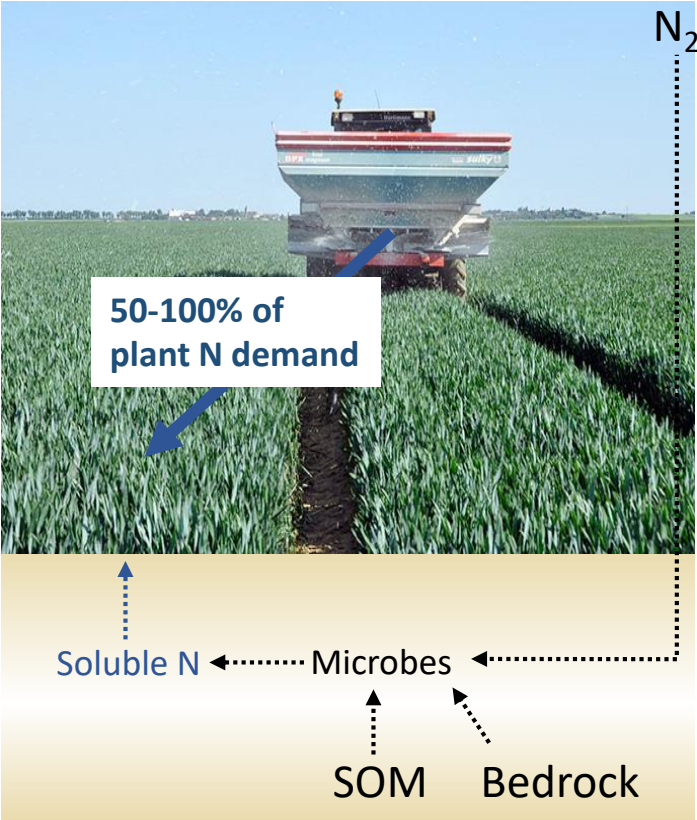


## High level of synchrony promotes

- **↑** biomass production by **↓** N limitation
- **↓** excess of soluble N, N losses (<5%)
- **↑** building of SOM

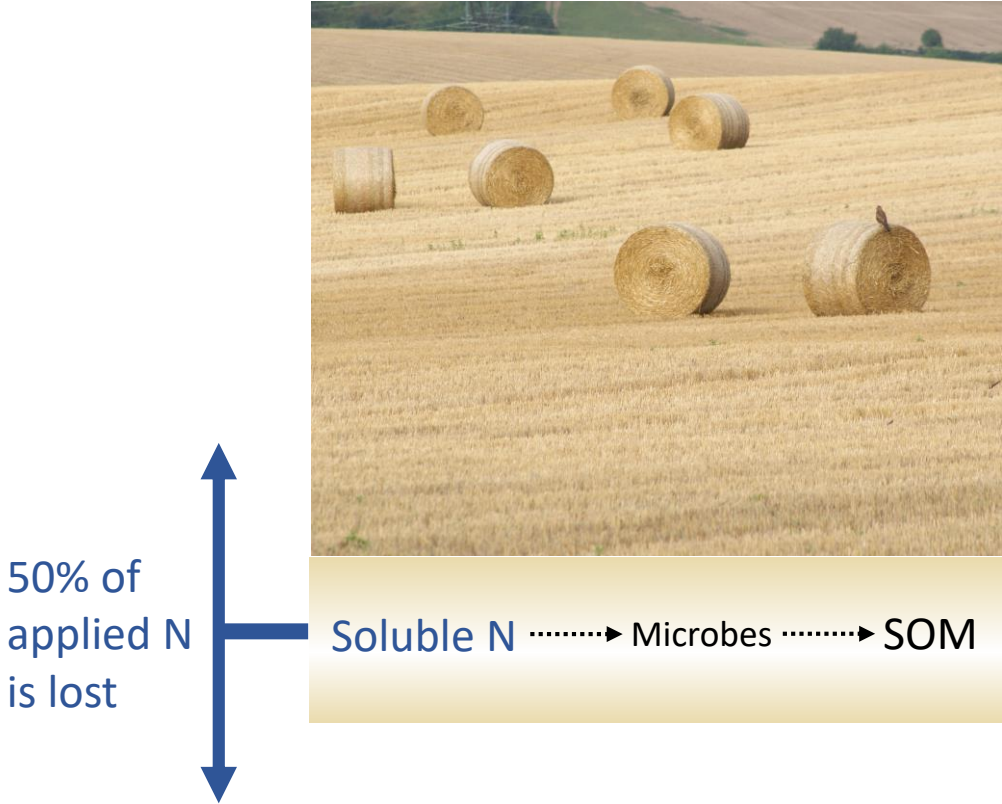
# Intensive agrosystems characterized by a low demand/supply synchrony

High plant demand



➤ Dependence to fertilizers

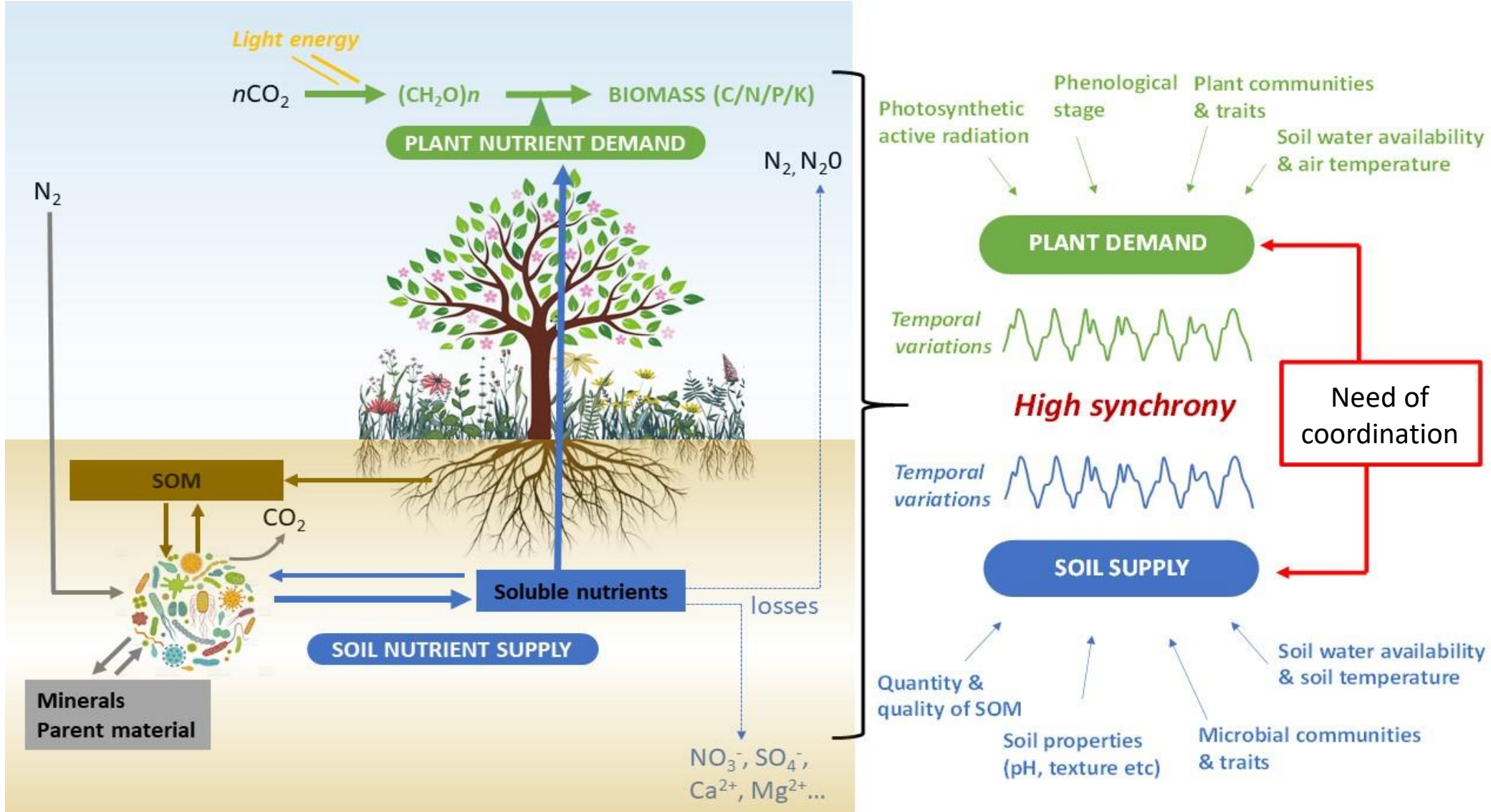
Low plant demand



➤ High loss of nutrient and SOM



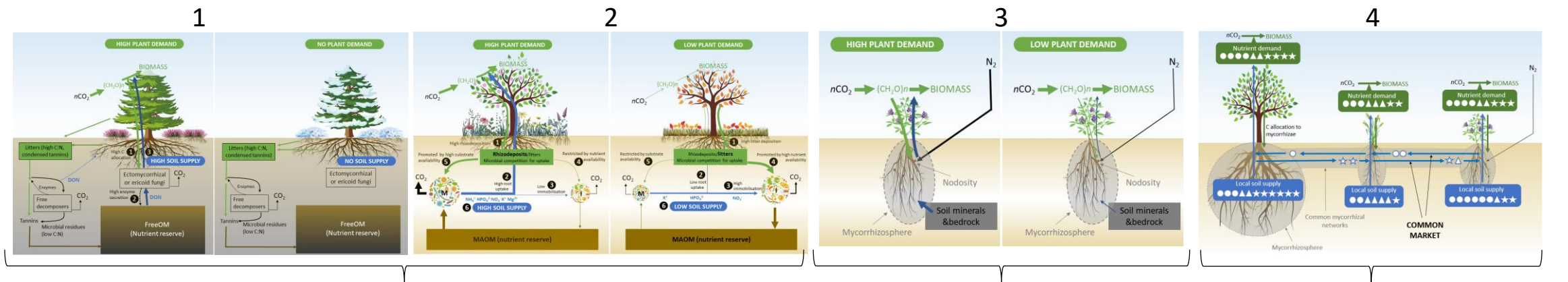
# How can a high level of synchrony can be reached in natural ecosystems?



➤ Synchrony requires the coordination of many plant-soil processes

# Review of latest advances in ecology, biogeochemistry & agronomy

## Identification of 4 systems of synchrony (coordination of processes)



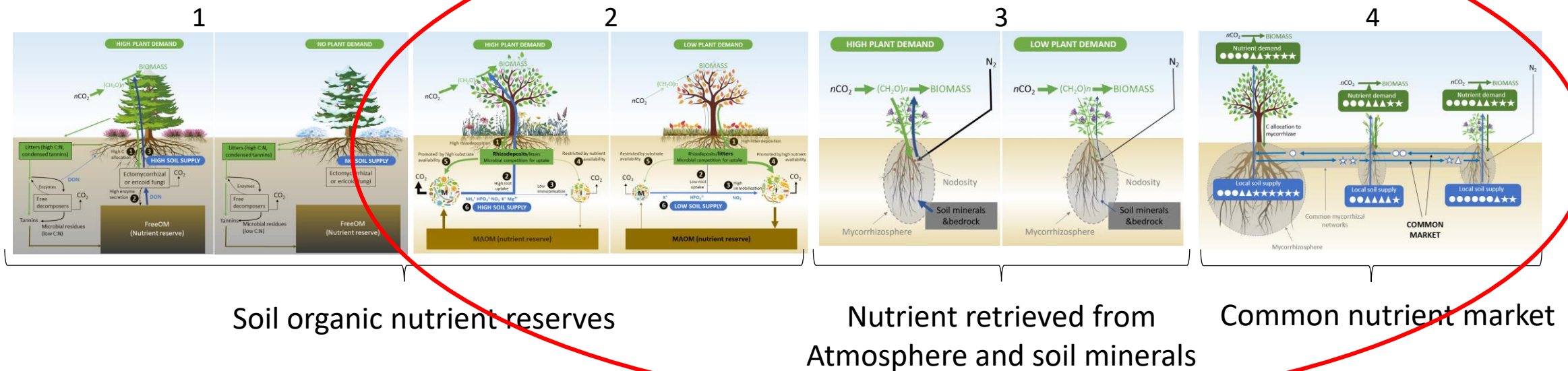
Soil organic nutrient reserves

Nutrient retrieved from atmosphere and soil minerals

Common nutrient market

# Review of latest advances in ecology, biogeochemistry & agronomy

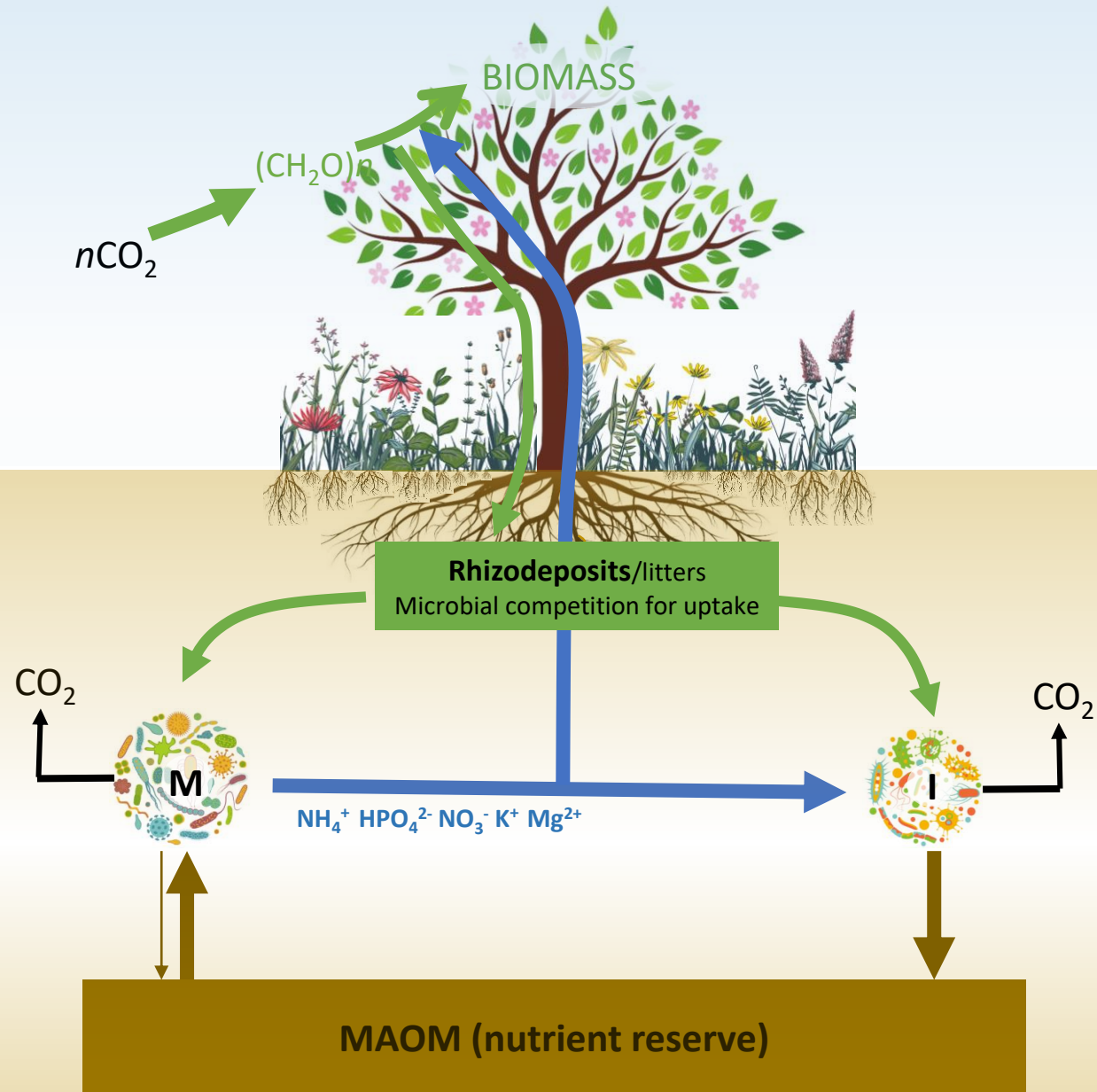
## Identification of 4 systems of synchrony (coordination of processes)



# Synchrony based on organic nutrient reserve

1. MAOM-based synchrony (Sync-MAOM)



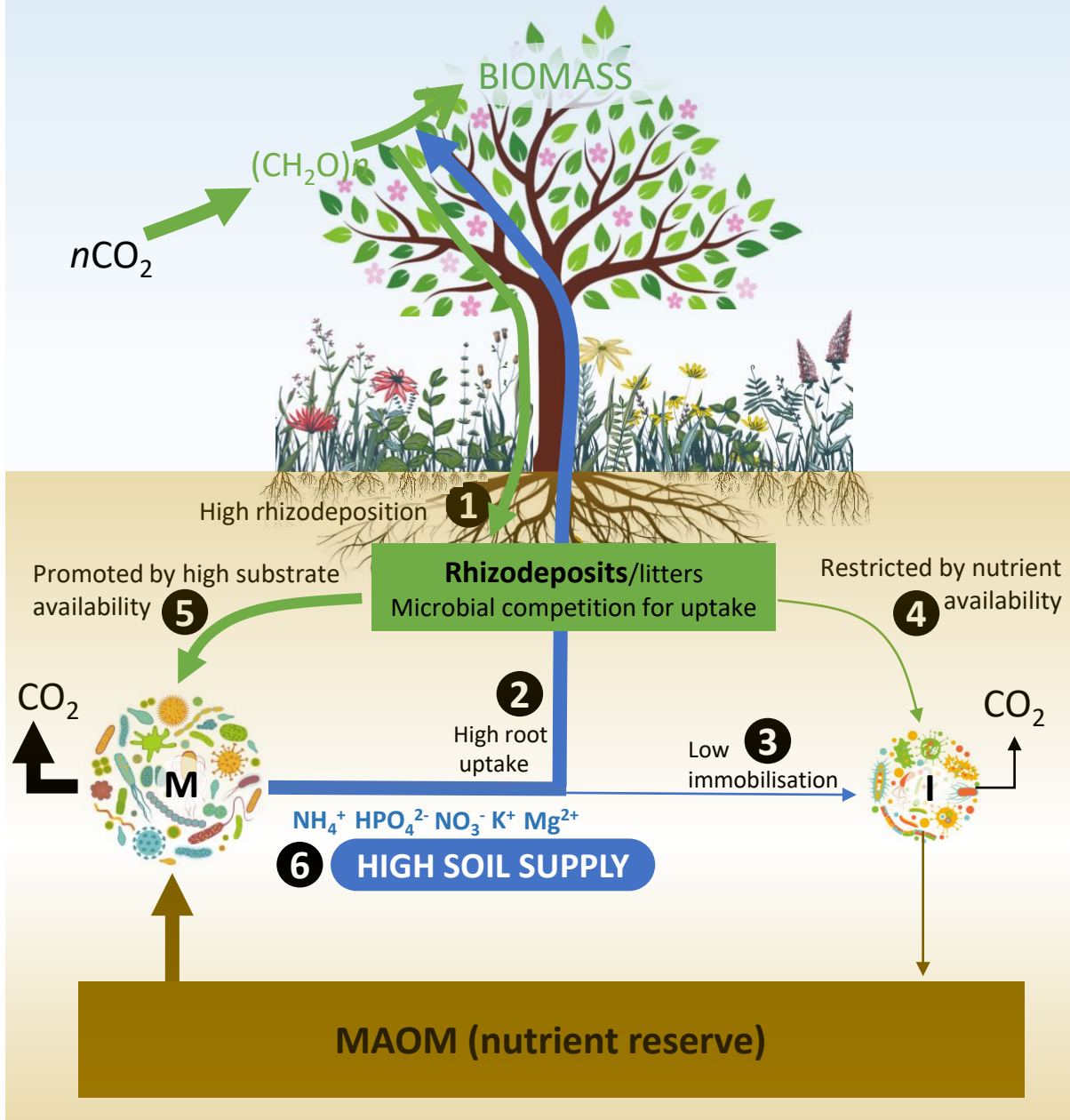


Resource-acquisitive plant species  
 Fast growth and tissue turnover  
 High rhizodeposition  
 Fast decomposing litter (low lignin, low C/N)

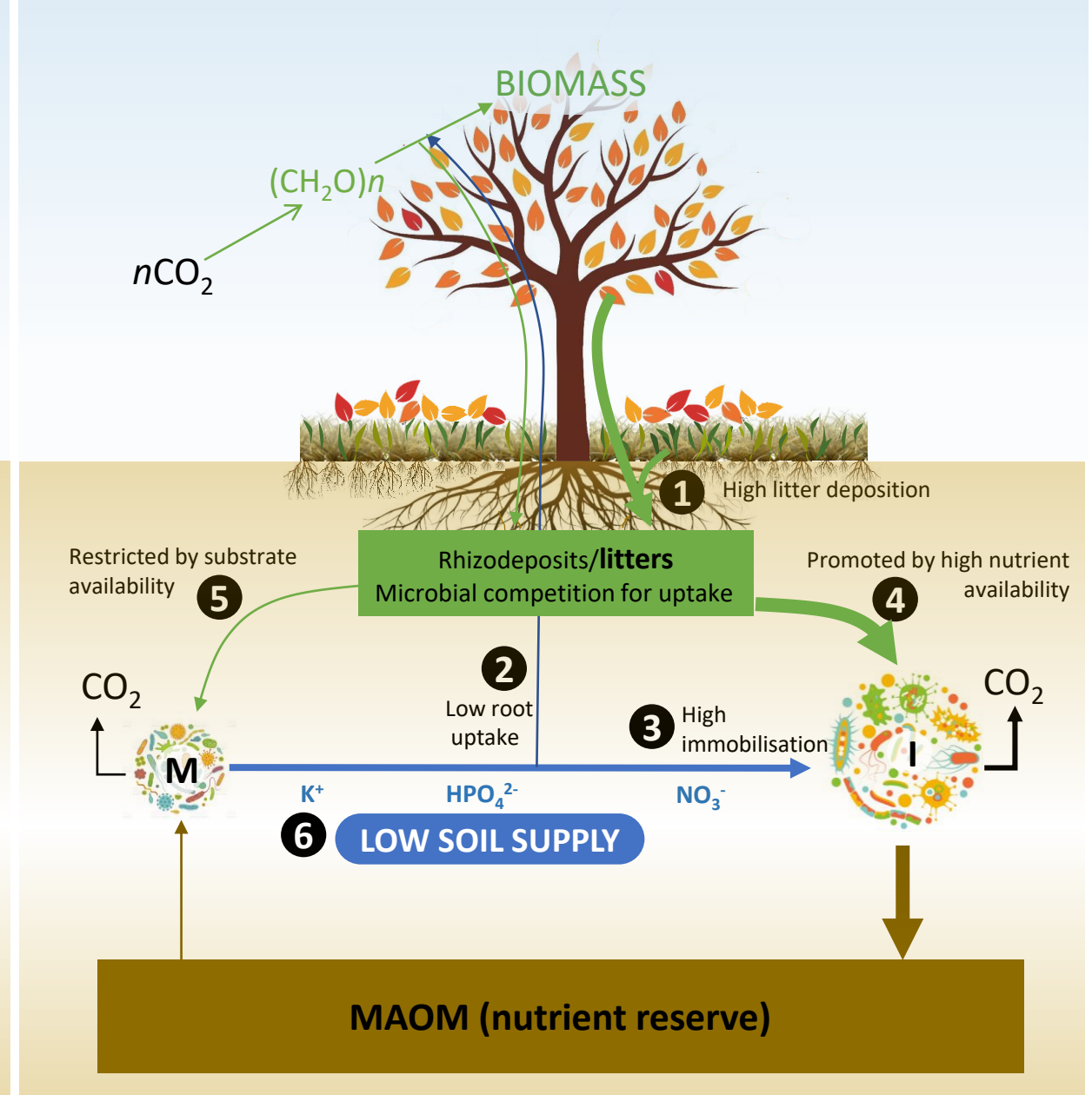
Two functional groups of microbes (M & I)  
**Supply chain of mineral nutrients for plants**

Main nutrient reserve : organic matters  
 bound to soil minerals

## HIGH PLANT DEMAND



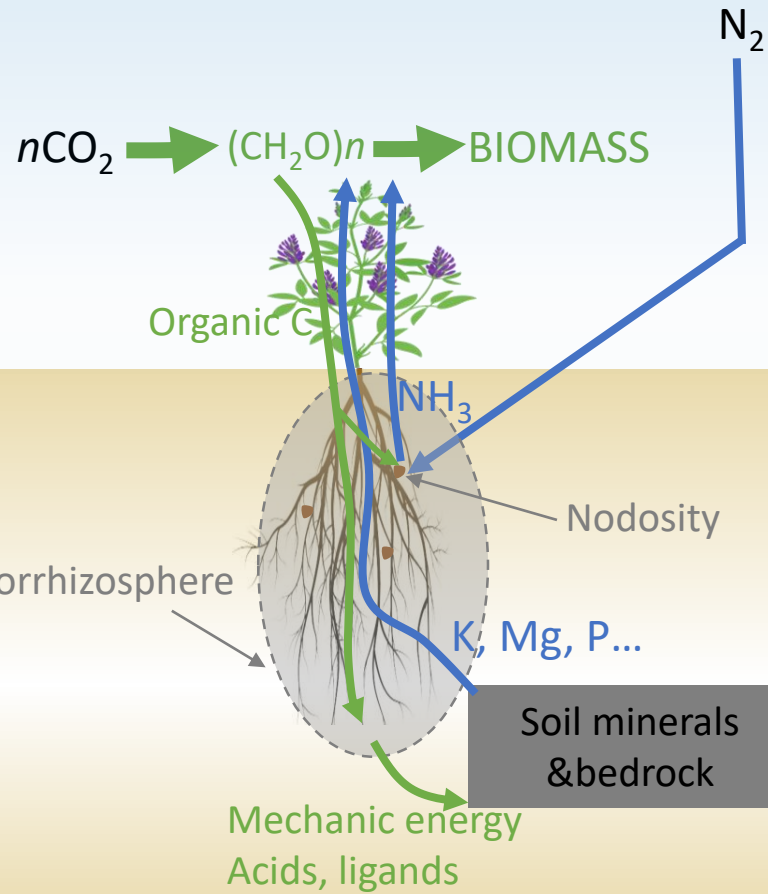
## LOW PLANT DEMAND



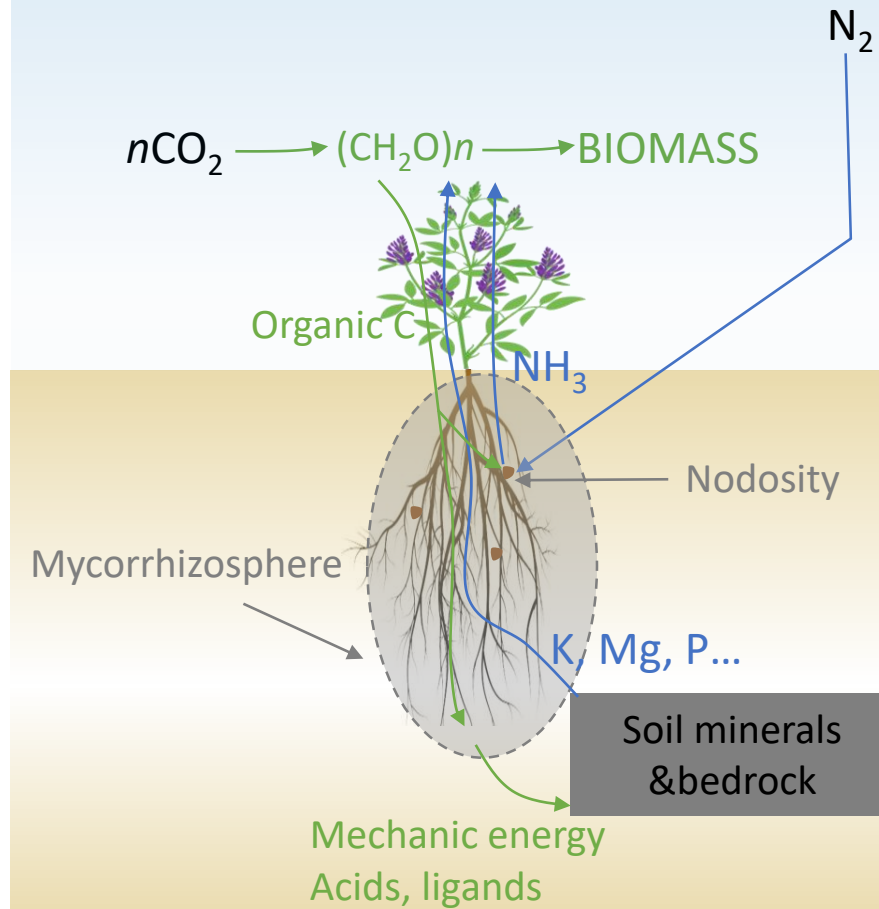
Synchrony based on nutrient  
retrieved from atmosphere and  
soil minerals

(Sync-Inorganic)

### HIGH PLANT DEMAND



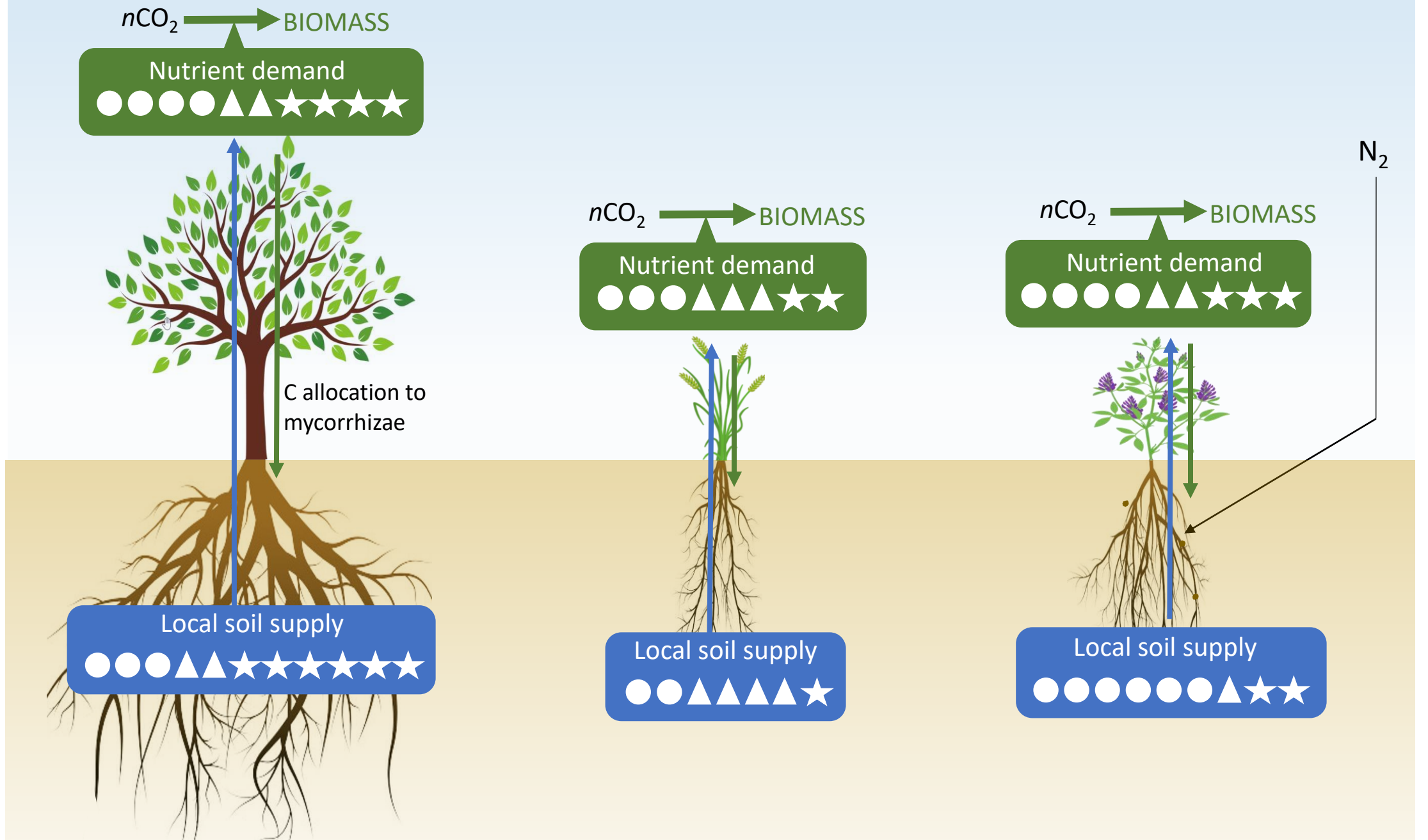
### LOW PLANT DEMAND

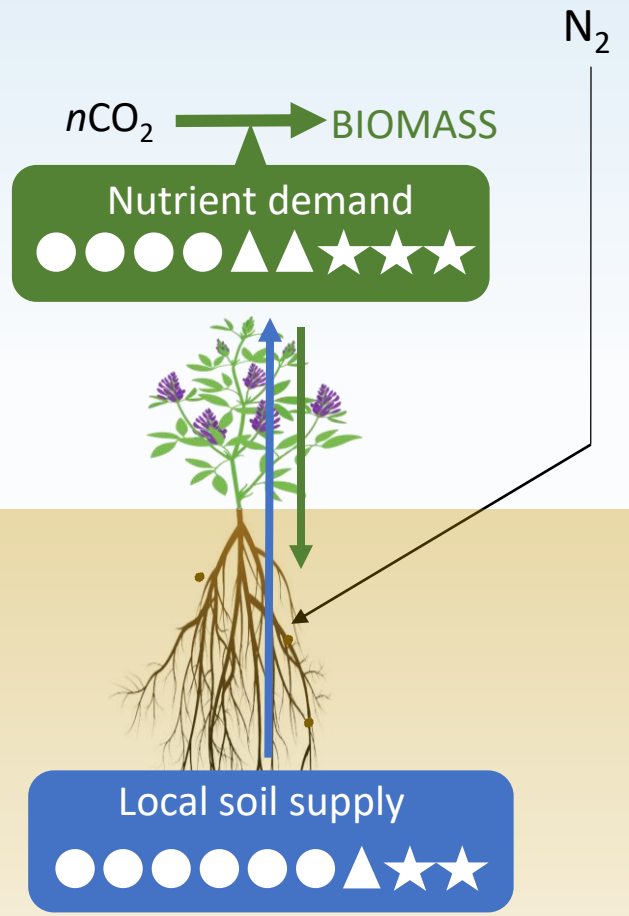
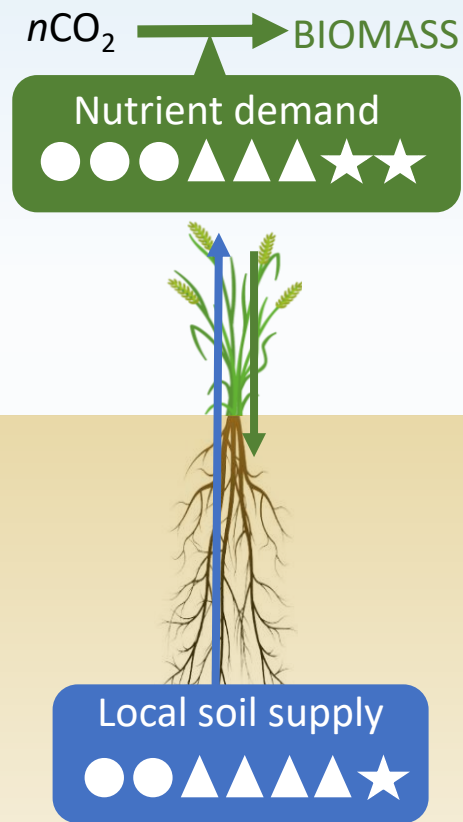
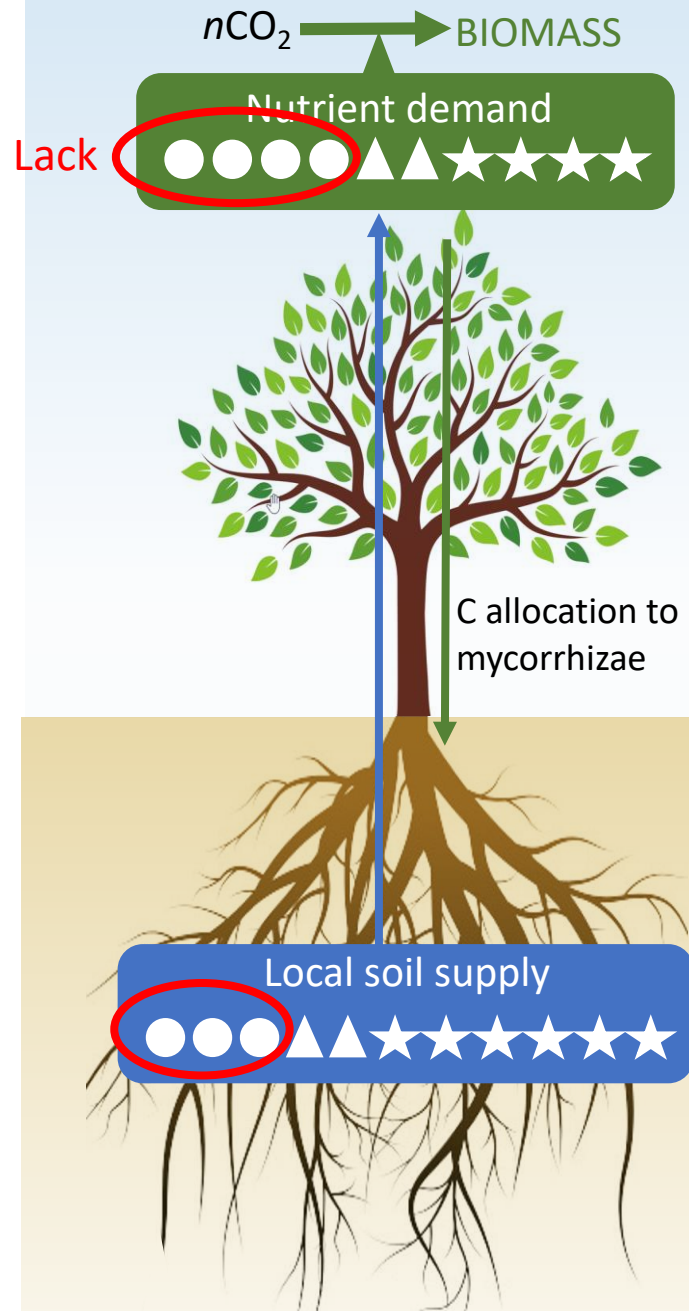


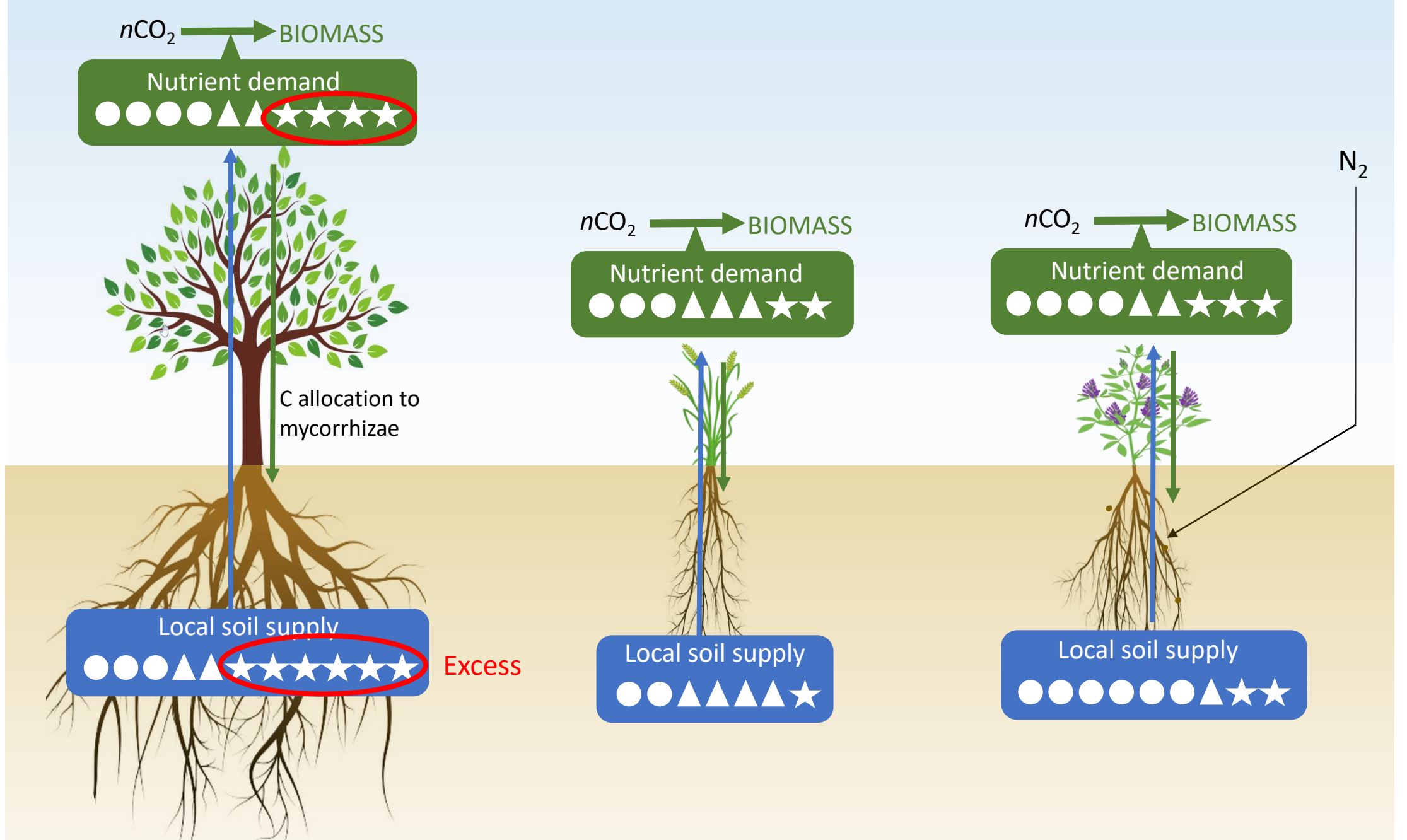


Multi-element synchrony based  
on a common nutrient market

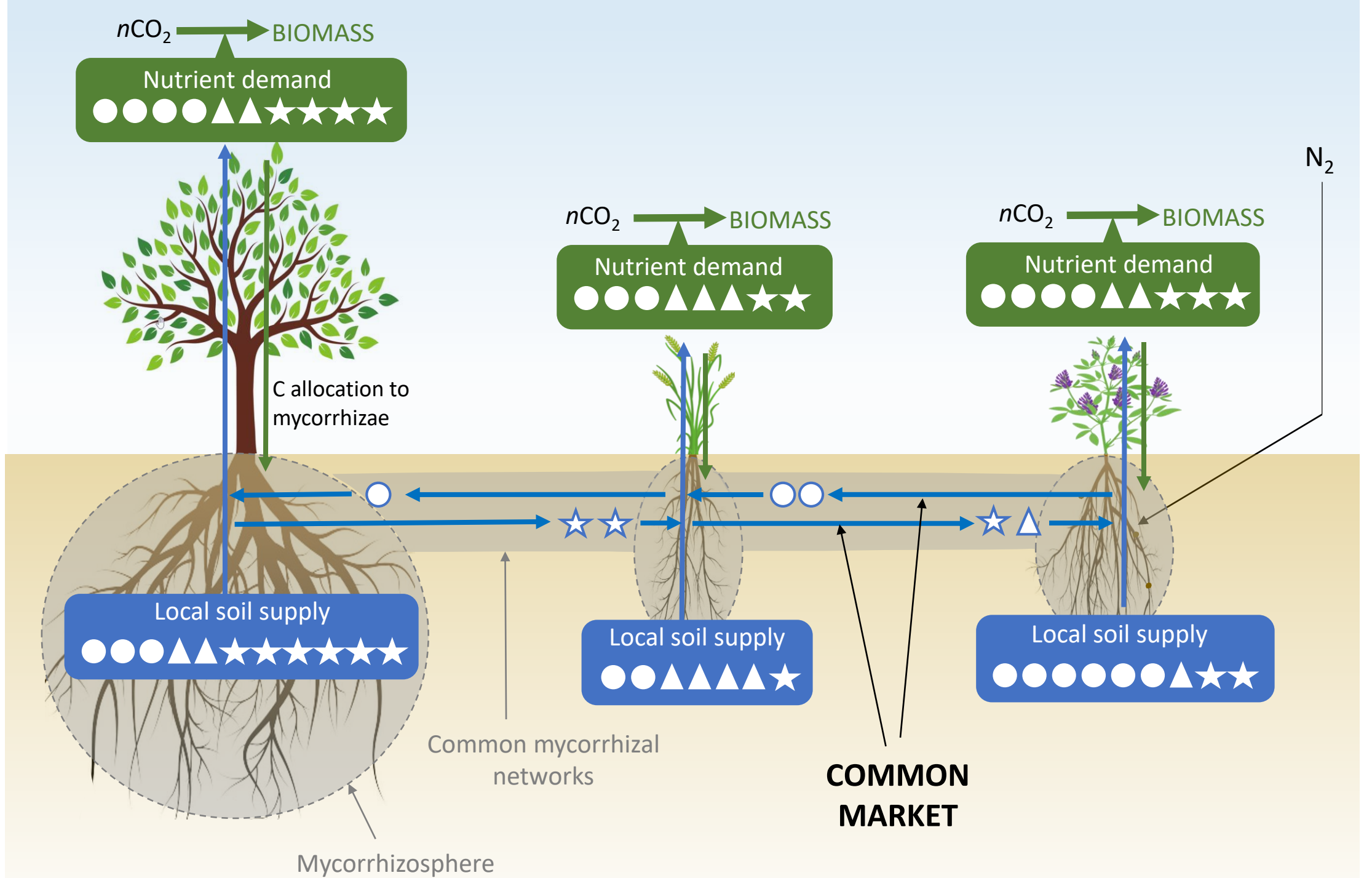
(Sync-Market)











# Implications for agrosystems

## 1. Redefining « Soil fertility »

# Redefining “Soil fertility”

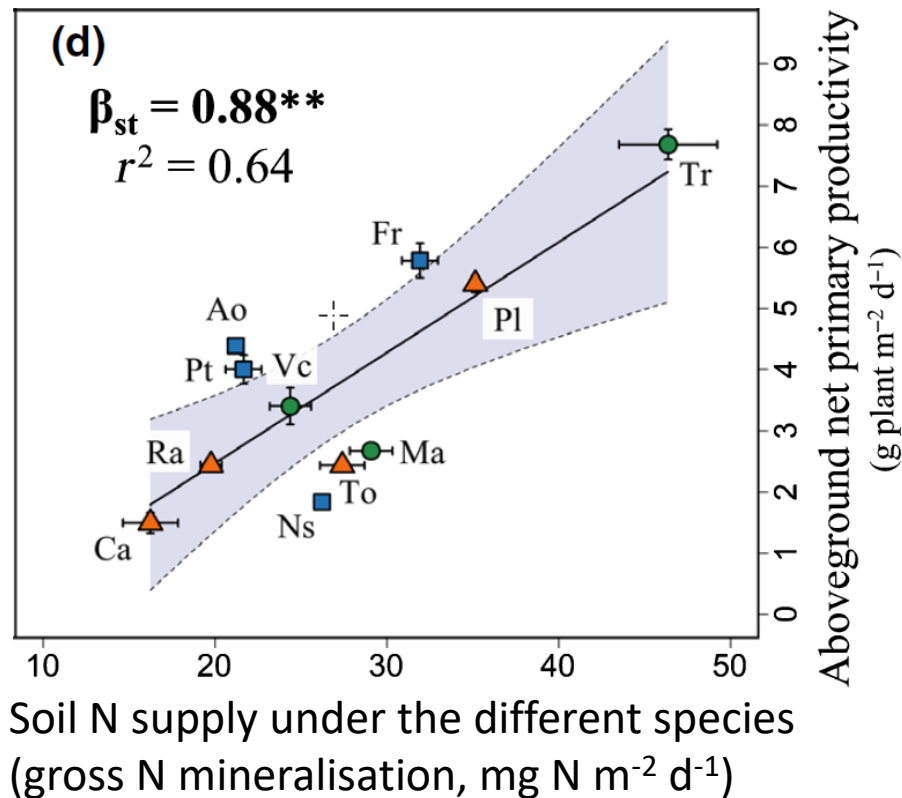


- Fertility is currently defined as an inherent capacity of a soil to sustain plant growth-production by providing nutrients in adequate amounts and in suitable proportion
  - Last advances on synchrony show:
    - Plants control the amount and proportion of nutrients supplied by the soil
    - The soil supply of nutrient must be considered in relation to the fluctuating plant demand.
- Fertility is not an inherent property of soil but is an emerging property of plant-soil interactions

# Redefining “Soil fertility”

- Practical consequence : the same soil can support different levels of nutrient supply and biomass production

12 species cultivated on the same soil:



# Implications for agrosystems

2. Managing synchrony to ensure both productivity and sustainability



# HIGH SYNCHRONY



1. Adapting synchrony systems to local pedoclimatic contexts
2. Coupling synchrony systems with complementary roles
3. Inclusion of plants with high organ reserve and/or plasticity

# HIGH SYNCHRONY

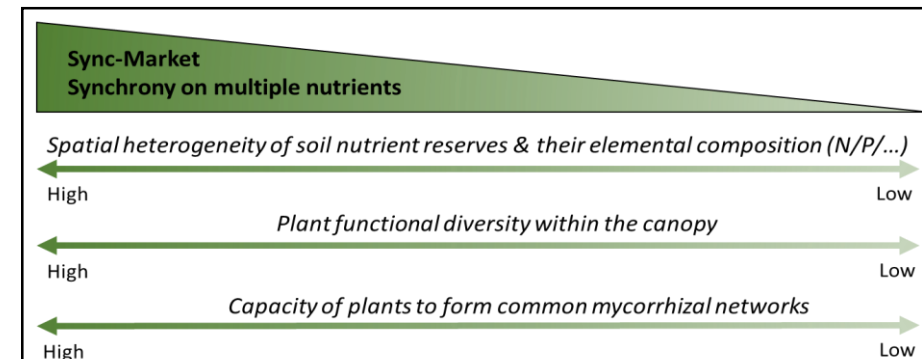
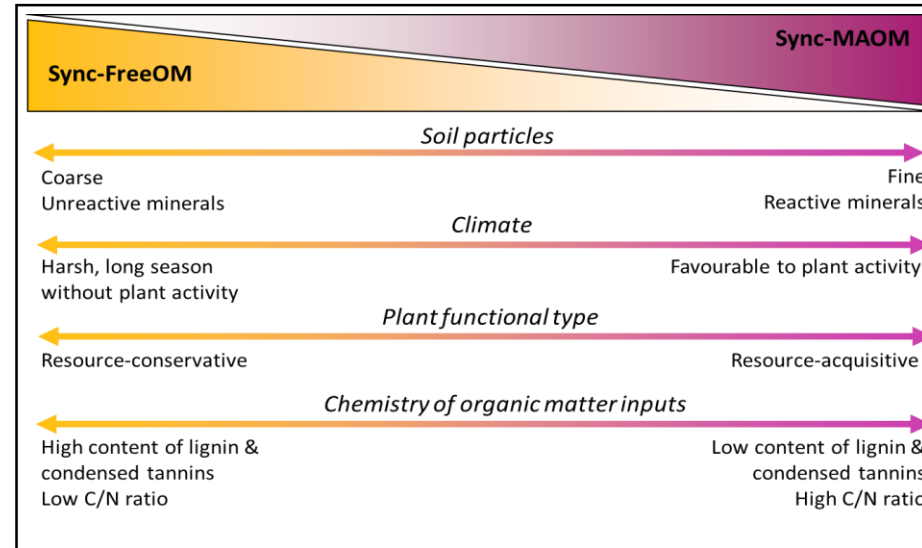
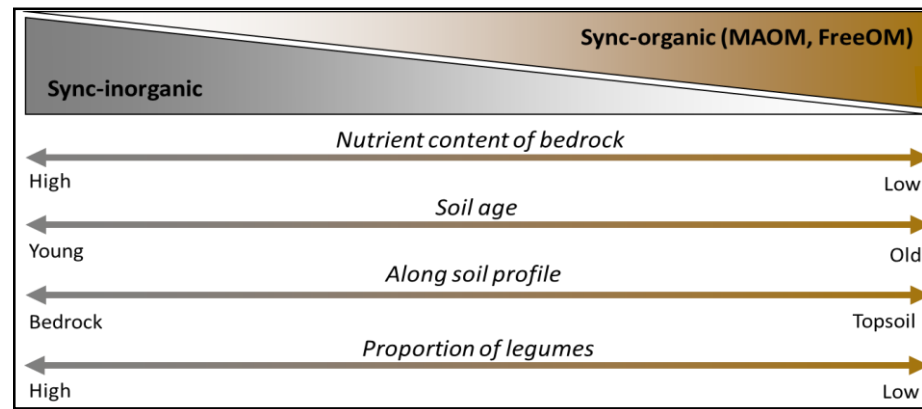


1. Adapting synchrony systems to local pedoclimatic contexts

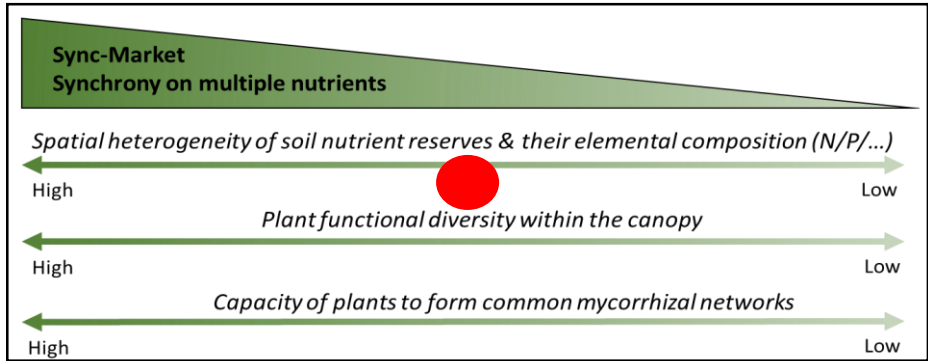
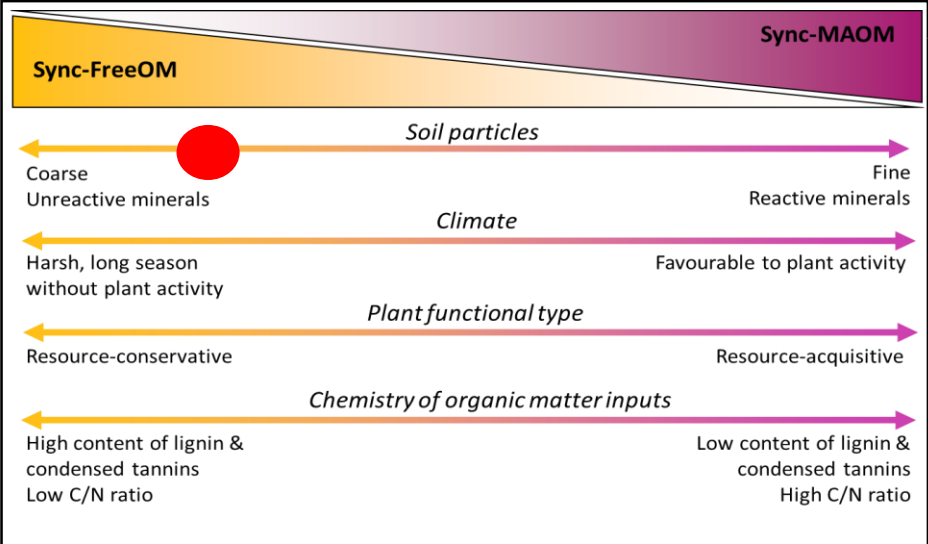
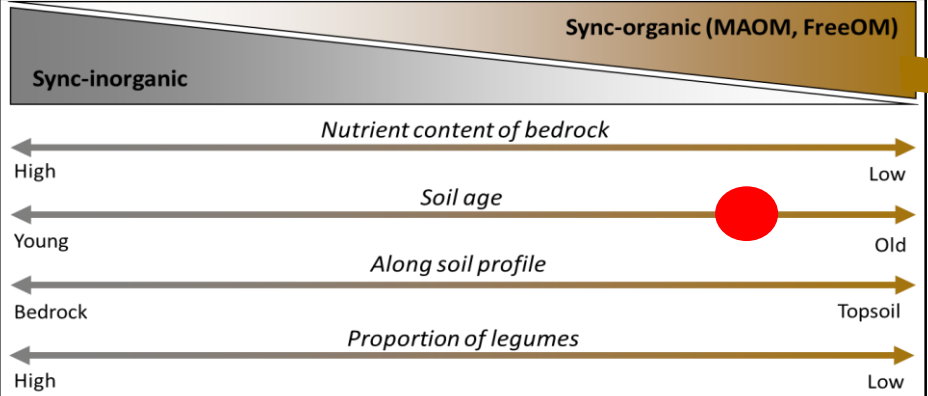
2. Coupling synchrony systems with complementary roles

3. Inclusion of plants with high organ reserve and/or plasticity

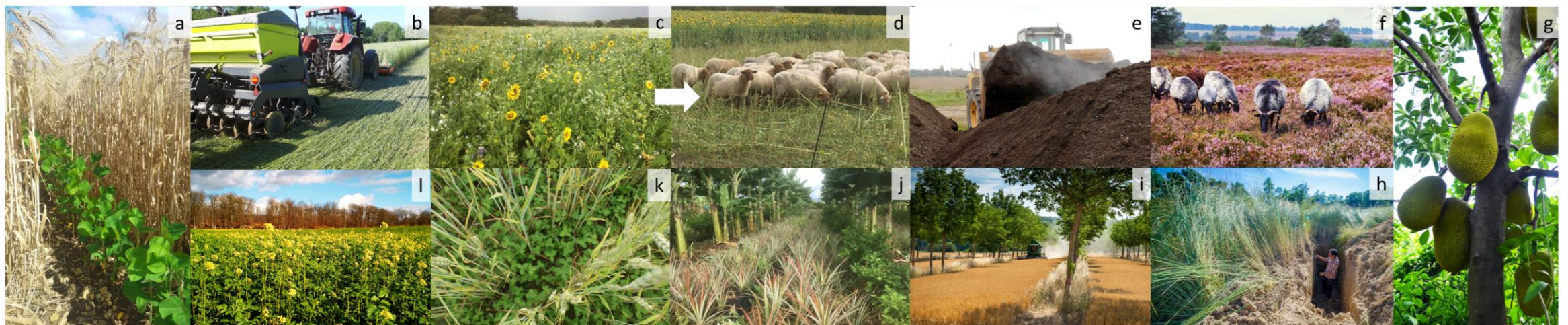
# 1. Adapting synchrony systems to local pedoclimatic contexts



Let's take an example



Synchrony	Conditions of synchrony	Combination of practices to set up for promoting the targeted synchrony
Sync-MAOM	<ul style="list-style-type: none"> <li>-Acquisitive plant species</li> <li>-Continuous activity of microbes M &amp; I</li> <li>-Reserve of MAOM in soil</li> </ul>	<ul style="list-style-type: none"> <li>- Insertion/breeding of acquisitive species with strong capacity of stimulating nutrient mineralization/immobilization (e.g., high C rhizodeposition)</li> <li>- The carbon:nutrient ratio of plant species or organic residues must be high enough to induce nutrient immobilization by I-Microbes. Ideally, the different plant species have contrasting carbon:nutrient ratios (a, c, l, j, k)</li> <li>- Maintaining a continuous cover of active plants fueling microbes in energy-rich C (all pictures but e)</li> <li>- Recycling organic nutrients at local scale (farm-watershed) to preserve soil organic reserve on the long-term (d, e, f)</li> </ul>
Sync-FreeOM	<ul style="list-style-type: none"> <li>-Conservative plant species</li> <li>-Mycorrhizal fungi</li> <li>-Reserve of FreeOM in soil</li> </ul>	<ul style="list-style-type: none"> <li>- Insertion/breeding of conservative species producing recalcitrant litter with reactive compounds fixing organic nutrients (e, f)*</li> <li>- Or/and amendment of recalcitrant organic residues harboring reactive compounds more or less charged in organic nutrients (e)</li> <li>- Recycling organic nutrients at local scale (farm-watershed) to preserve soil organic reserve on the long-term (d, e, f)</li> </ul>
Sync-Inorganic	<ul style="list-style-type: none"> <li>-Plant symbiosis with mycorrhizal fungi &amp; N<sub>2</sub> fixing bacteria</li> <li>-Nutrients stored in bedrock, soil minerals and/or precipitates</li> </ul>	<ul style="list-style-type: none"> <li>- Insertion/breeding of species with strong capacity of mobilizing nutrients from rock and soil minerals (e.g., mycorrhized roots exerting strong mechanic pressure on minerals, secreting high amount of organic acids &amp; ligands)</li> <li>- Insertion of plant with deep roots colonizing bedrock (g, h, i)</li> <li>- Insertion of legumes (a, c, k)</li> <li>- Inoculation with mixed mycorrhizal fungi &amp; N<sub>2</sub> fixing bacteria in highly degraded soils</li> </ul>
Sync-Market	<ul style="list-style-type: none"> <li>-Plant species with complementary nutritional needs</li> <li>-Common mycorrhizal networks</li> </ul>	<ul style="list-style-type: none"> <li>- Mixing plant species with different nutrient acquisition strategies and carbon:nutrient ratios (a, c, l, j, k)</li> <li>- Promoting perennial plants (f, g, h, l, k) and/or permanent plant cover (all pictures but e) to fuel mycorrhizae in energy-rich carbon</li> <li>- No or limited use of soil tillage (b) and pesticides to preserve mycorrhizae networks</li> <li>- Inoculation with mixed mycorrhizal fungi in highly degraded soils</li> </ul>
Increasing overall synchrony	<ul style="list-style-type: none"> <li>-Synchrony systems adapted to pedoclimatic context</li> <li>-Complementary synchrony systems</li> <li>-Plant plasticity &amp; reserve</li> </ul>	<ul style="list-style-type: none"> <li>- Analyzing the soil profile and climate, defining the most adapted synchrony systems</li> <li>- Mixing plant species with different nutrient acquisition strategies (a, c, l, j, k)</li> <li>- Breeding crops species on their suitability to association</li> <li>- Promoting perennial plants with high reserve and organ plasticity (f, g, h, l, j, k)</li> </ul>





Thank you for your attention



Let's continue to play the synchrony's doctor