Designing sustainable agrosystems to promote plant-soil synchrony

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

Designing sustainable agrosystems to promote plant-soil synchrony

Sébastien FONTAINE

With collaborations of

Luc Abbadie, Gaël Alvarez, Michaël Aubert, Sébastien Barot, Juliette Bloor, Delphine Derrien, Olivier Duchene, Nicolas Gross, Ludovic Henneron, Xavier Le Roux, Nicolas Loeuille, Jennifer Michel, Sylvie Recous, Daniel Wipf & Partners of AGROECOSeqC

Annual Science Days 2022 / Breakout Session 4 - Soil biodiversity and ecosystem services

How to develop efficient agroecological strategies to reduce the carbon footprint of agrosystems?

- Semi-natural forests and grasslands 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 : ecosystem attributes such as high diversity, root biomass, fungal biomass…
  - Improvement of specific functions

How to develop efficient agroecological strategies to reduce the carbon footprint of agrosystems?

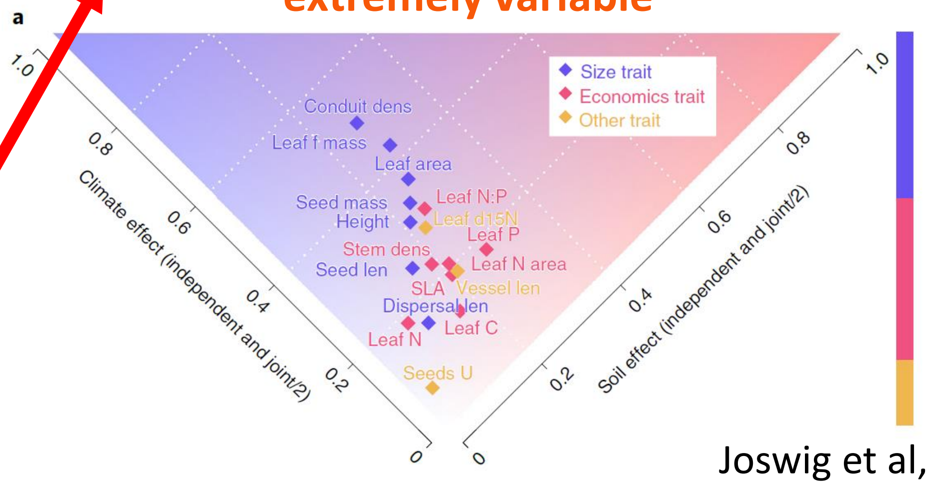
- Semi-natural forests and grasslands as models
  - As productive as high-input annual crops
  - Accumulate soil C, retain nutrients, low GHG emissions

- Which aspects should be copied ? How to translate in practices?
  - Current focus : ecosystem attributes such as high diversity, high root and fungal biomass…
  - Improvement of specific functions

- **Need of a more systemic approach** considering:
  - the interactions of multiple co-occurring processes and organisms,
  - the adaptation of organisms/processes to pedoclimatic contexts

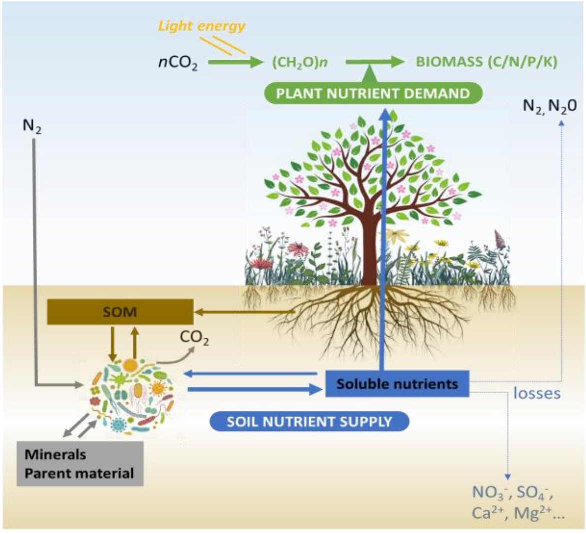
Limits

Plant-soil diversity and traits are extremely variable

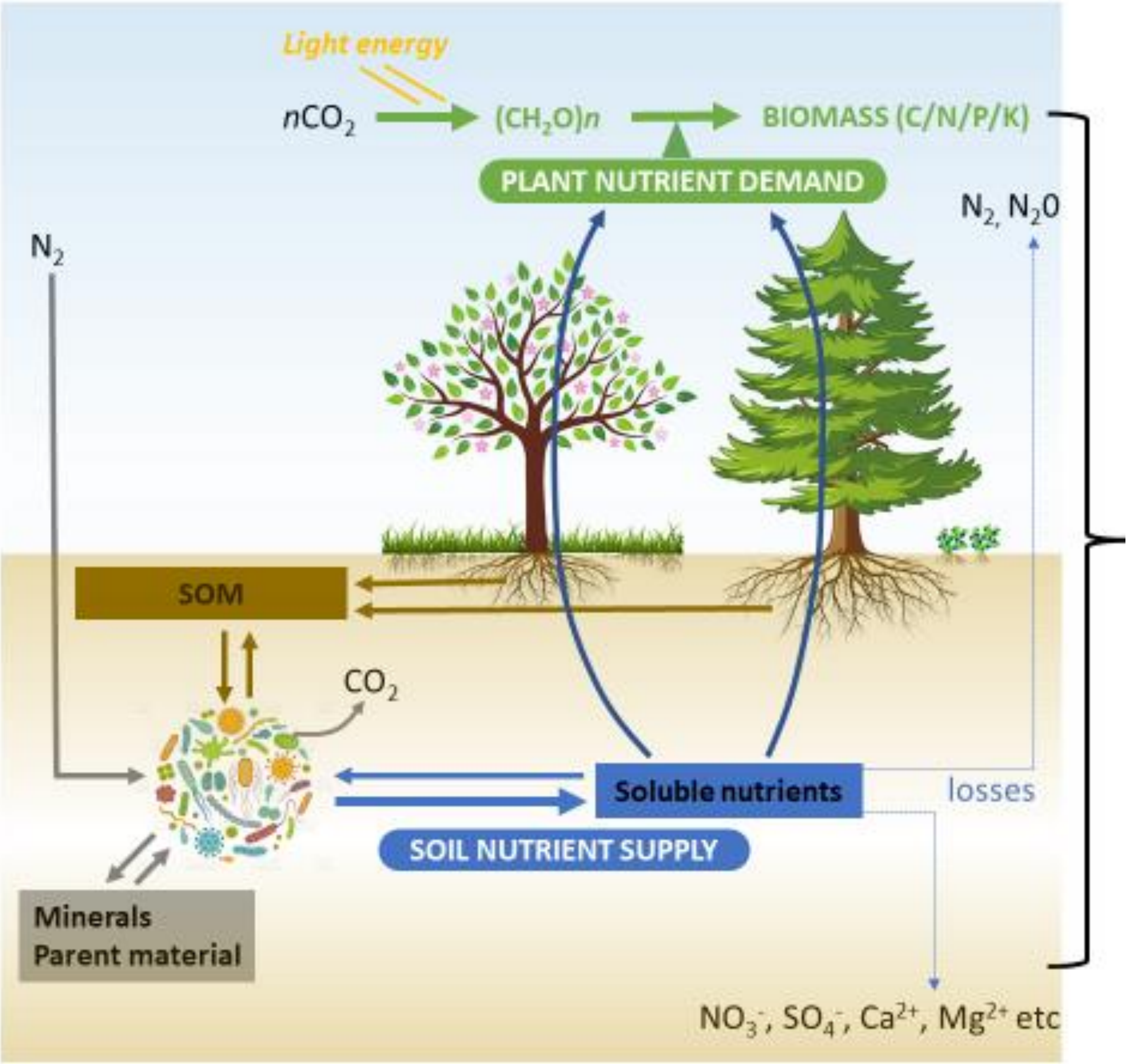


Joswig et al, 2022

Ecosystem functioning depends on the coupling of numerous soil-plant processes/organisms



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



Natural ecosystems : high synchrony

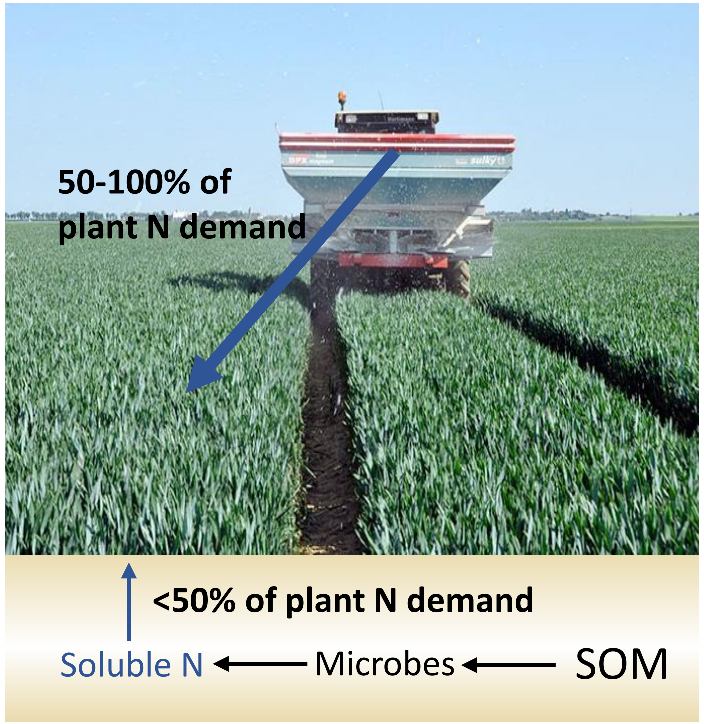
- ↑ biomass production by ↓ N limitation
- ↓ excess of soluble N, N losses (<5%)
- ↑ building of SOM

➢ N recycling and BNF account for 90 and 10% of plant N uptake

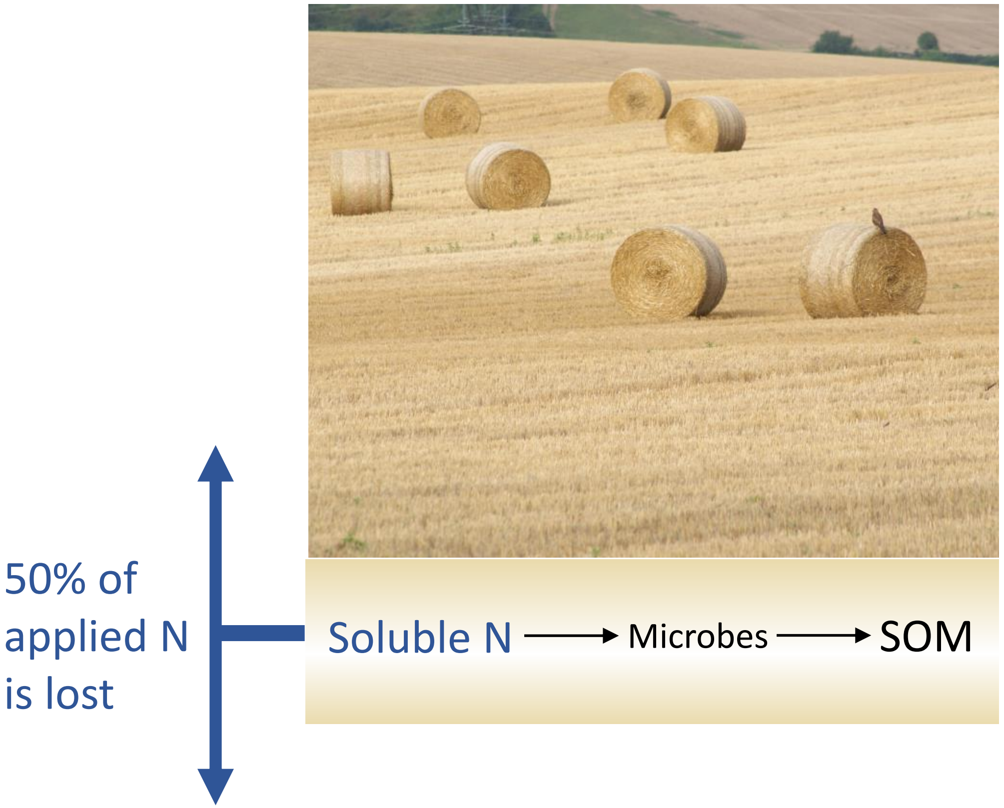
Cleveland et al 2013; Cameron et al 2013

The strong C footprint of annual crops due to a low demand/supply synchrony

High plant demand



Low plant demand



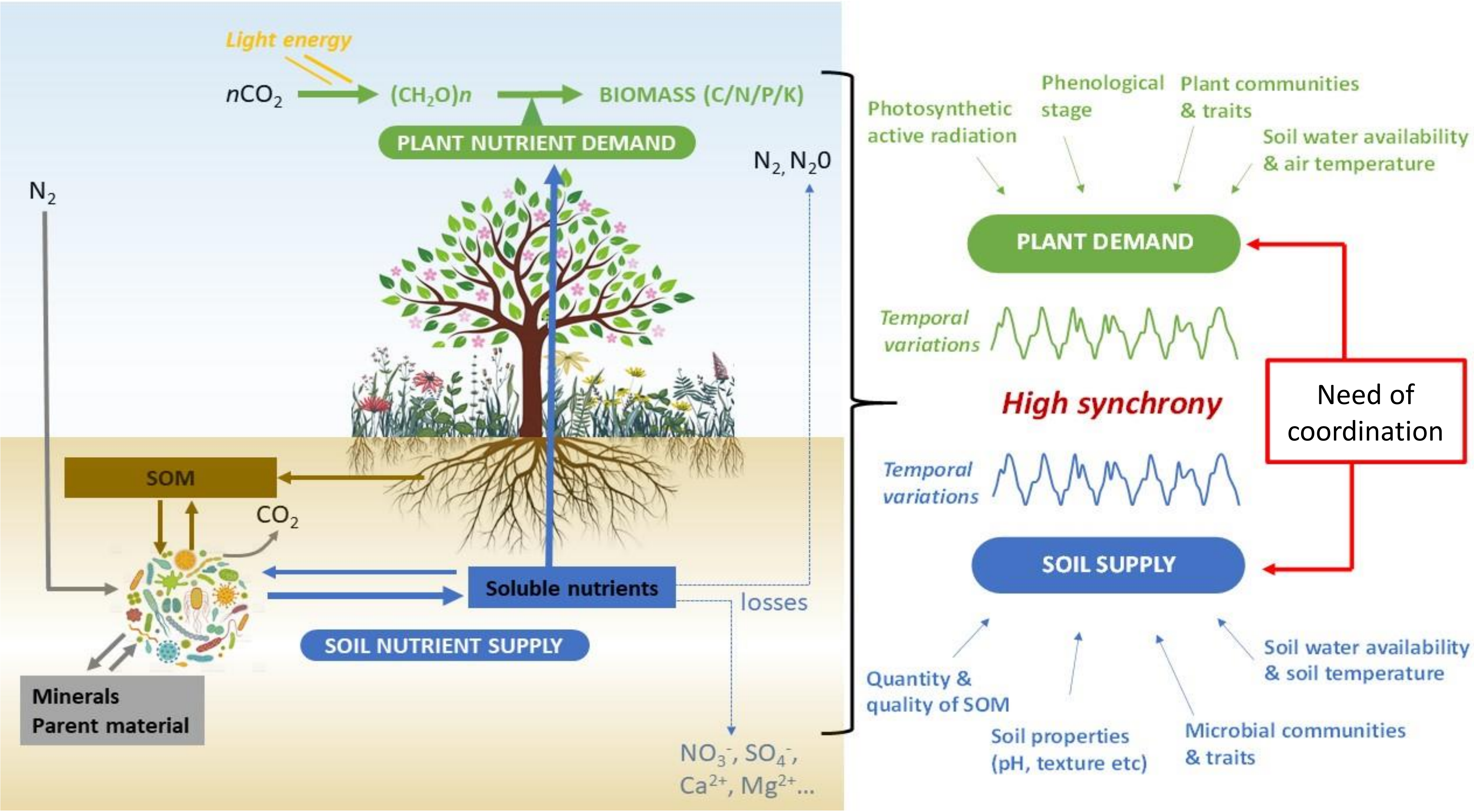
- Dependence to fertilizer
- N losses -> water pollution, GHG
- SOM depletion -> C emissions

\+

Strong C footprint

Robertson et al., 2012; Fowler et al., 2017; Zhang et al., 2021

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

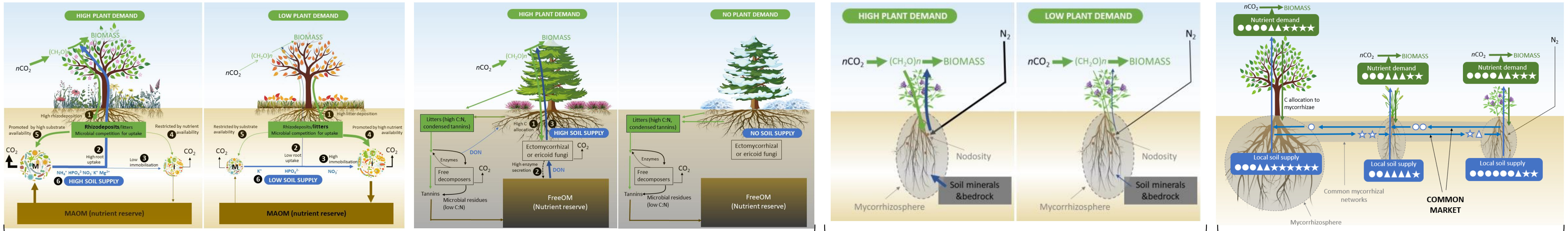


➢ **Synchrony requires the coordination of many plant-soil processes**

Review of latest advances in ecology and biogeochemistry

1. Identification of 4 systems of synchrony (coordination of processes)

1 2 3 4



Soil organic nutrient reserves

Nutrient retrieved from Atmosphere and soil minerals

Common nutrient market

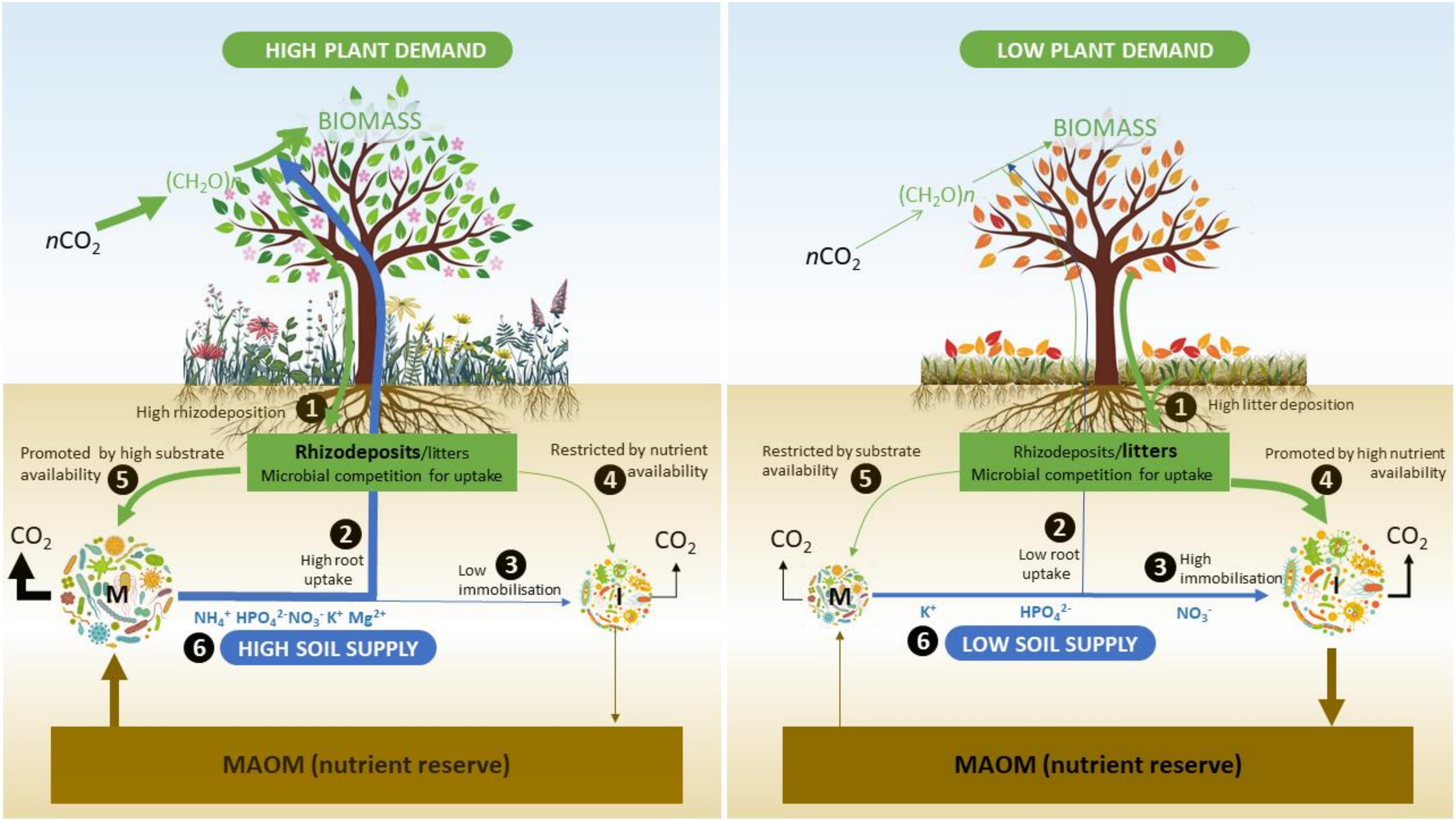
2. Dominance of these different systems change according to pedoclimatic context -> different agroecological practices to adapt to local conditions

3. Plants partly drive their own nutrition -> Challenges the classical view of fertility as an intrinsic property of soil

-> Ecological intensification of production

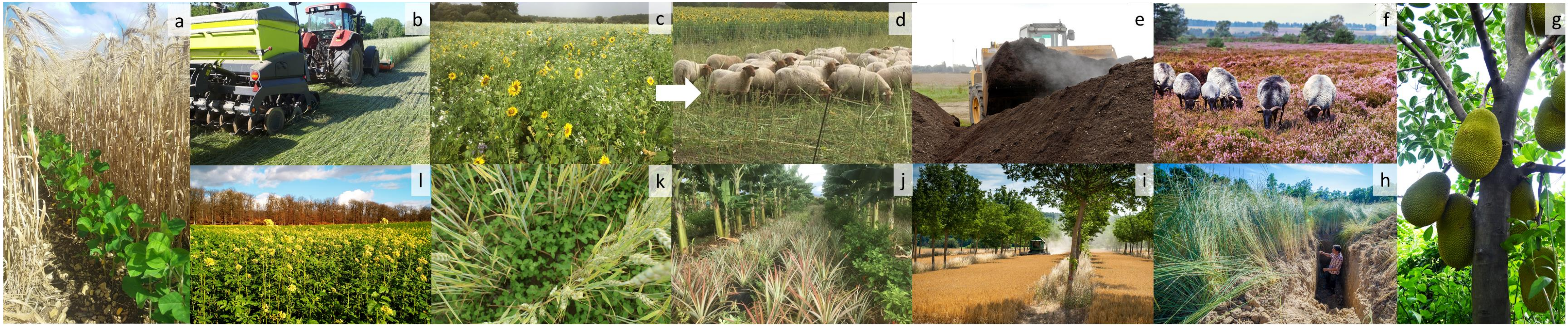
C’est extra

Example of system of coordination based on nutrient storage in mineral-associated organic matter (MAOM)

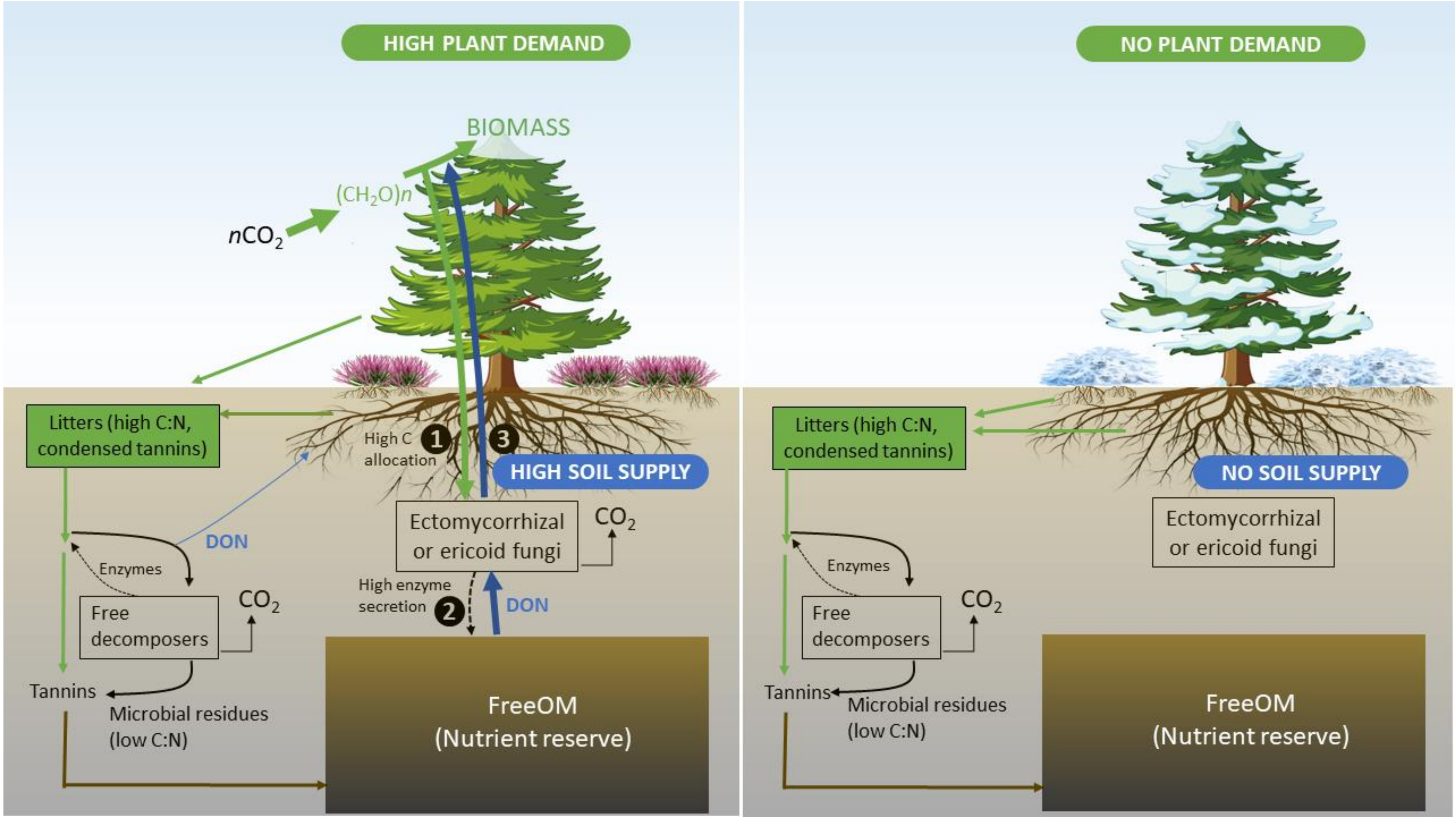


Implications of MAOM-based synchrony for the design of sustainable/productive agrosystems

Synchrony	Biological conditions of synchrony	Combination of practices to set up for promoting the targeted synchrony
Sync-MAOM	-Acquisitive plant species -Continuous activity of microbes M & I	- Insertion/selection of acquisitive species with strong capacity of stimulating nutrient mineralization/immobilization (e.g., high C rhizodeposition) - 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) - Maintaining a continuous cover of active plants fueling microbes in energy-rich C (all pictures but e) - Recycling organic nutrients at local scale (farm-watershed) to preserve soil organic reserve on the long-term (d, e, f)

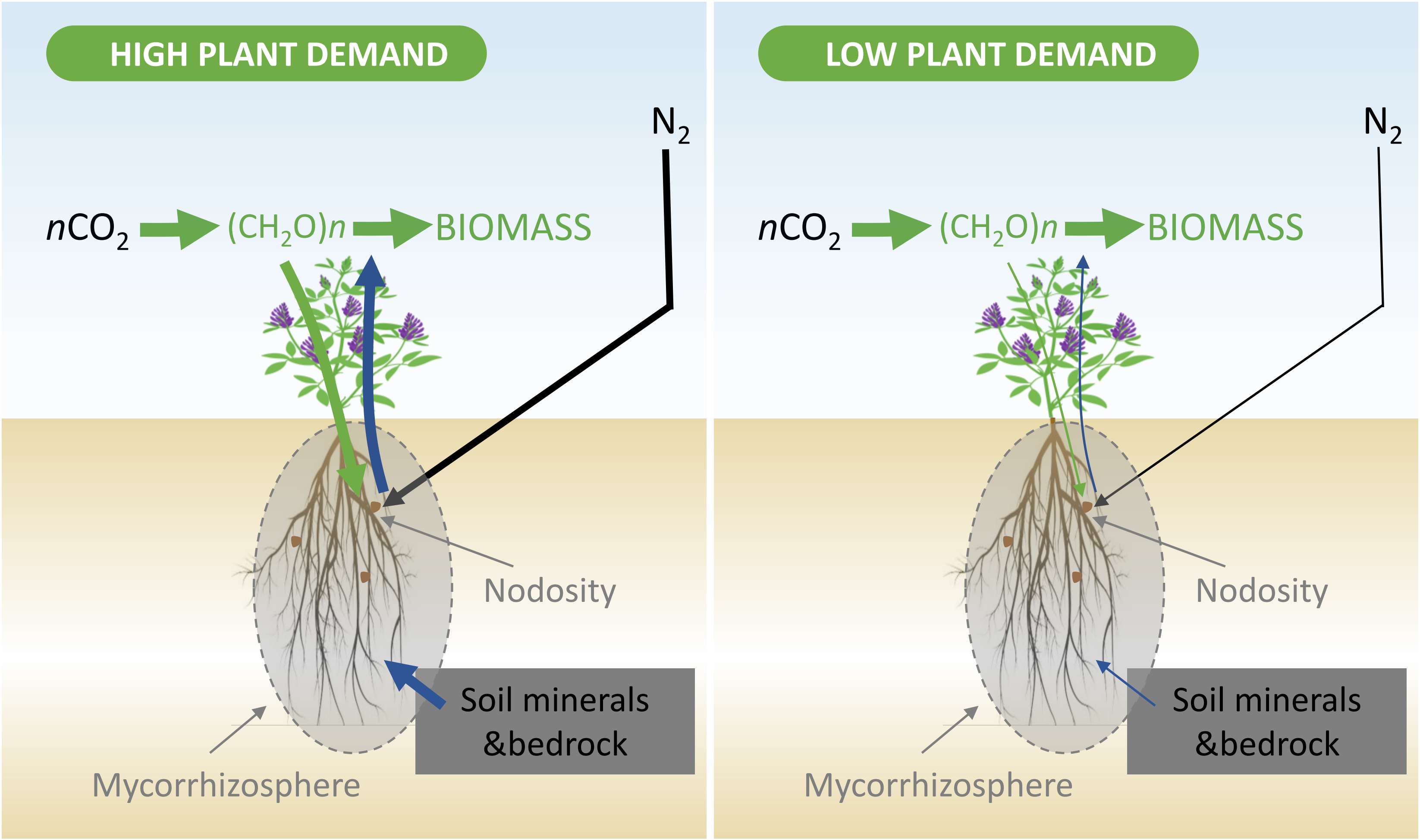


2) System of synchrony based on FreeOM

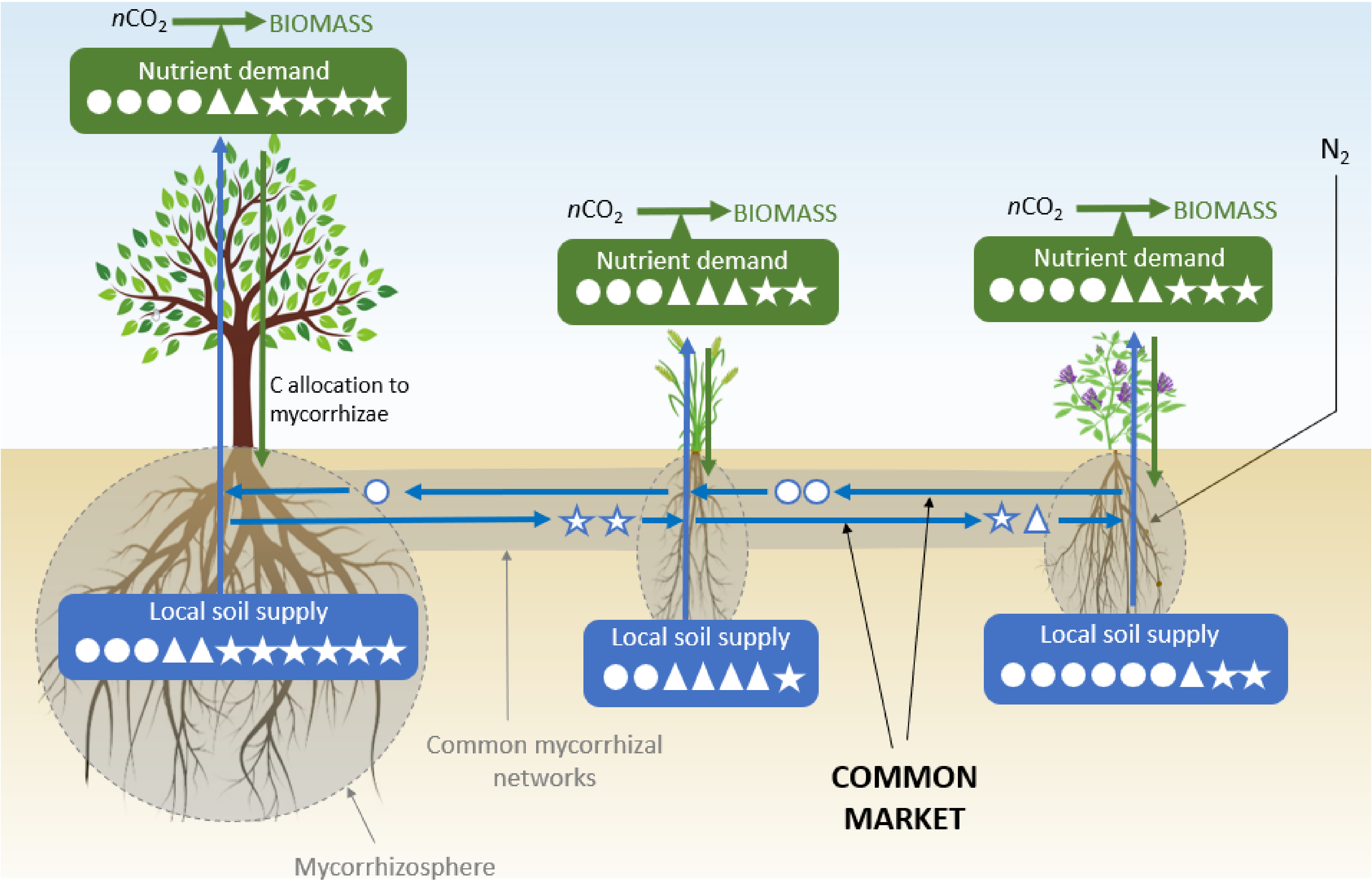


- Ecosystems with thick organic layer (Heathlands, alpine grasslands…)

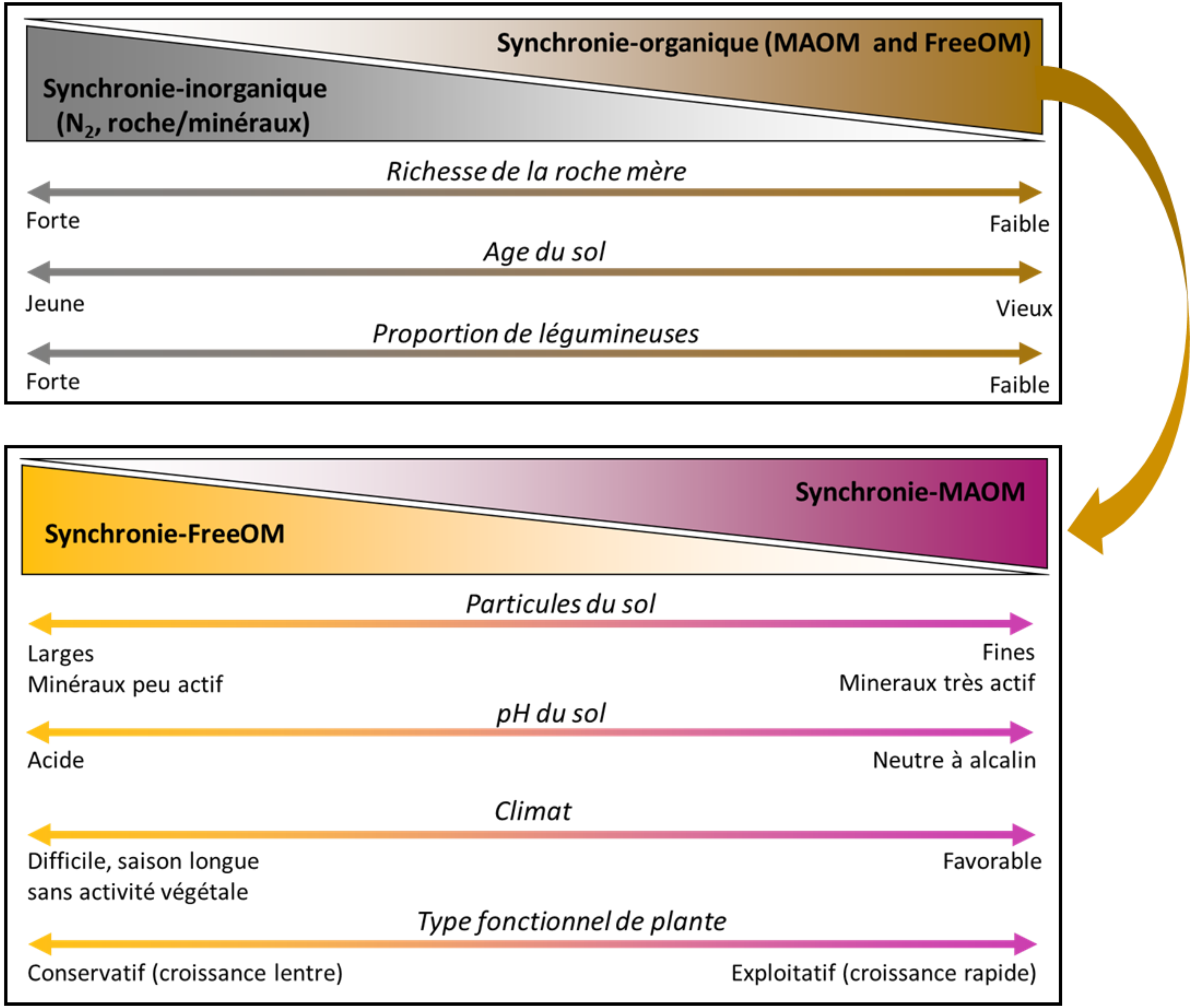
3) System of synchrony based on nutrient retrieved from atmosphere and soil minerals



4) System of synchrony based on a common nutrient market emerging from mycorrhizal networks



Dominance of 3 systems of synchrony according to pedoclimatic context and plant communities



Synchrony	Biological conditions of synchrony	Combination of practices to set up for promoting the targeted synchrony
Sync-MAOM	-Acquisitive plant species -Continuous activity of microbes M & I	- Insertion/selection of acquisitive species with strong capacity of stimulating nutrient mineralization/immobilization (e.g., high C rhizodeposition) - 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, I, j, k) - Maintaining a continuous cover of active plants fueling microbes in energy-rich C (all pictures but e) - Recycling organic nutrients at local scale (farm-watershed) to preserve soil organic reserve on the long-term (d, e, f)
Sync-FreeOM	-Conservative plant species -Mycorrhizal fungi	- Insertion/selection of conservative species producing recalcitrant litter with reactive compounds fixing organic nutrients (e, f)* - Or/and amendment of recalcitrant organic residues harboring reactive compounds more or less charged in organic nutrients (e) - Recycling organic nutrients at local scale (farm-watershed) to preserve soil organic reserve on the long-term (d, e, f)
Sync-Inorganic	-Plant symbiosis with mycorrhizal fungi & N_2 fixing bacteria	- Insertion/selection 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 & ligands) - Insertion of plant with deep roots colonizing bedrock (g, h, i) - Insertion of legumes (a, c, k) - Inoculation with mixed mycorrhizal fungi & N_2 fixing bacteria in highly degraded soils
Sync-Market	-Common mycorrhizal networks (CMN) -Species with different nutritional needs	- Mixing plant species with different nutrient acquisition strategies and nutrient requirements (a, c, I, j, k) - Promoting perennial plants (f, g, h, I, k) and/or permanent plant cover (all pictures but e) to fuel the CMN in energy-rich carbon - No or limited use of soil tillage (b) and pesticides to preserve the CMC - Inoculation with mixed mycorrhizal fungi in highly degraded soils
Overall synchrony	-High plant functional diversity -Plant plasticity & reserve	- Mixing plant species with contrasted functional traits (e.g. phenology) & nutrient acquisition strategies (a, c, I, j, k) - Promoting perennial plants with high reserve and organ plasticity (f, g, h, I, j, k)