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SUSTENTABILIDADE
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SOIL: RECONCILING FARMING TECHNOLOGIES WITH ECOSYSTEM SERVICES

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LAYOUT

- Ecosystem services in terrestrial ecosystems – the role of SOIL
  - What are ecosystem services?
  - Examples

- Global changes
  - Global change drivers
  - Soil degradation

- Sustainable technologies
  - What are sustainable technologies?
  - Examples

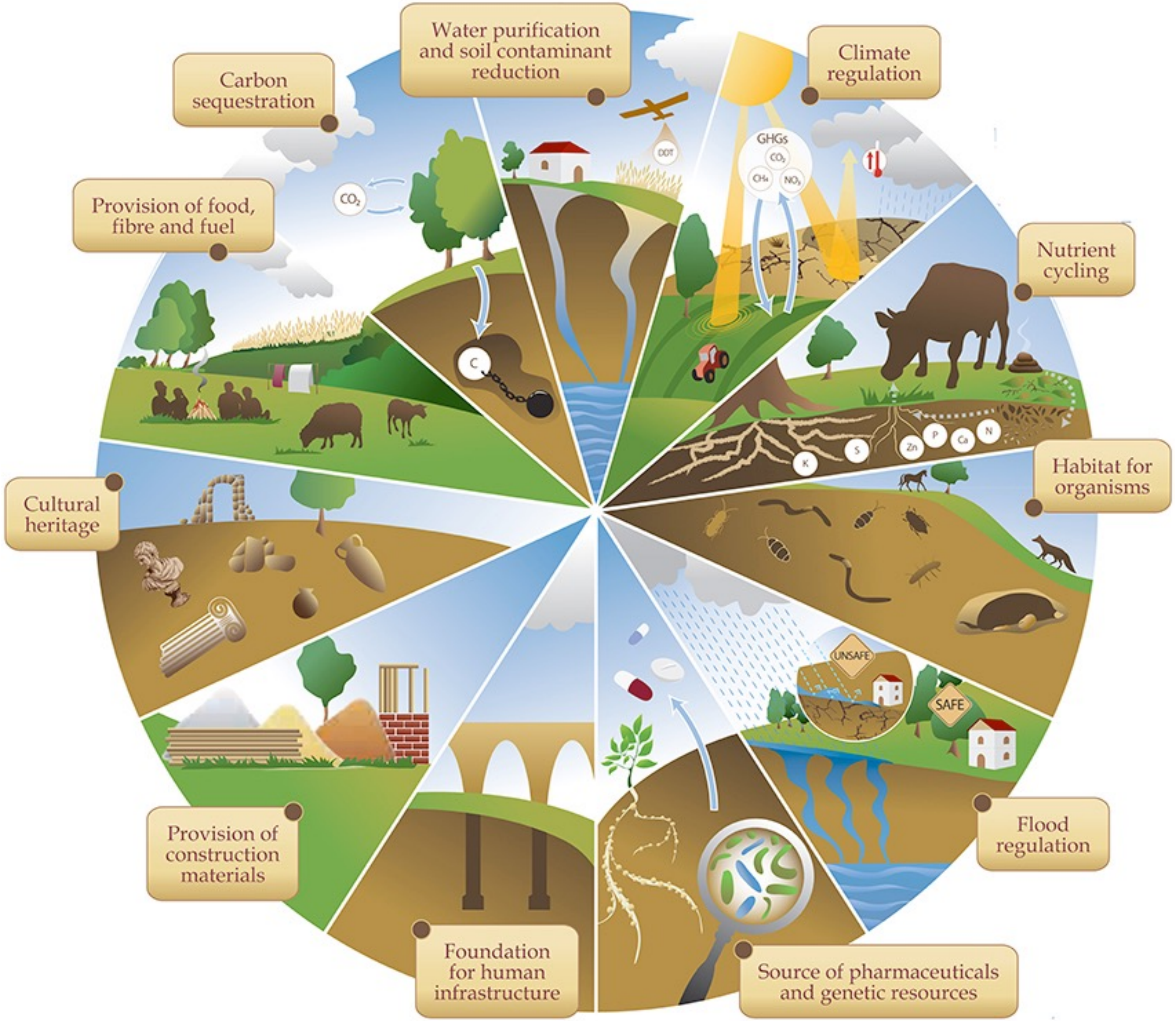
- Reconciling sustainable technologies with ecosystem services
  - Examples
  - Assessing multiple ecosystem services simultaneously

TERRESTRIAL ECOSYSTEMS

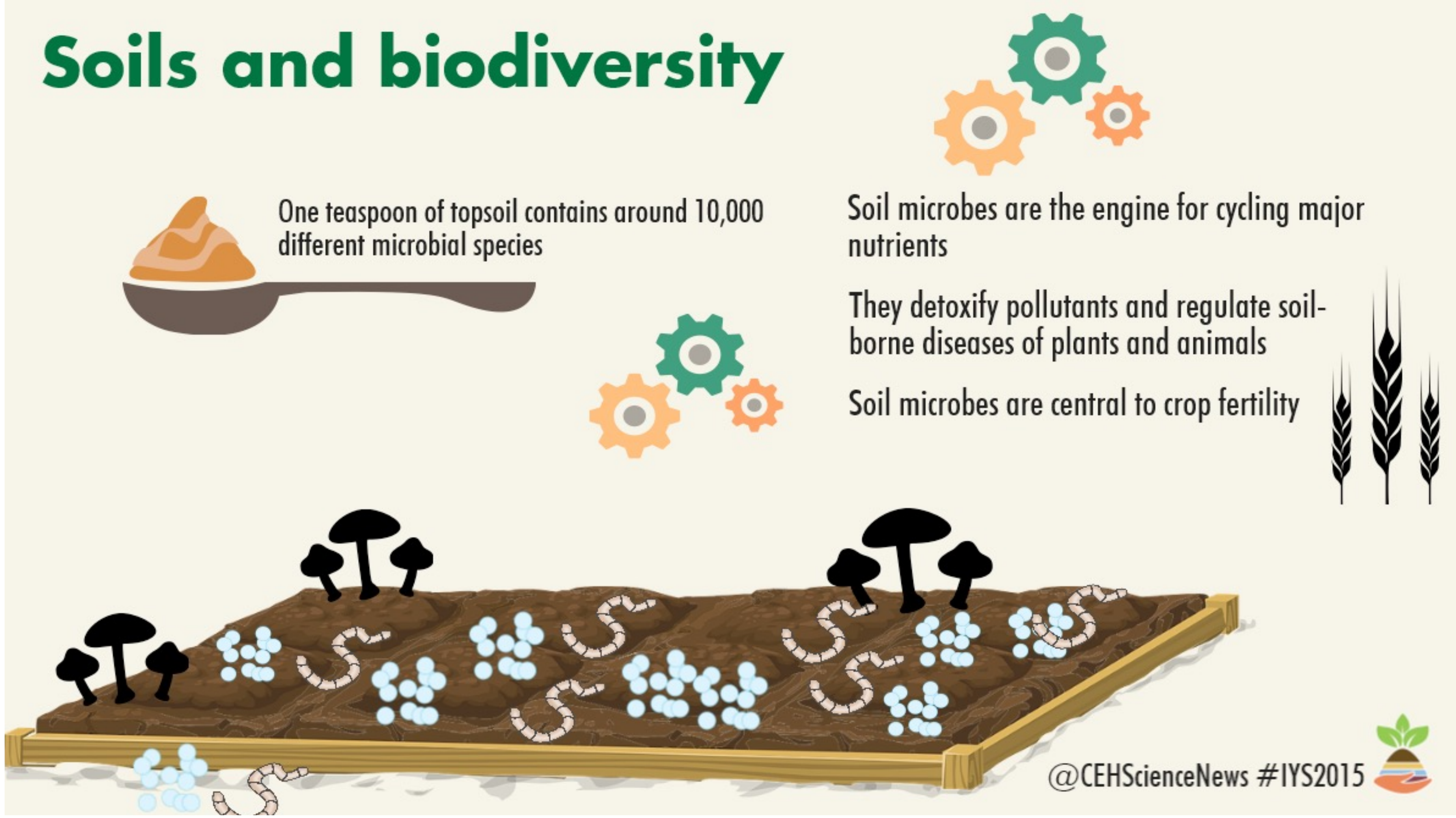
SOILS SUSTAIN ALL TERRESTRIAL ECOSYSTEMS

ECOSYSTEM SERVICES ARE PROVIDED BY SOILS (DIRECTLY AND/OR INDIRECTLY)

ECOSYSTEM SERVICES PROVIDED BY SOILS

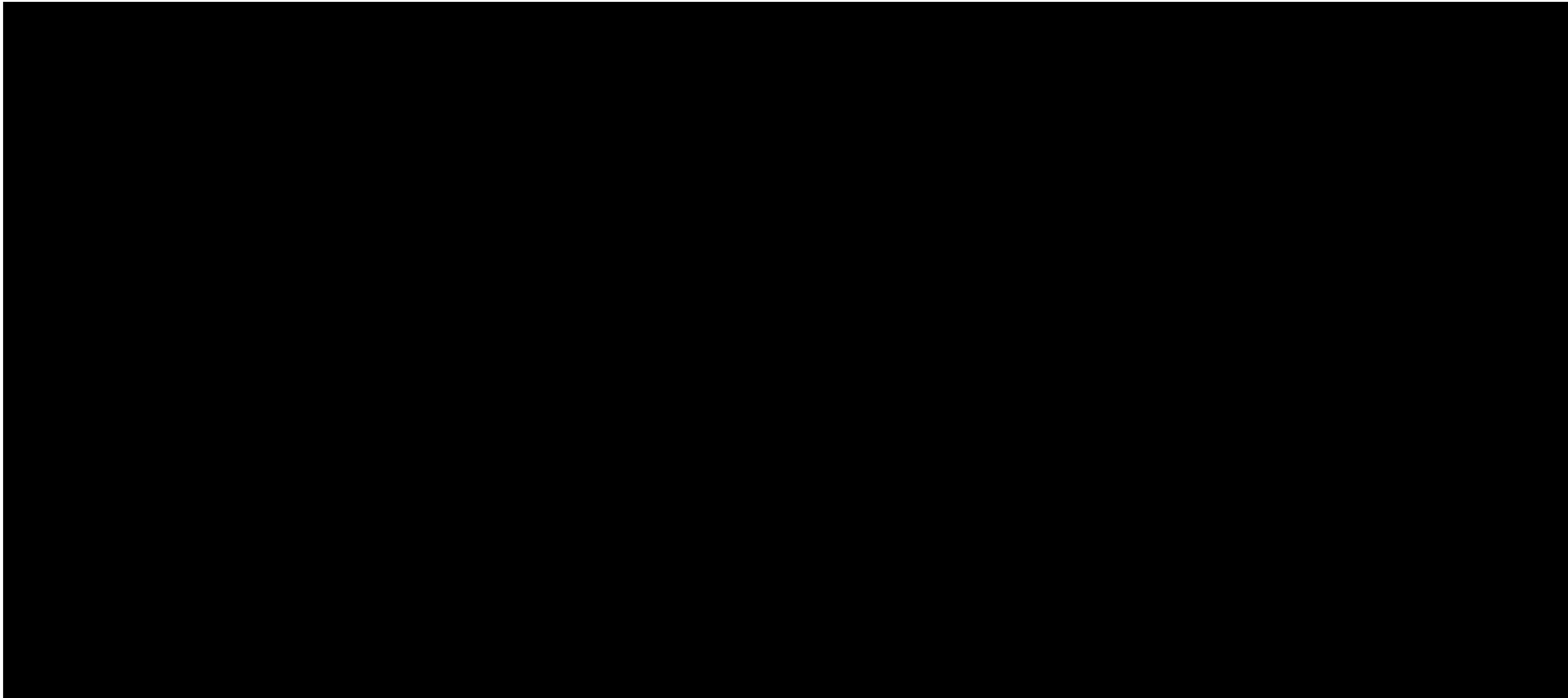


Baveye et al 2016, Frontiers in Environmental Science



'WHO' IS RESPONSIBLE FOR THE ECOSYSTEM SERVICES PROVIDED BY **SOILS**?

Keep soil alive – protect biodiversity (video)



Global changes

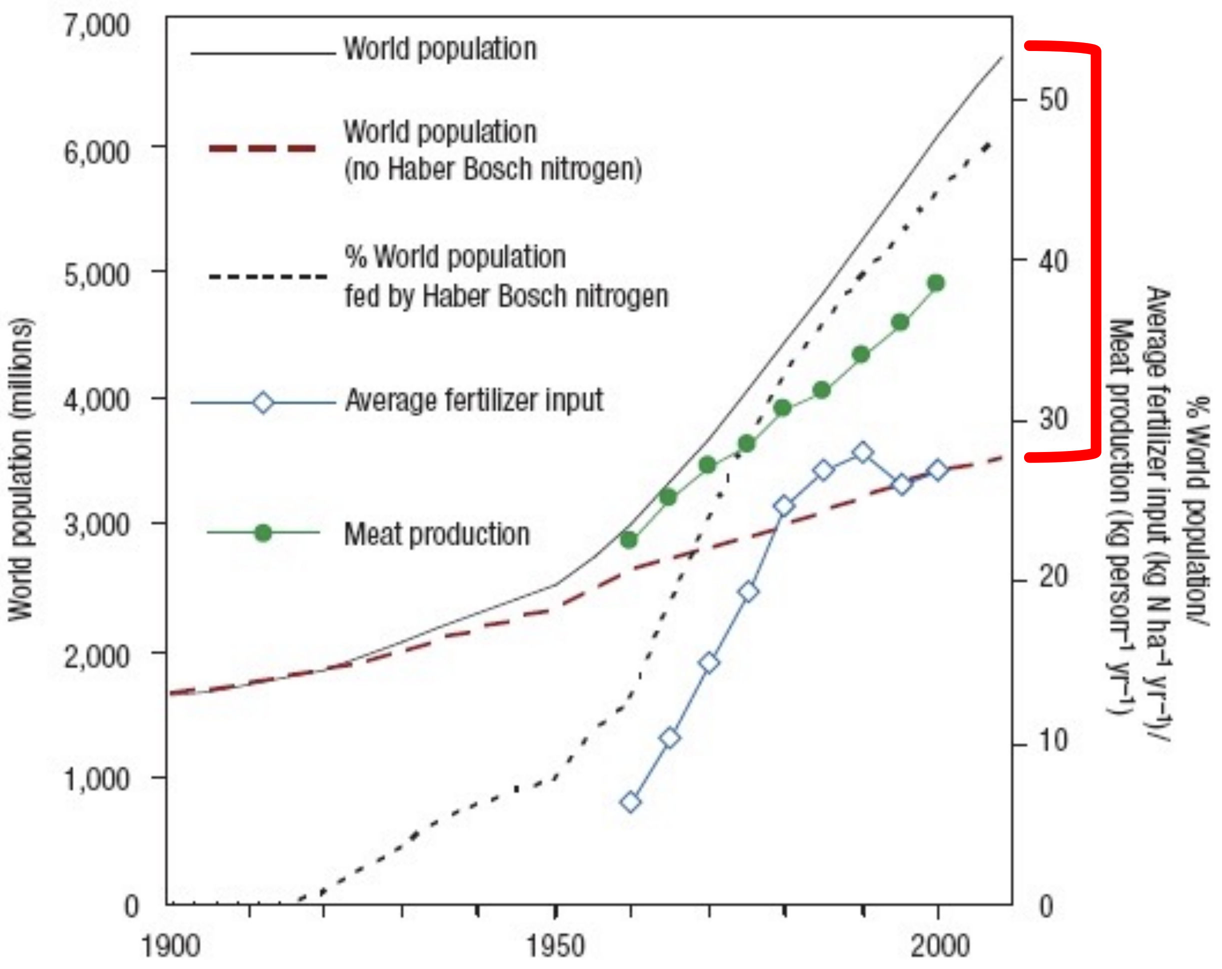
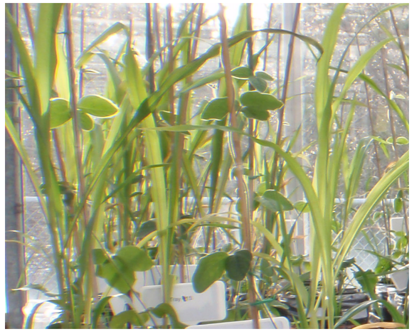
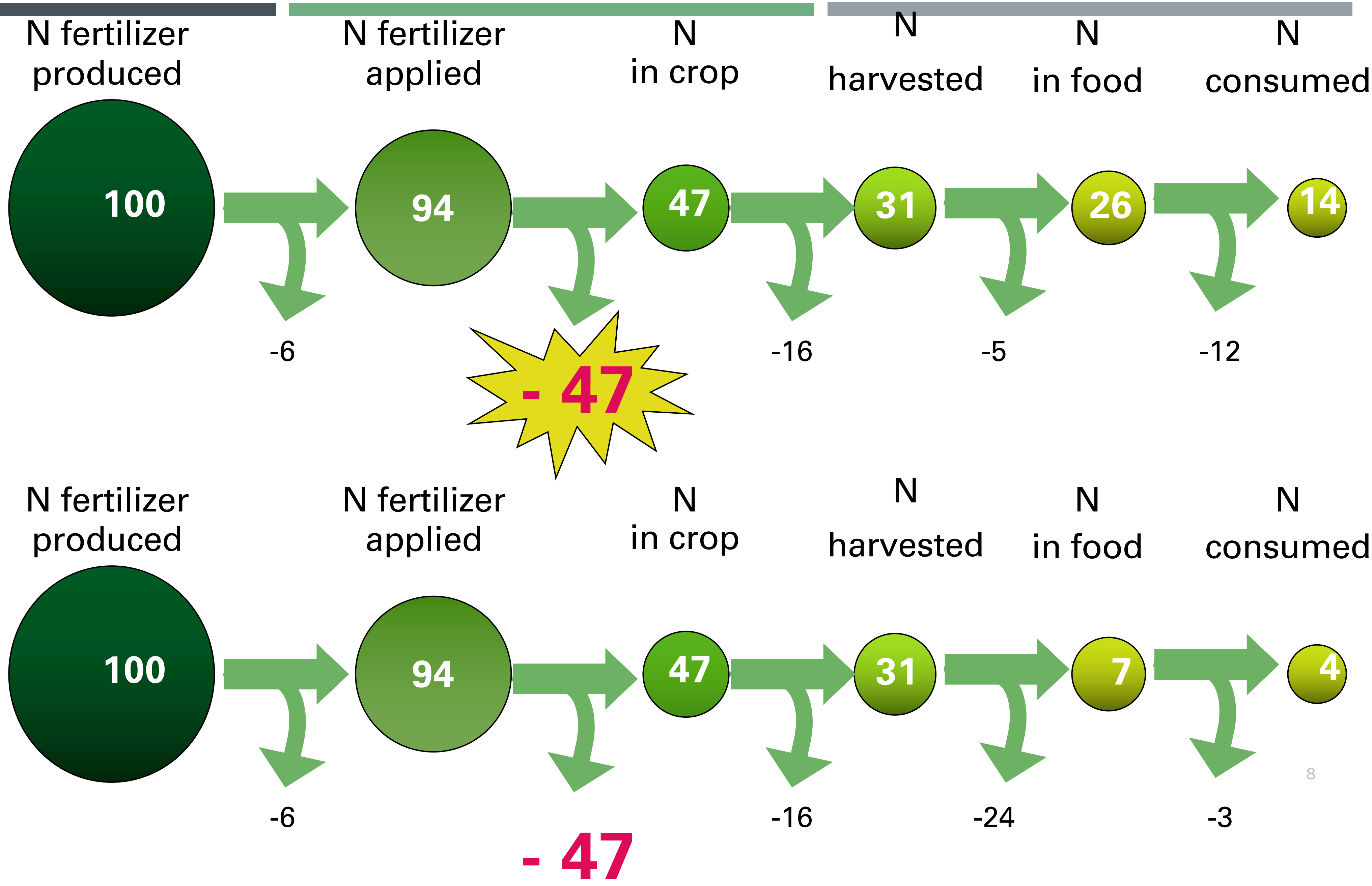


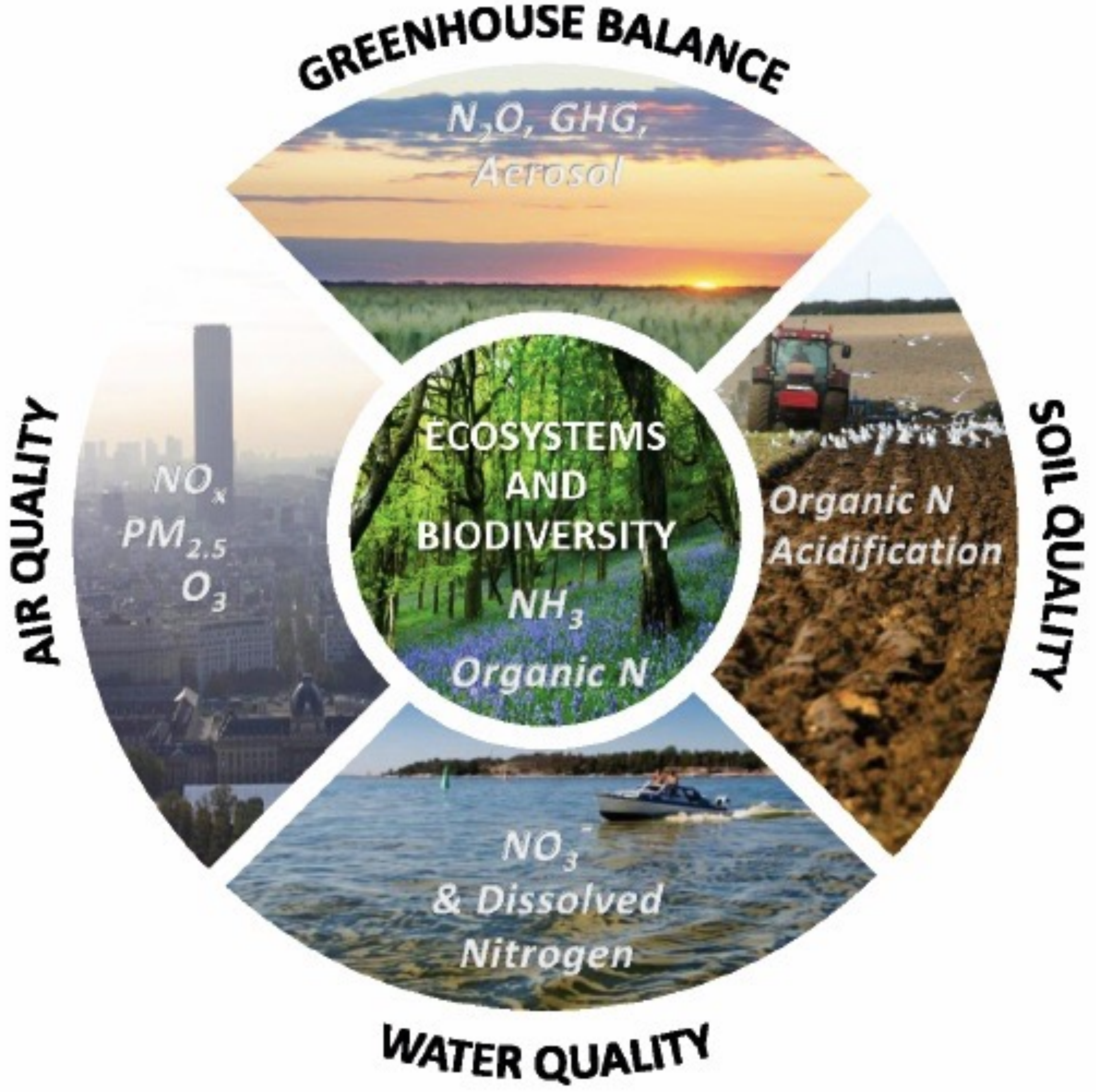
Figure 1 Trends in human population and nitrogen use throughout the twentieth century. Of the total world population (solid line), an estimate is made of the number of people that could be sustained without reactive nitrogen from the Haber–Bosch process (long dashed line), also expressed as a percentage of the global population (short dashed line). The recorded increase in average fertilizer use per hectare of agricultural land (blue symbols) and the increase in per capita meat production (green symbols) is also shown.





N fertilizer produced
N fertilizer applied
N in crop
N harvested
N in food
N consumed
100
94
47
31
26
14
-6
- 47
-16
-5
-12
N fertilizer produced
N fertilizer applied
N in crop
N harvested
N in food
N consumed
100
94
47
31
7
4
-6
- 47
-16
-24
-3

All the N losses cause negative impacts on:

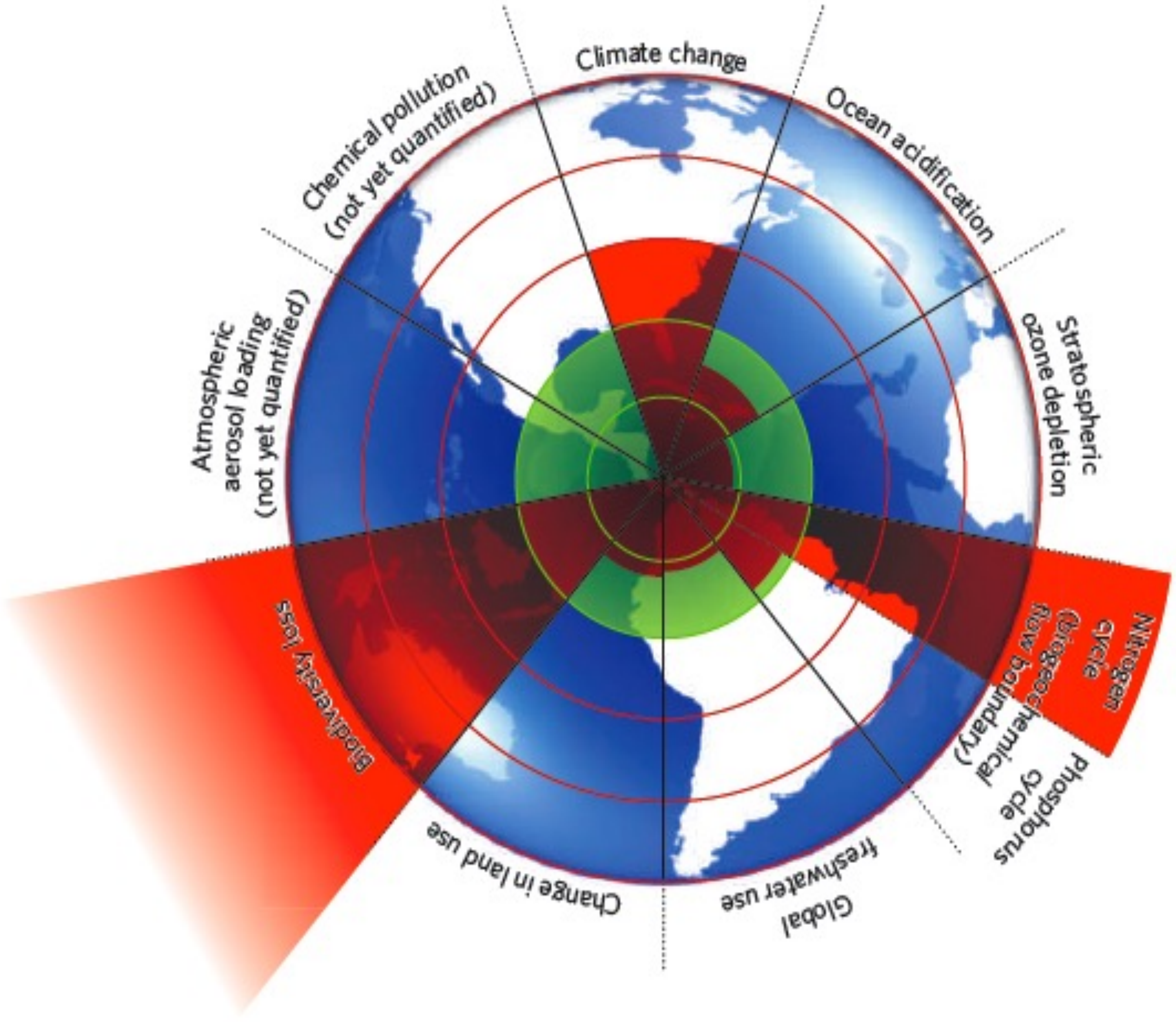


N pollution costs the European Union between €70 billion and €320 billion per year

Sutton et al, 2011, European Nitrogen Assessement


our Soils under threat
2015 International Year of Soils
fao.org/soils-2015
#IYS2015
Deforestation
Population growth
Urban expansion
Pollution and waste disposal
Climate change
Unsustainable soil management practices
Drivers of soil degradation
Biodiversity loss
Salinization and sodification
Nutrient imbalance
Compaction
Sealing
Pollution
Acidification
Erosion
Loss of organic carbon
Types of soil degradation
Water scarcity
Food and nutrition insecurity
Rapid climate change
Poverty and social insecurity
Migration
Reduction of ecosystem services
Consequences of soil degradation
Solution: sustainable soil management
Inclusive soil governance
Increase investment in sustainable soil management
Advocacy/ awareness raising
Establish soil information systems
Develop capacities and strengthen extension on soils
Stop soil degradation
Restore/ rehabilitate degraded soils
Implement land use planning
Analyse/ assess soil condition
Increase soil organic matter content
Keep soil surface covered
Use nutrients wisely
Minimum tillage
Crop rotation
Reduce erosion
Appropriate waste disposal
Waste water treatment
Food and Agriculture Organization of the United Nations
with the support of
Land Development Department of Thailand

Global changes



Rockström et al 2009

SOIL DEGRADATION:

1. It is a key process for the stability of the Earth system (soil is key for ecosystem services provision and for achieving the UN Sustainable Development Goals)
2. Has the potential to cause unacceptable environmental change (e.g., erosion, contamination, loss of organic C)
3. Is caused by human activity (e.g., agriculture, deforestation, urbanization)
4. Shows tipping point behaviour when forced beyond a critical level (soil restoration is so slow that soil is considered a non-renewable resource for our timescale)
5. Is relevant on both local and global scales (already affects 3.2 billion people and in 2050, 90% of soils will be degraded)
6. Is strongly interrelated with the other Earth system processes (e.g., biodiversity loss, changes in N and P cycles, climate change)

Kraamwinkel et al 2021

Communication Earth & Environment

SUSTAINABLE DEVELOPMENT GOALS

Inherent to the **SOCIETAL CHALLENGES**, we need to **produce more with less resources and causing less impacts**

SUSTAINABLE TECHNOLOGIES

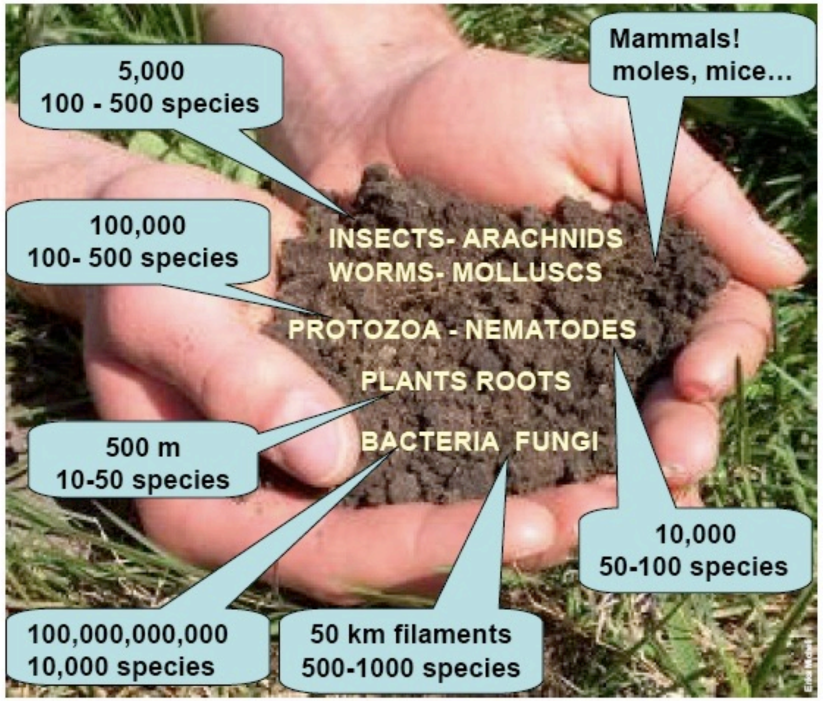
- **We are currently faced with the need to develop / implement technologies to help agriculture produce food in a sustainable and socially responsible manner.**

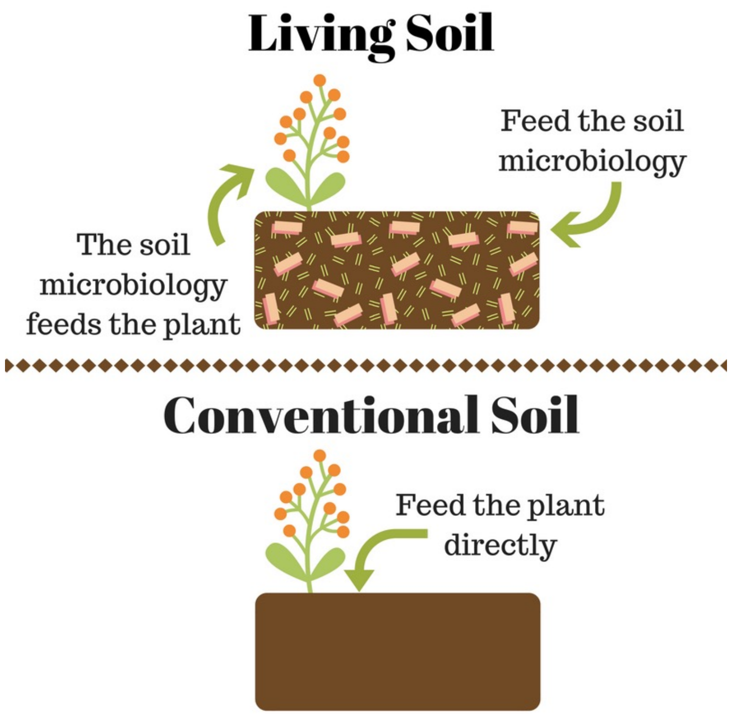
‘NEW’ SUSTAINABLE TECHNOLOGIES

- Examples:
- **PRECISION AGRICULTURE**: refers to a set of techniques that allow localized crop management. It is characterized by the application of various forms of fertilizers, pesticides and other inputs, according to the needs of the different areas of the same farm. Today, with the availability of microcomputers, sensors and terrestrial or satellite tracking systems, Precision Agriculture has become commonplace on many farms, contributing to the sustainability of agriculture.
- **CROP IMPROVEMENT**: aims to develop more productive and / or more tolerant varieties to factors of biotic stress (e.g. pathogens, pests) and abiotic (e.g. resistance to water stress, greater efficiency in the acquisition of nutrients). This improvement can be by traditional methods or by genetic engineering.
- **BIOFERTILIZERS**: products that contain soil microorganisms and that promote plant growth (Herrmann and Lesueur, 2013).
- **NANOTECHNOLOGY**, etc.

‘OLD’ SUSTAINABLE TECHNOLOGIES

- Examples:
- **FALLOW**: ‘rest’ of cultivated land to make the soil more fertile and to control 'weeds' and pathogens that cause pests.
- **CROP ROTATION**: alternate crops in a given agricultural area to decrease soil depletion and control 'weeds' and pathogens that cause pests. The crops used must have different characteristics and as a whole contribute to soil recovery and productivity.
- **CROP IMPROVEMENT**: based on Mendelian inheritance concepts ONLY and for that reason the selection and recombination of plants with characters of interest is made.
- **MANURE/ORGANIC MATTER AMENDMENTS**: nutrient addition and microbial inoculation.
- **REDUCED OR EVEN NO-TILLAGE**: allows maintaining soil structure (both physical and biological).

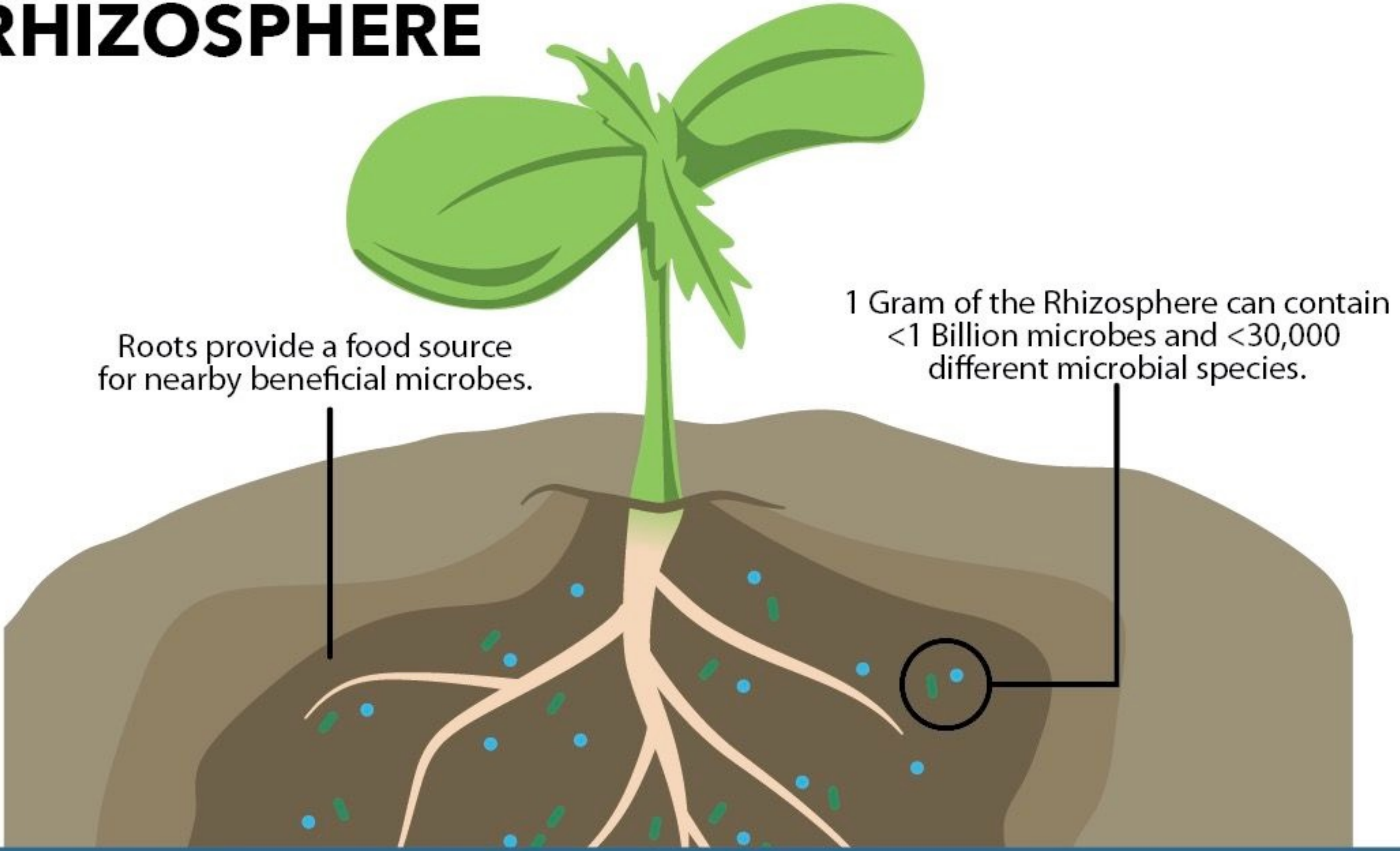




Manipulate biotic interactions (e.g. plant-animal, plant-microbe, microbe-microbe) to deliver the desired services and thus reduce or eliminate the need for external inputs which is essential for sustainable agriculture.

The challenge is to favour positive interactions and at the same time reduce negative interactionsas.

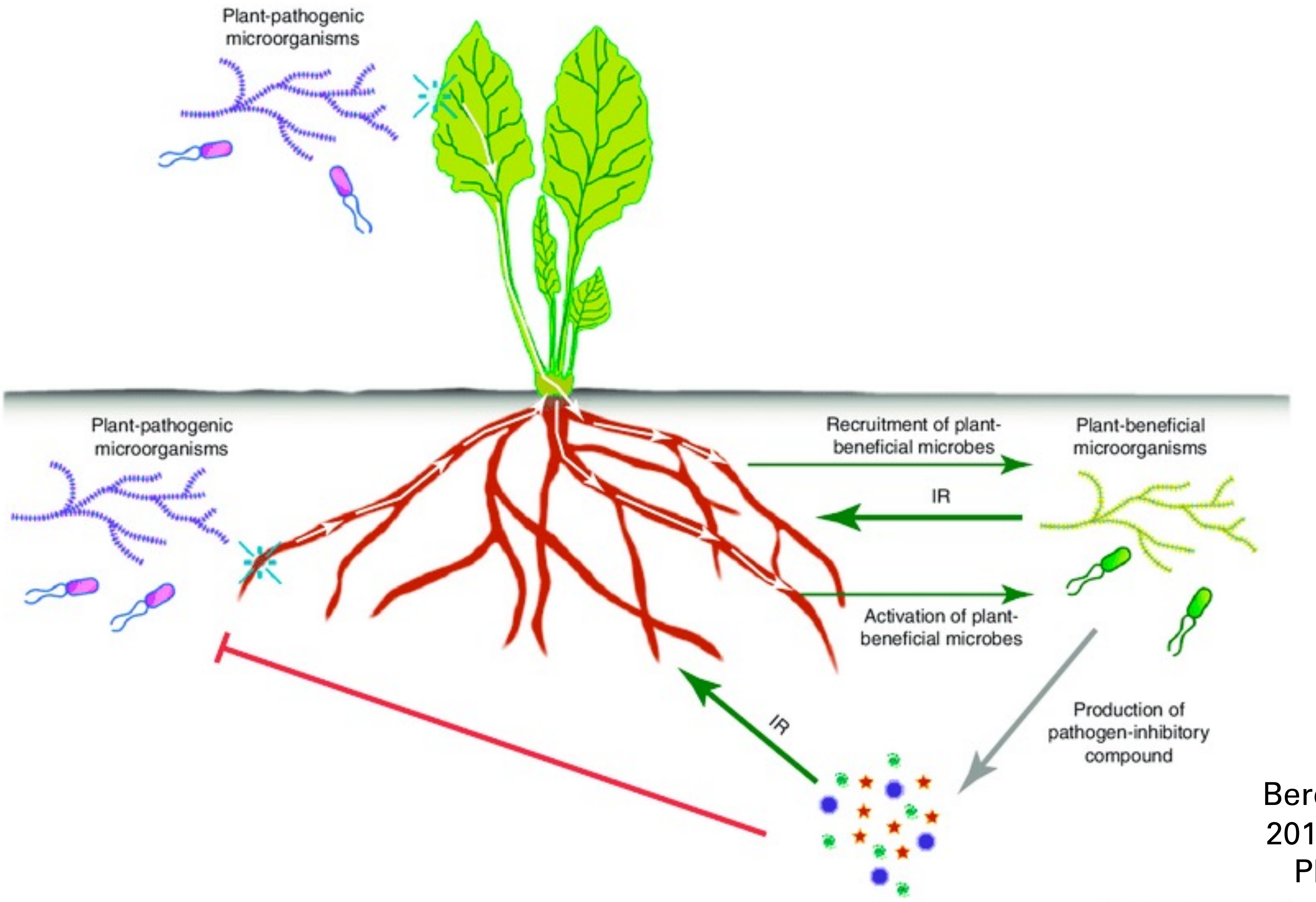
RHIZOSPHERE



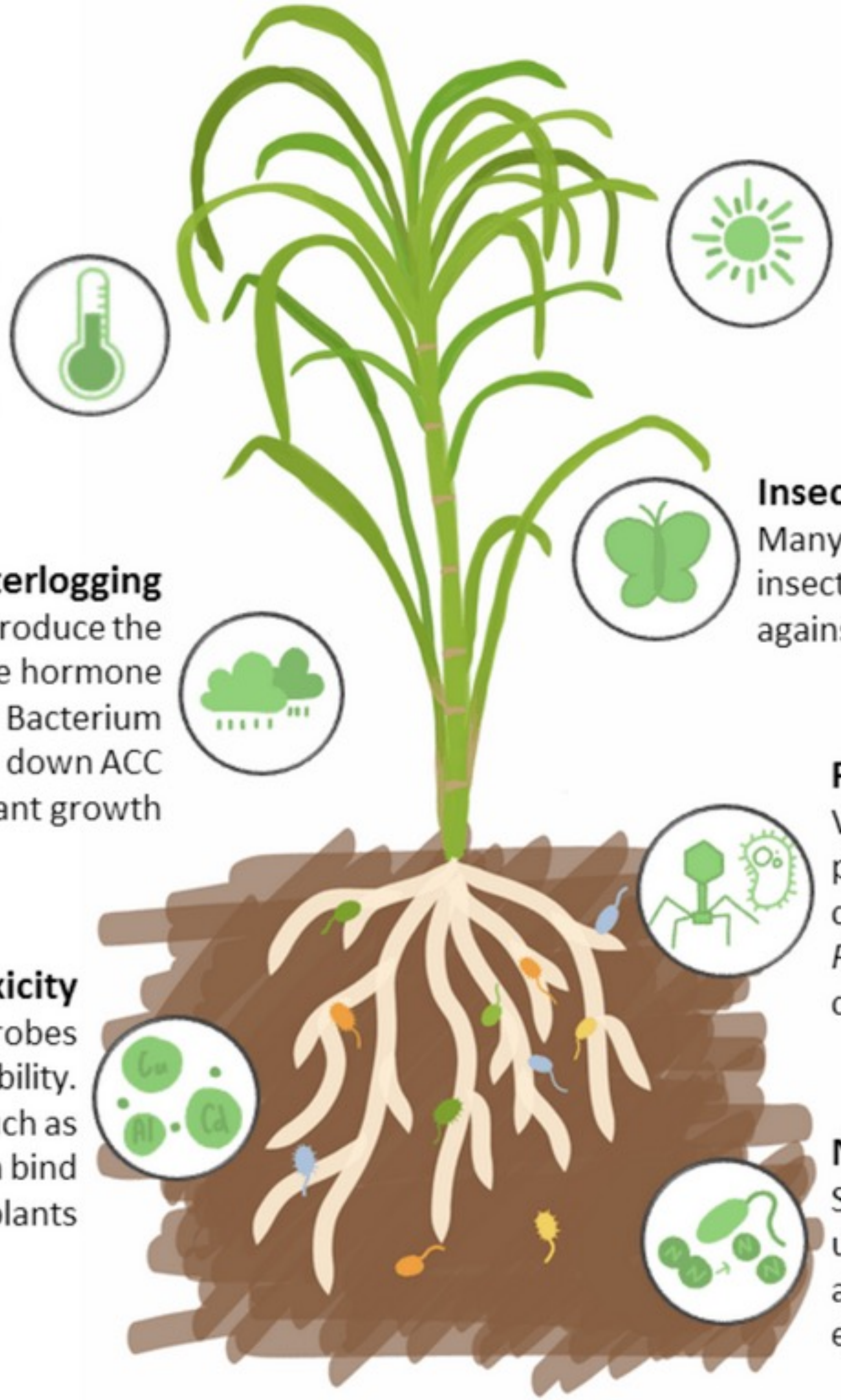
PATHOGENIC
Causes infection and creates
a harmful environment

BENEFICIAL
Supplies beneficial nutrients
Enhances root growth
Repels pests and disease

COMMENSAL
Creates a healthier plant
by balancing the plant's
ecosystem



Berendsen et al
2012, Trends in
Plant Science



Temperature
Some soil microbes are very tolerant to harsh environments. *Pseudomonas putida* can significantly enhance growth of wheat under heat stress

Waterlogging
Under stressful conditions plants produce the chemical substance ACC, a precursor to the hormone ethylene which stunts plant growth. Bacterium *Serratia* produces an enzyme that breaks down ACC which results in better plant growth

Mineral toxicity
Some salt or heavy metal resistant microbes can enhance plant growth and survivability. Siderophore producing bacteria, such as *Microbacterium* and *Pseudomonas*, can bind heavy metals and reduce toxicity to plants

Drought
Some *Bacillus subtilis* strains produce cytokinin, a plant hormone that interferes with drought induced suppression of shoot growth thereby enhancing plant growth throughout periods of drought

Insects
Many *Pseudomonas* and *Bacillus* isolates have insecticidal activity and can prime plants against insect attack

Pests and pathogens
Various bacteria including *Pseudomonas fluorescens*, produce antibiotic compounds like pyrrolnitrin, which confers resistance to various fungal pathogens such as *Rhizoctonia solani* which causes damping-off disease in cotton

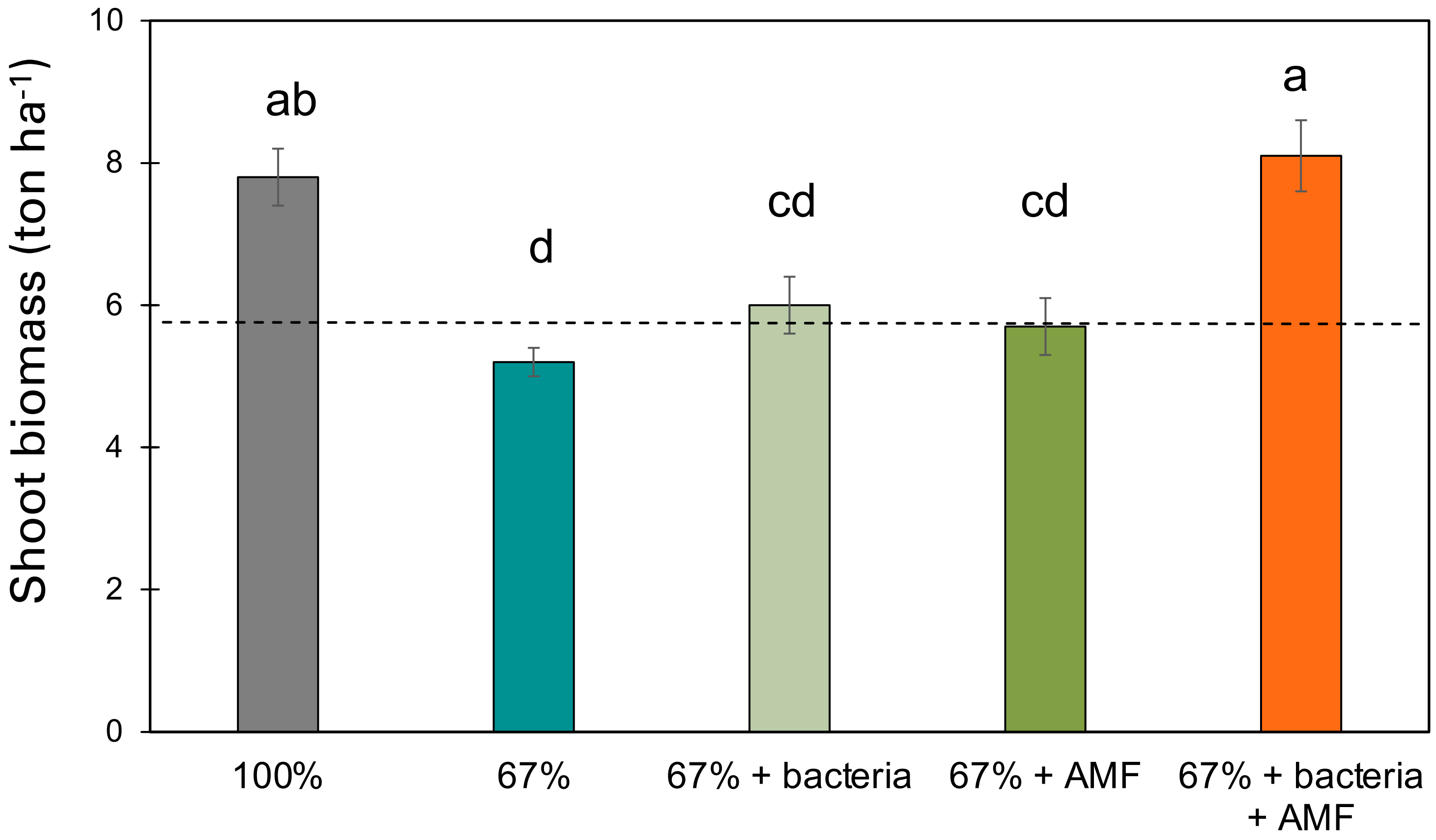
Nutrient limitation
Some microbes can access nutrients that are unavailable to plants including atmospheric nitrogen and organic phosphorus. The best understood example is the rhizobia-legume symbiosis

RECONCILING SUSTAINABLE TECHNOLOGIES WITH ECOSYSTEM SERVICES

EXAMPLES


BIOFERTILIZERS

BIOFERTILIZERS (SUSTAINABLE TECHNOLOGY) & FOOD PRODUCTION (ECOSYSTEM SERVICE)



Bacteria = plant growth promoting bacteria

AMF = arbuscular mycorrhizal fungi

The inoculation of the **microbial consortium** was able to compensate the reduction of **1/3 of the fertilizer**

Dias et al, unpublished

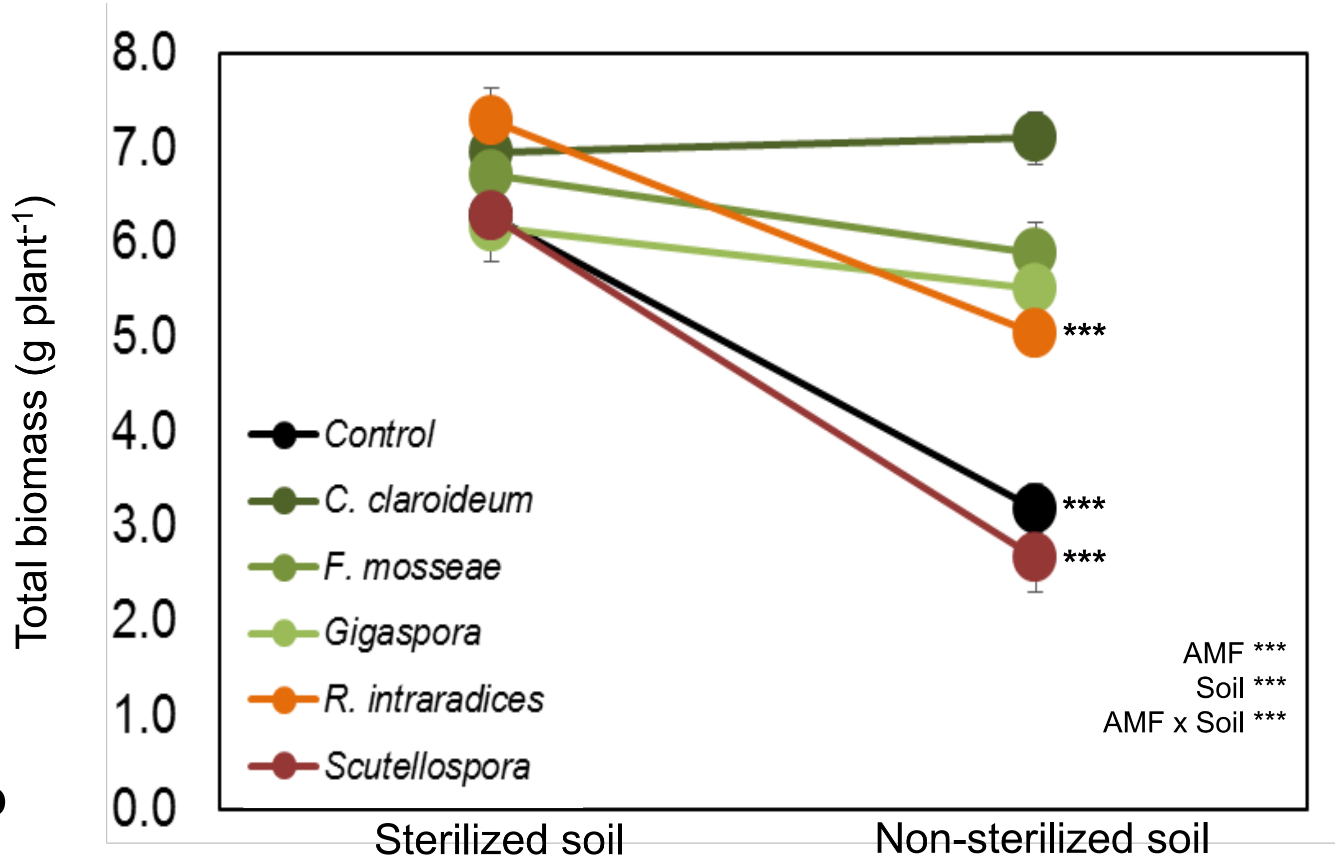
WHAT ARE MYCORRHIZA AND WHY ARE THEY IMPORTANT FOR PLANTS?

https://www.youtube.com/watch?v=v88gbtKBTv4

BIOFERTILIZERS (SUSTAINABLE TECHNOLOGY) & FOOD PRODUCTION (ECOSYSTEM SERVICE)

Maize monocropping under field conditions

Pretrained soil microbial community



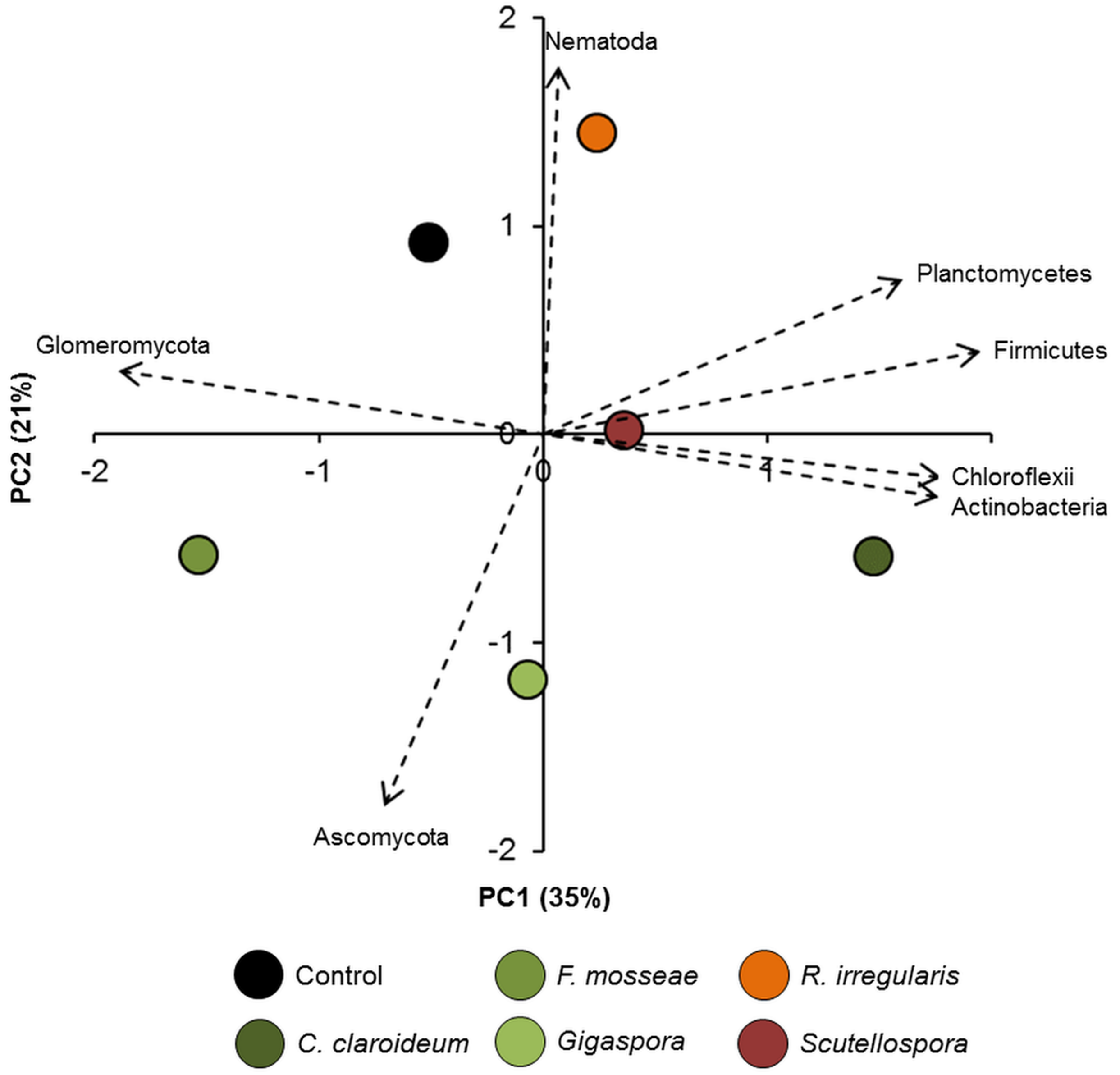
Some AMF isolates were **capable** to overcome the negative effects of monoculture.

Dias et al 2018, Applied Soil Ecology

BIOFERTILIZERS (SUSTAINABLE TECHNOLOGY) & PEST CONTROL (ECOSYSTEM SERVICE)

The different AMF isolates socialized differently with the rest of the soil microbial community.

Some isolates were able to **keep the nematodes away** from the plant's roots.



Dias et al 2018, Applied Soil Ecology

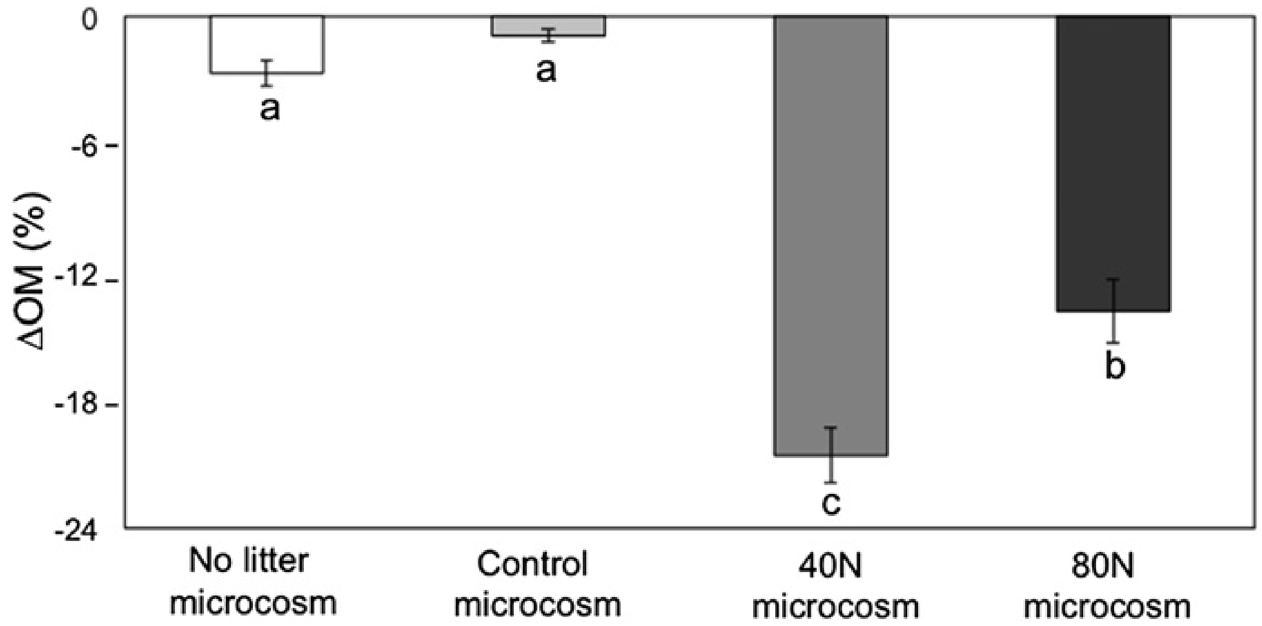

Food Discharges
Animal Manures
Industrial Discharges
ORGANIC SOIL AMENDMENTS
Municipal Wastes
Composts
Green Manures

ORGANIC SOIL AMENDMENT – LITTER (SUSTAINABLE TECHNOLOGY) & DECOMPOSITION (ECOSYSTEM SERVIVE)

Depending on the composition and quality (in terms of lignin, nitrogen, etc.), the incorporation of organic matter can:

Stimulate (example 40AN)
Inhibit (example 80AN)
Have no effect (example control)

On organic matter decomposition



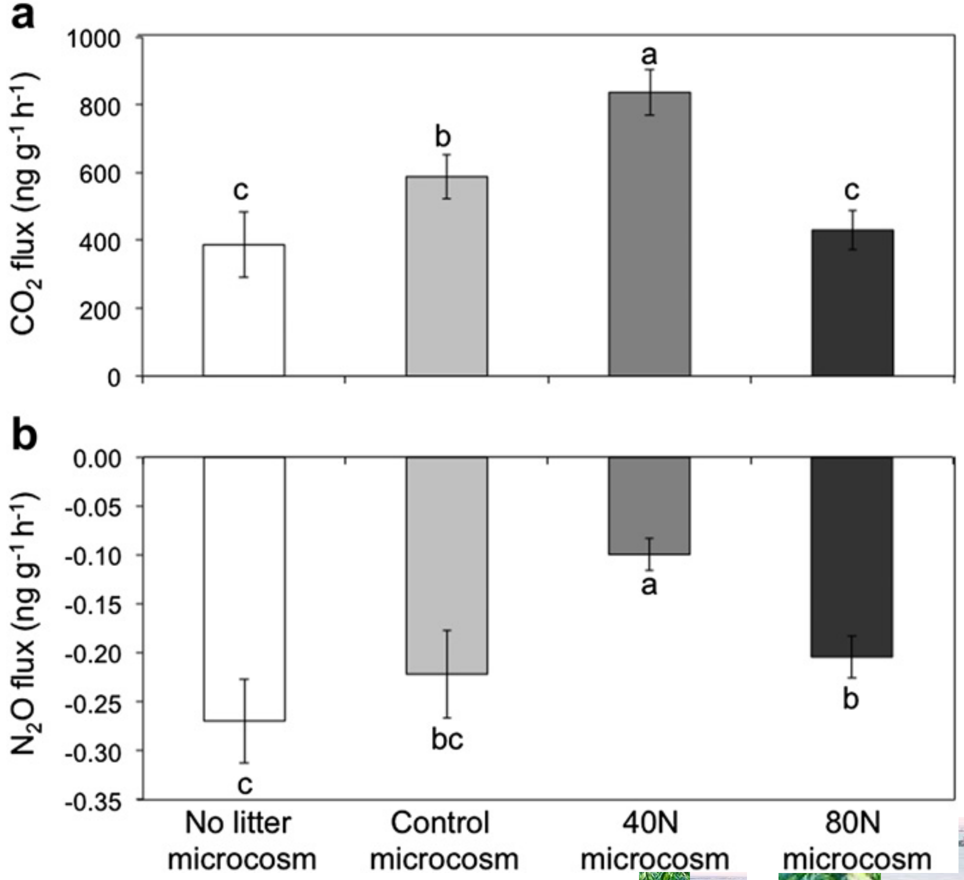
Dias et al 2013, Soil Biology and Biochemistry

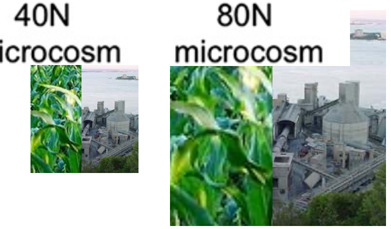
ORGANIC SOIL AMENDMENT – LITTER (SUSTAINABLE TECHNOLOGY) & GHG EMISSIONS REGULATION (ECOSYSTEM SERVIVE)

Depending on the composition and quality (in terms of lignin, nitrogen, etc.), the incorporation of organic matter can:

Increase CO_2 emissions
Reduce soil capacity to sequester N_2O

(example 40AN)





Dias et al 2013, Soil Biology and Biochemistry

ORGANIC SOIL AMENDMENT – COMPOST (SUSTAINABLE TECHNOLOGY) & BIOMASS PRODUCTION (ECOSYSTEM SERVIVE)

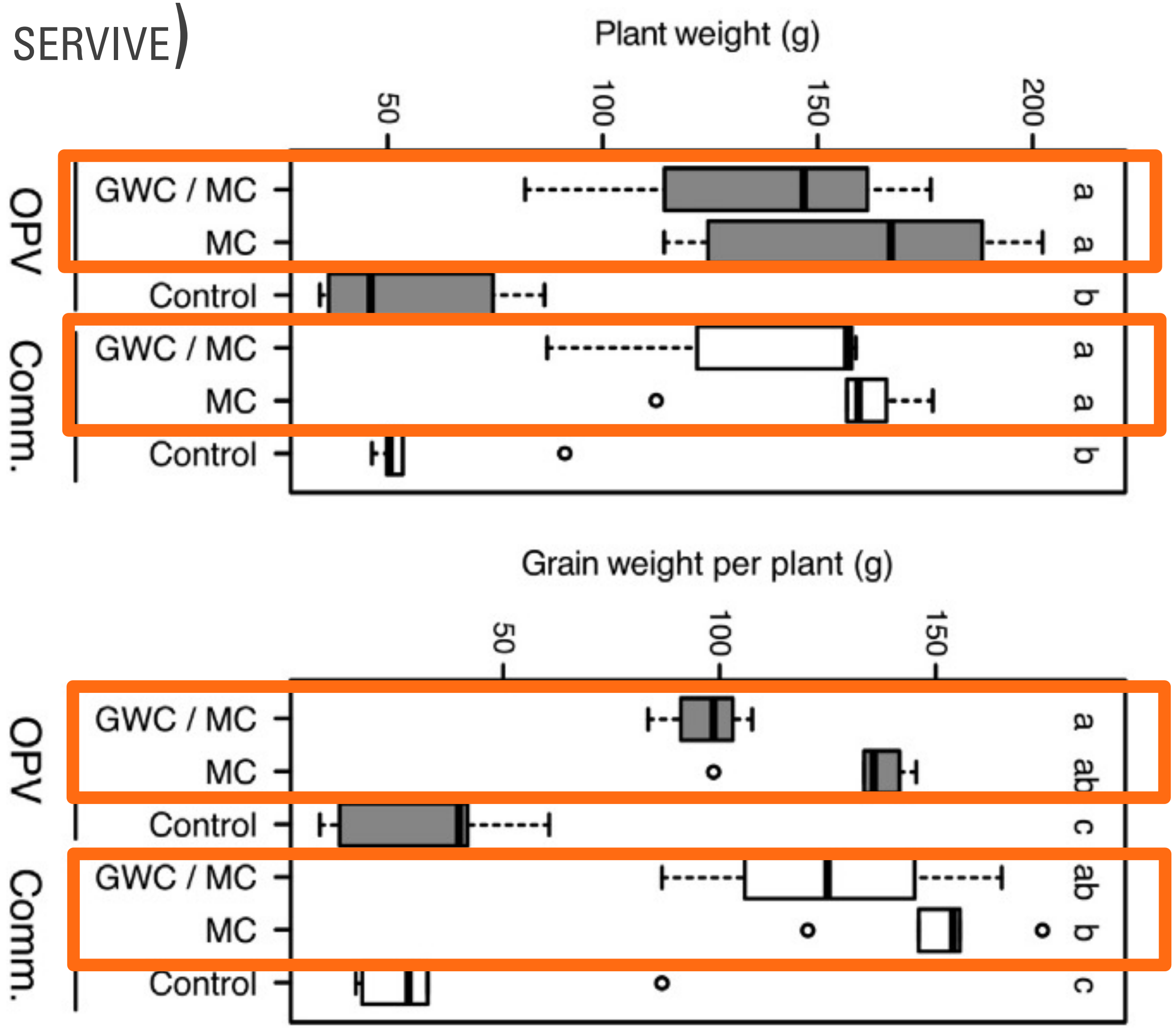
Adding organic matter
(MC and GWC / MC)

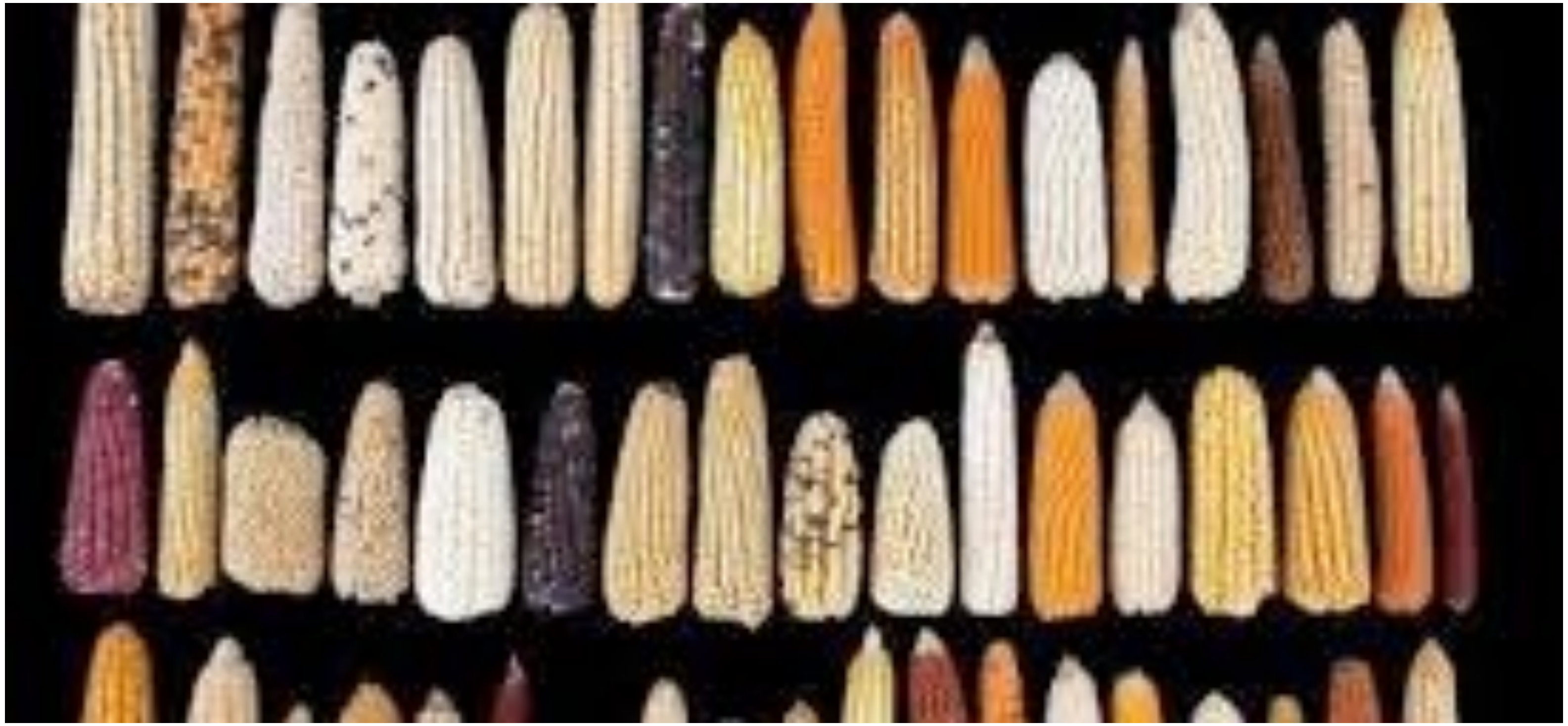
Increased production per plant
Increased grain production per plant

Regardless of the variety of maize used

MC - derived from food waste anaerobically digested for biogas production and then composted using wood chips as a bulking agent;
GWC - was prepared on site from Acacia longifolia plant material .

Ulm et al 2019, Journal of Cleaner Production





SELECTING CROP VARIETIES

CROP VARIETIES (SUSTAINABLE TECHNOLOGY) & FOOD QUALITY (ECOSYSTEM SERVICE)

The ancestral variety guaranteed

Higher food quality in terms of macro and micronutrients

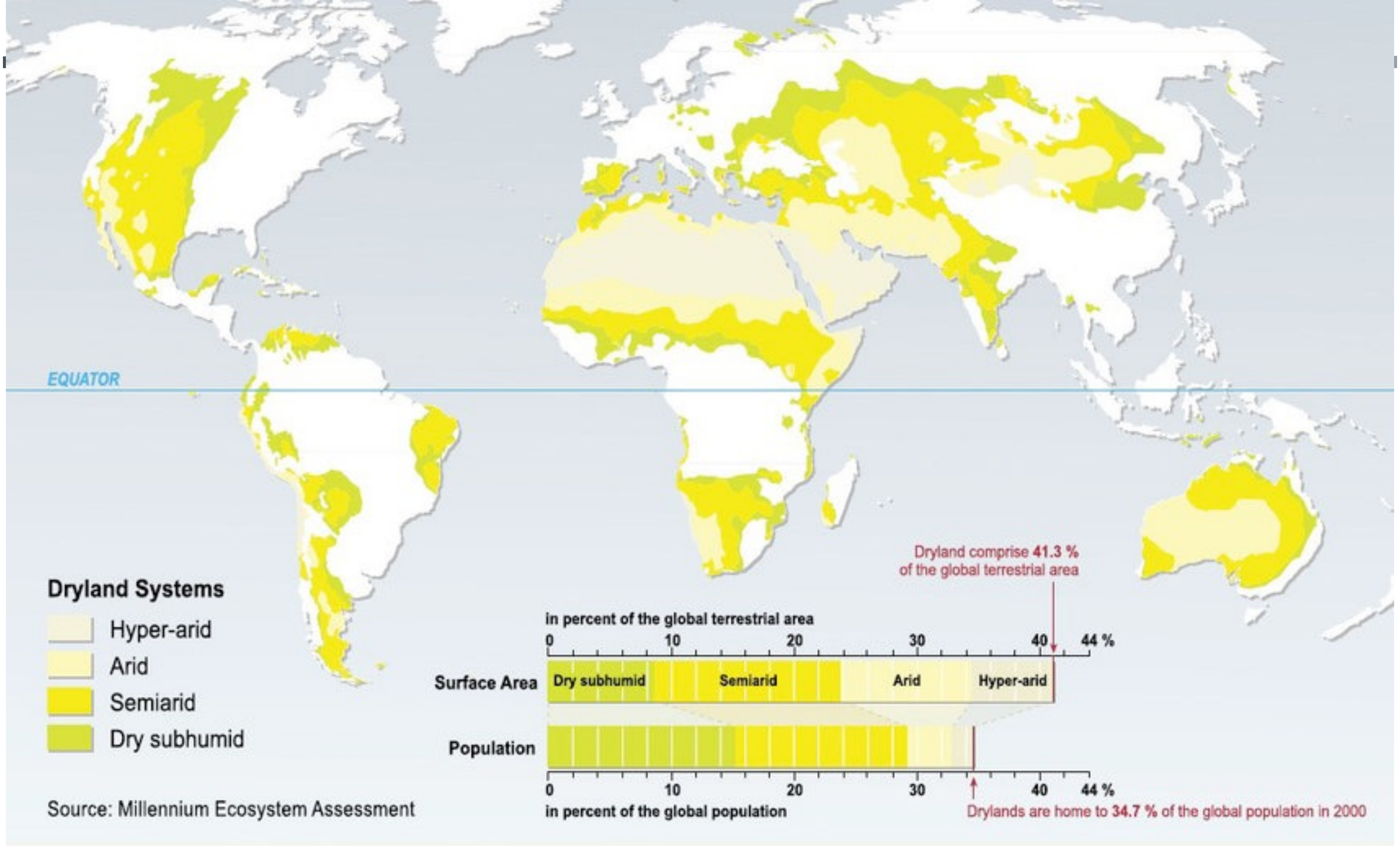
Regardless of the availability of nutrients in the soil

Adapted from Ulm et al 2019, Journal of Cleaner Production

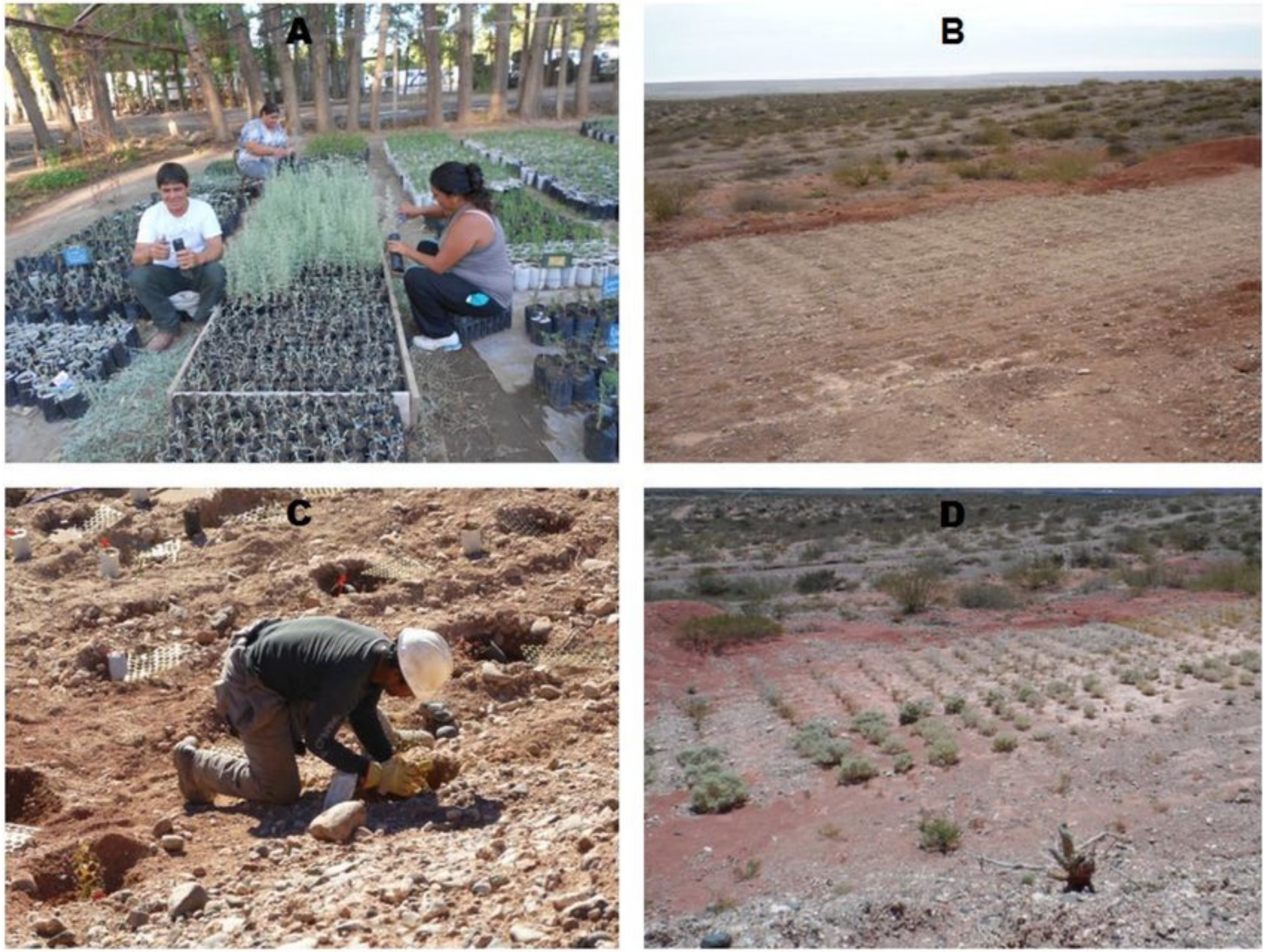
Nutrient (µg g-1)	Ancestral variety	Commercial variety
N *	**14200**	**9800**
**P ** **	**4000**	**2700**
**K ** **	**5300**	**3700**
S	1000	800
Mg *	**1600**	**1000**
Ca	100	90
B *	**2,4**	**1,9**
**Mn ** **	**19**	**12**
**Zn ** **	**50**	**26**
Fe *	**32**	**22**
**Cu ** **	**3.2**	**1.8**
**Mo ** **	**0.2**	**0.0**
Ni *	**0.2**	**0.5**

ASSESSING MULTIPLE ECOSYSTEM SERVICES SIMULTANEOUSLY

EXAMPLE


EQUATOR
Dryland Systems
Hyper-arid
Arid
Semiarid
Dry subhumid
Source: Millennium Ecosystem Assessment
Dryland comprise 41.3 %
of the global terrestrial area
in percent of the global terrestrial area
0
10
20
30
40
44 %
Surface Area
Dry subhumid
Semiarid
Arid
Hyper-arid
Population
in percent of the global population
Drylands are home to 34.7 % of the global population in 2000

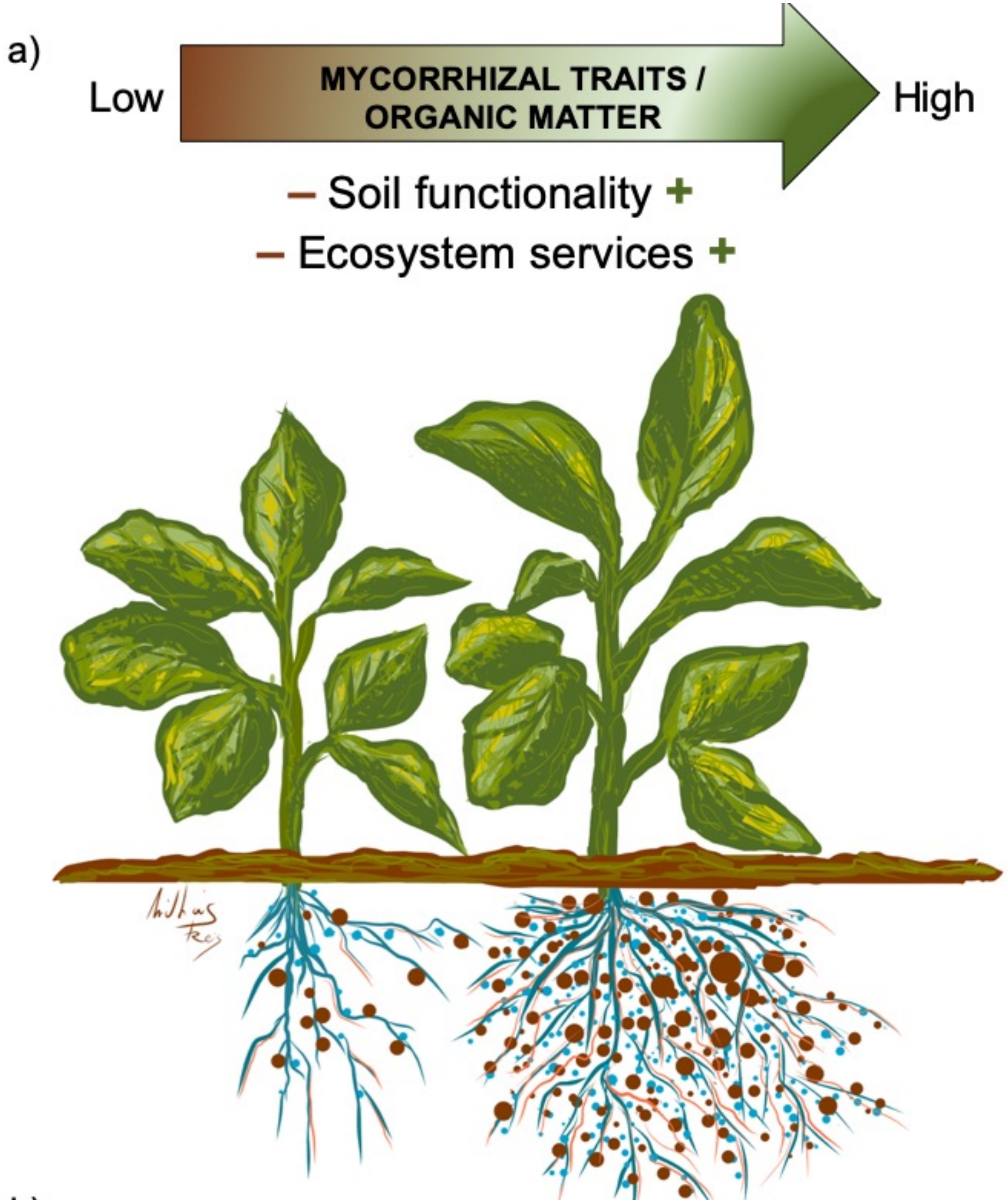
When ecological restoration is possible/needed



Pérez et al, 2019

- Which plant species to use?
- Native/exotic
- How to select them?
- Importance of plant functional traits

So far, **belowground functional traits** have not been considered



Mahmoudi et al, 2021 Geoderma

We tested the use of arbuscular mycorrhizal traits

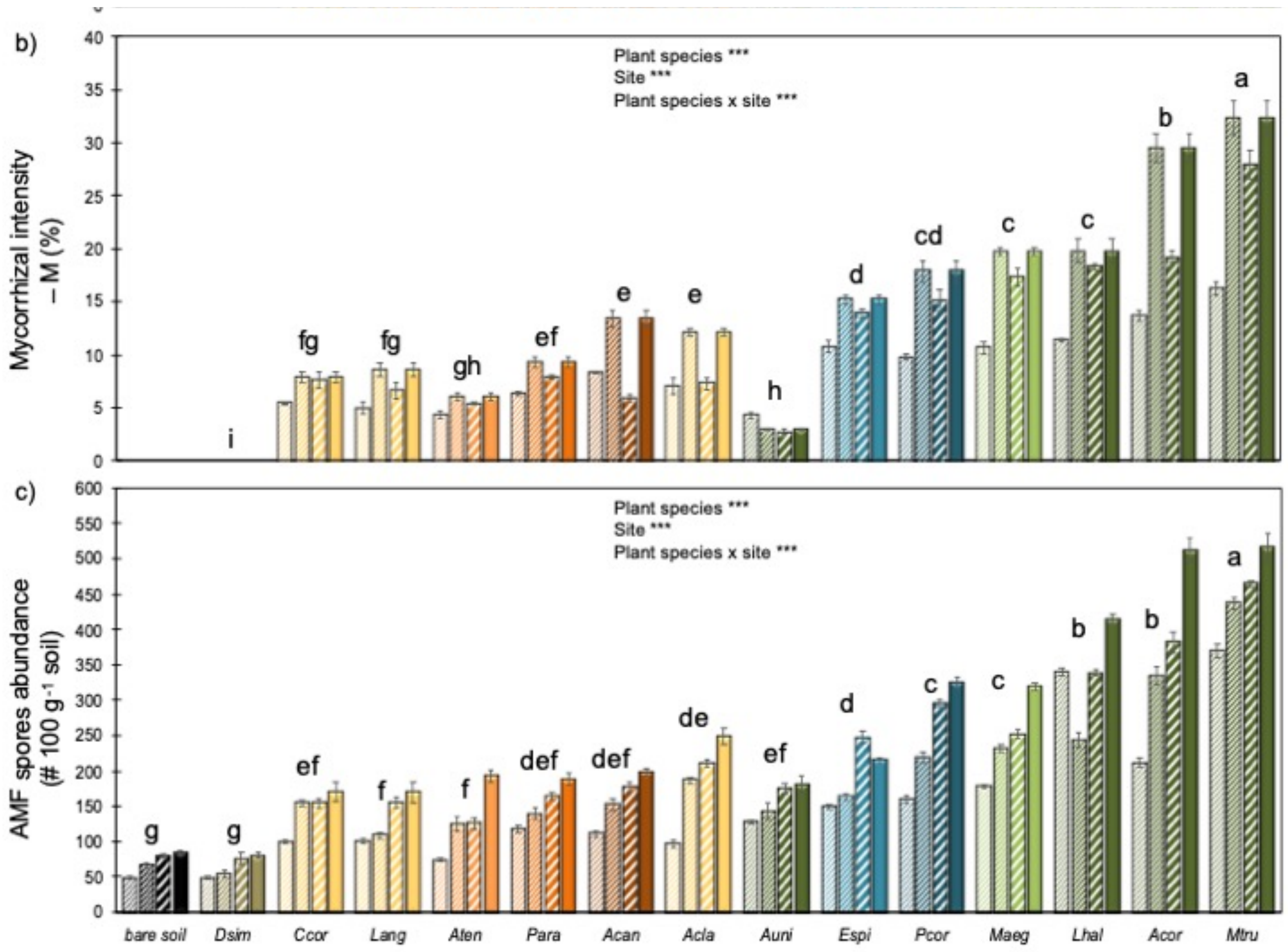
Soil organic matter gradient

0.9 % | 1.1 % | 1.4 % | 1.9 %

Native herbaceous plant speciesas

Family	Plant species	Abbreviation
Asteraceae	*Anacyclus clavatus* (Desf.) Pers.	Acla
	Chrysanthemum coronarium L.	Ccor
	Launaea angustifolia (Desf.) O.Kuntze	Lang
Aizoaceae	*Aizoon canariense* L.	Acan
Brassicaceae	*Diplotaxis simplex* Asch. ex Rohlfs	Dsim
Caryophyllaceae	*Paronychia arabica* (L.) DC.	Para
Fabaceae	*Argyrolobium uniflorum* (Decne.) Jaub. & Spach	Auni
	Astragalus corrugatus Bertol.	Acor
	Lotus halophilus Boiss.et Spruner	Lhal
	Medicago truncatula Gaertn.	Mtru
Malvaceae	*Malva aegyptiaca* L.	Maeg
Plantaginaceae	*Plantago coronopus* L.	Pcor
Polygonaceae	*Emex spinosa* (L.) Campd.	Espi
Xanthorrhoeaceae	*Asphodelus tenuifolius* Cav.	Aten

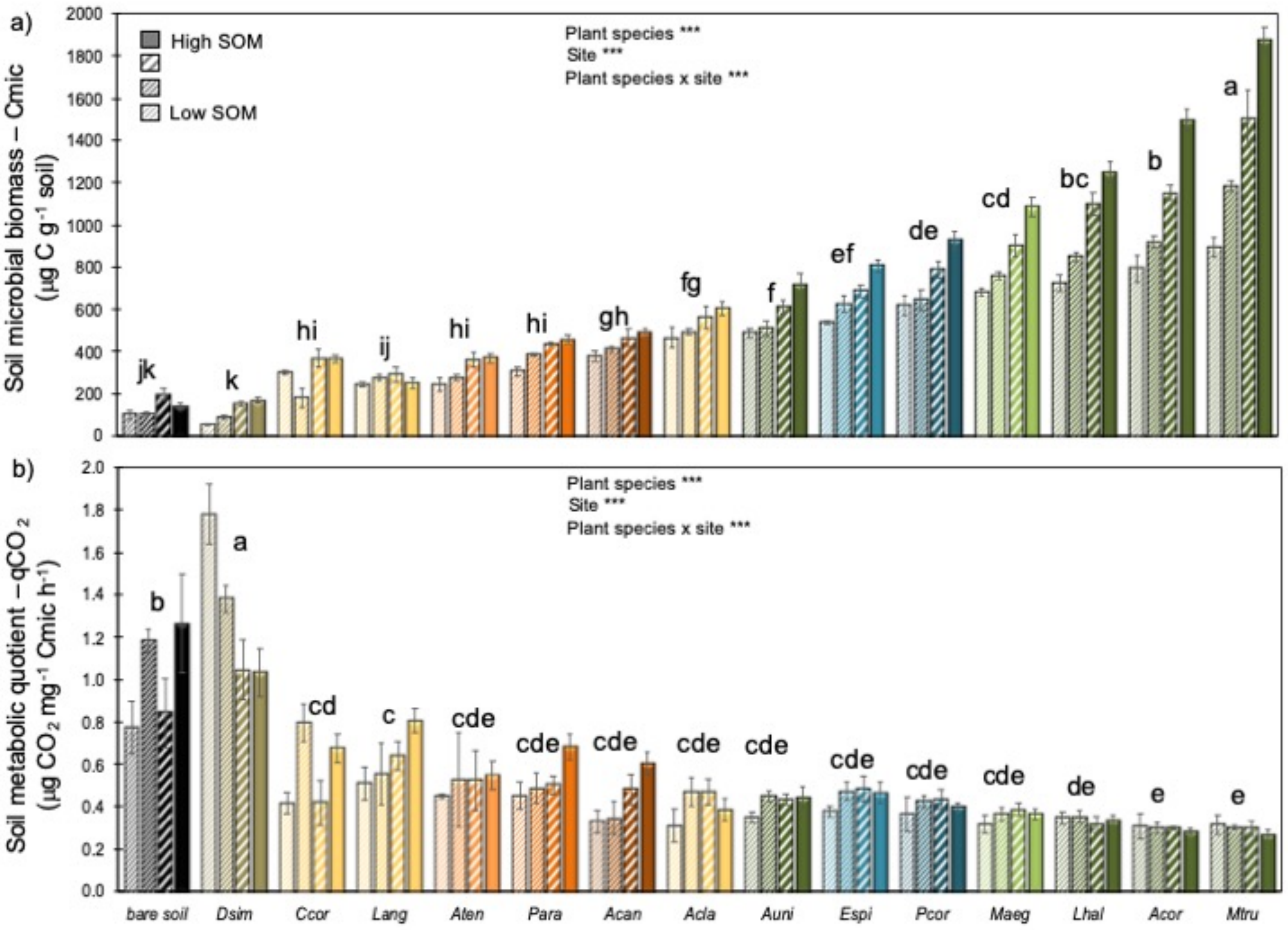
Arbuscular mycorrhizal traits



- All plant species were AMF-mycorrhized except *Diplotaxis simplex;*
- There was a gradient in terms of mycorrhization;
- The number of AMF spores under *D. simplex* was as low as under bare soil.

Mahmoudi et al, 2021 Geoderma

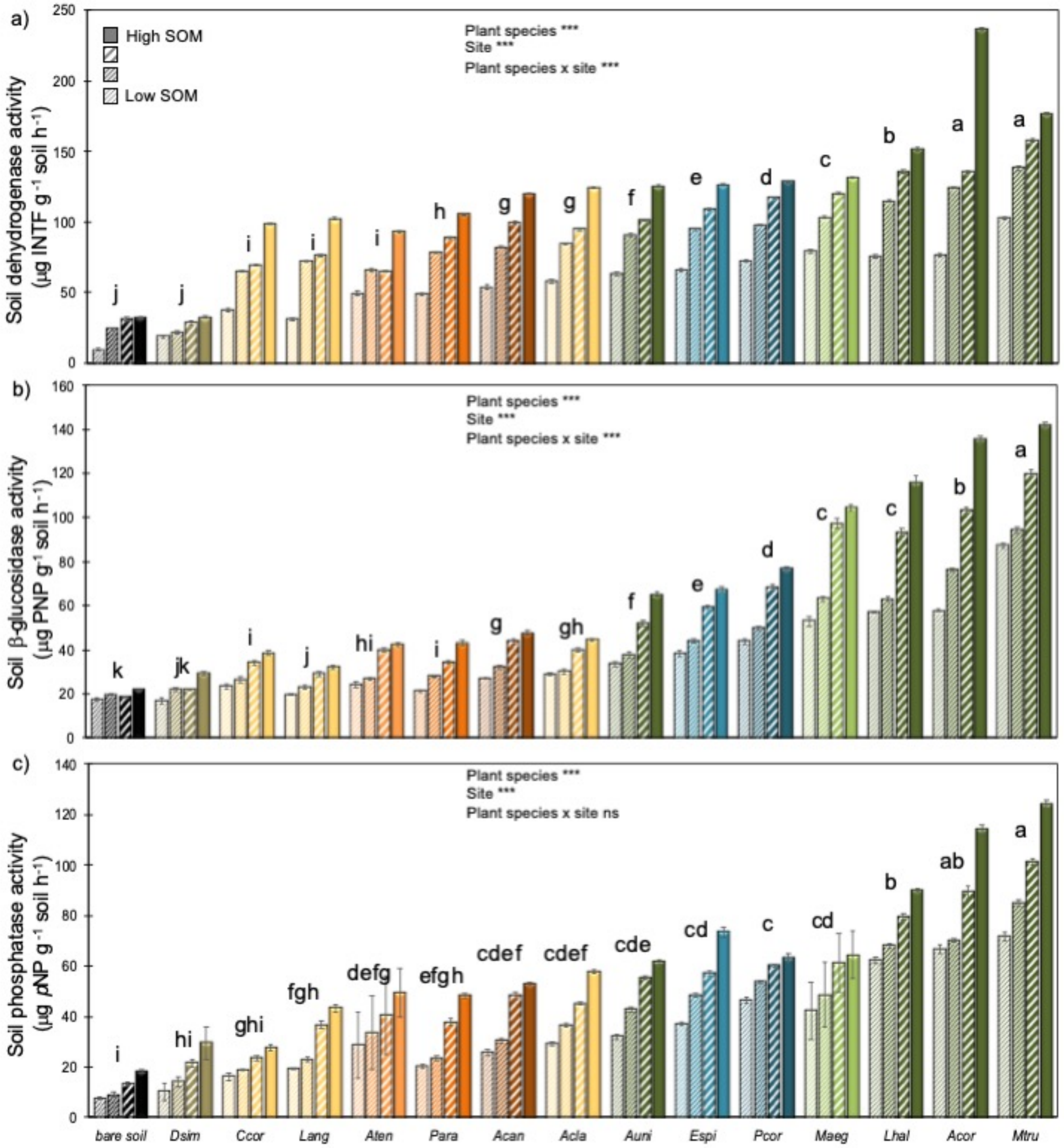
Soil microbial community functionality



- **The plant species that 'mycorrhized the most' (> AMF intensity and > AMF spores) showed > microbial biomass and > metabolic efficiency;**

- **Microbial biomass and metabolic efficiency under *D. simplex* were as low as in bare soil.**

Mahmoudi et al, 2021
Geoderma



Soil microbial community functionality

dehydrogenase is a measure of the metabolic state of soil microbes;

β-glucosidase is involved in C cycling and is one of the limiting steps in cellulose degradation;

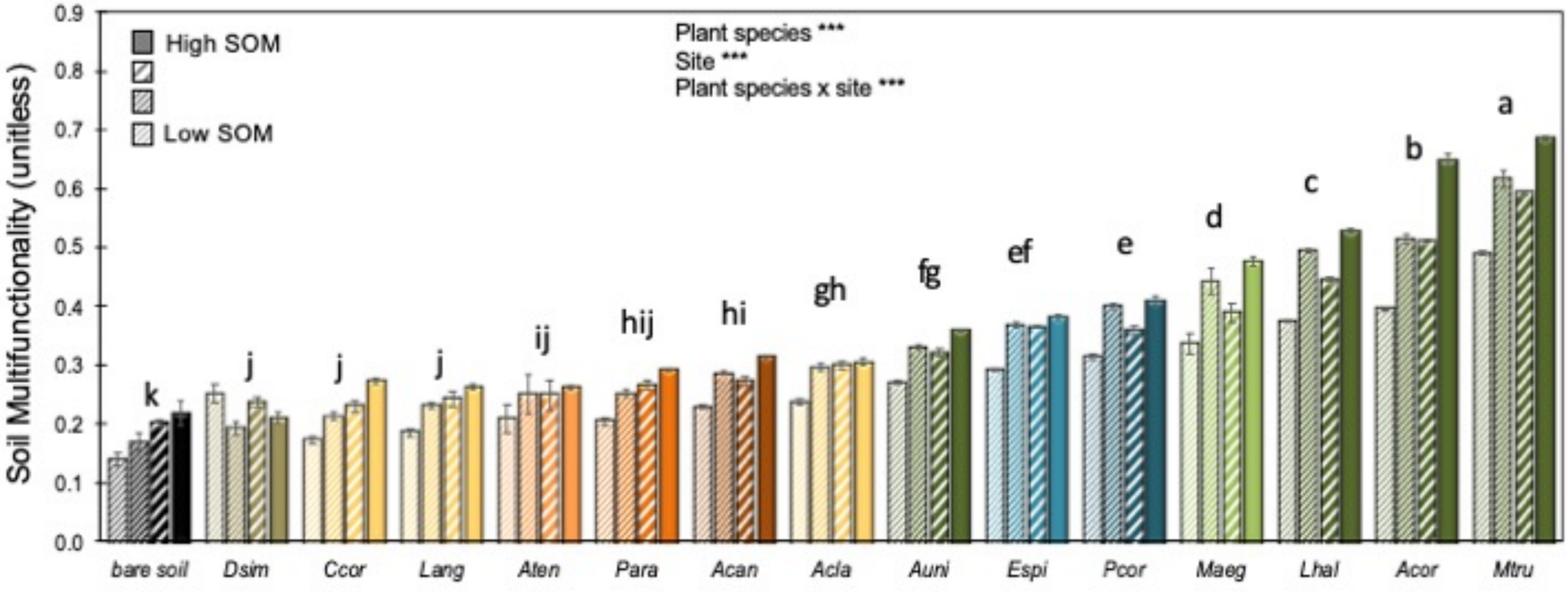
Phosphatase belongs to a group of enzymes involved in P cycling (P is a limiting nutrient);

- **The plant species that 'mycorrhized the most' showed enzymatic activities;**
- **Enzymatic activities under *D. simplex* were as low as in bare soil.**

Mahmoudi et al, 2021
Geoderma

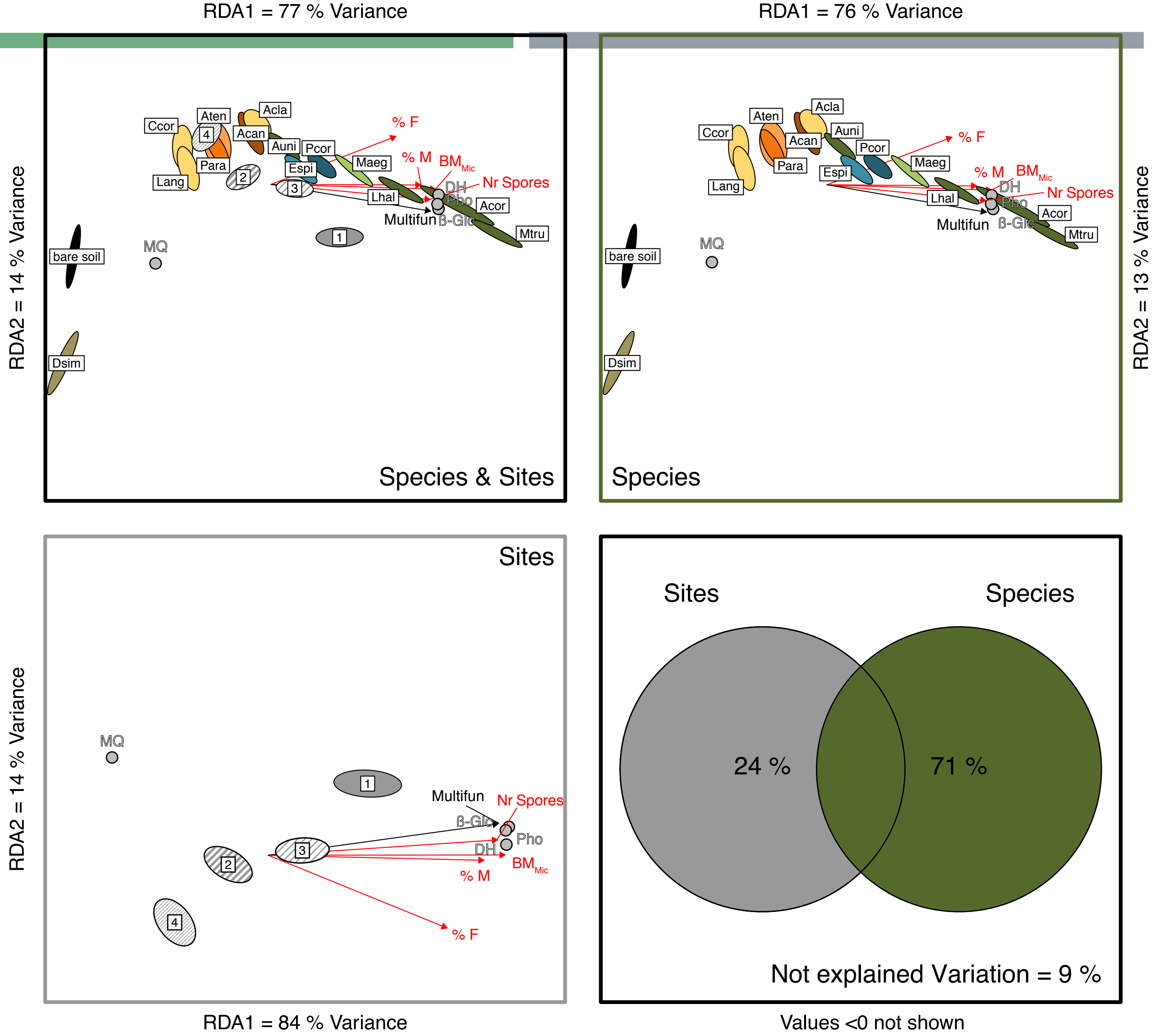
Soil Multifuncionality = (function $_1$ + function $_1$ + … + function $_n$) / n

Delgado-Baquerizo et al., 2016

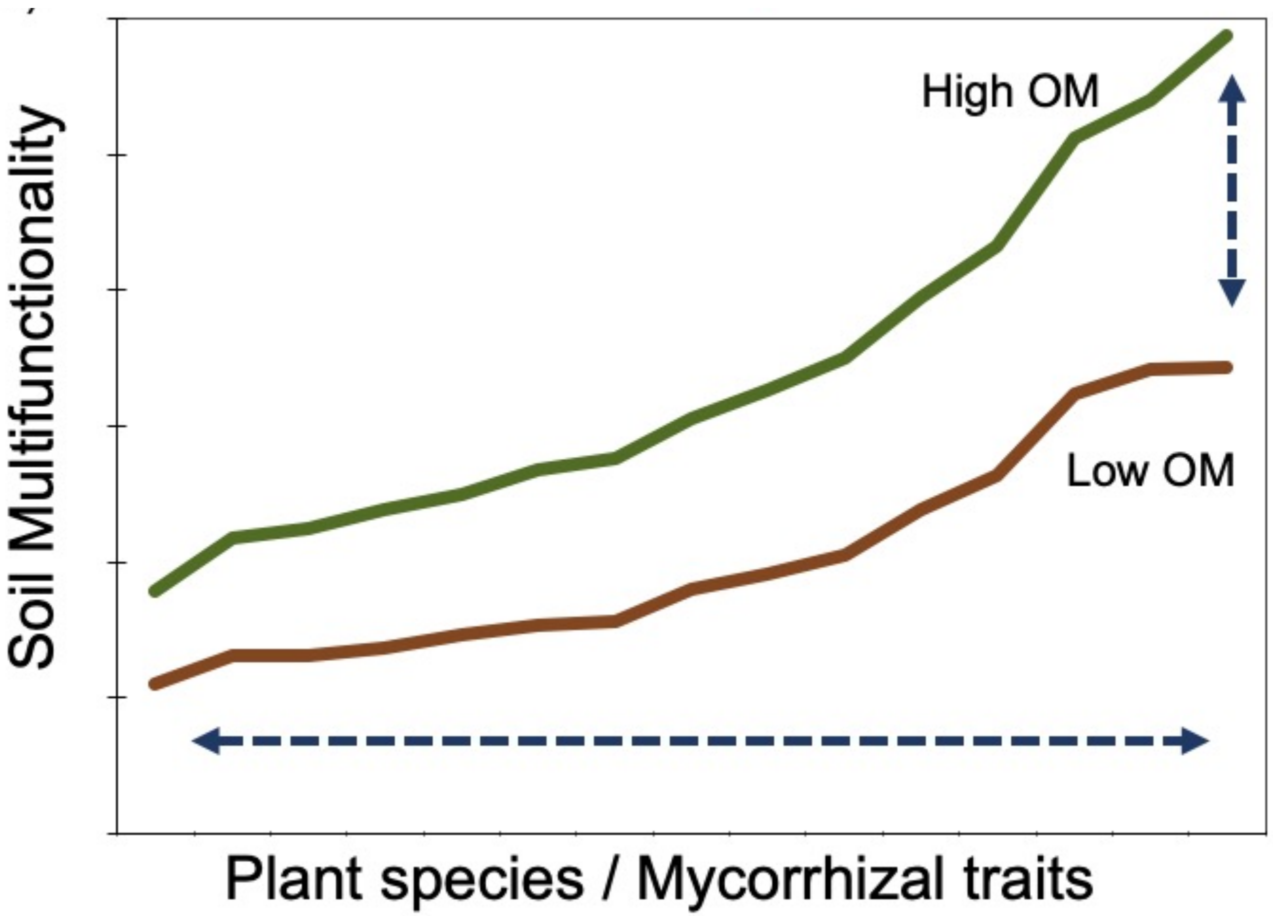


Mahmoudi et al, 2021, Geoderma

AMF traits can be good indicators of soil functionality in drylands

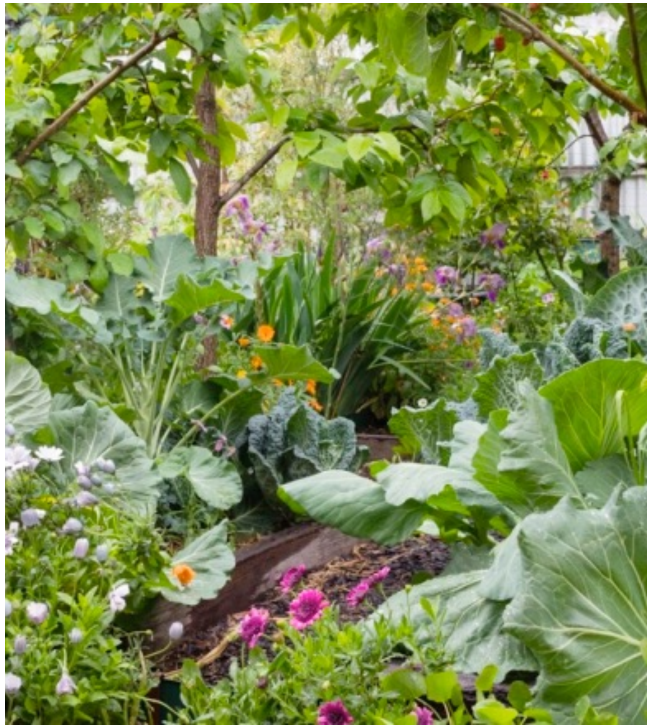


Mahmoudi et al,
2021, Geoderma

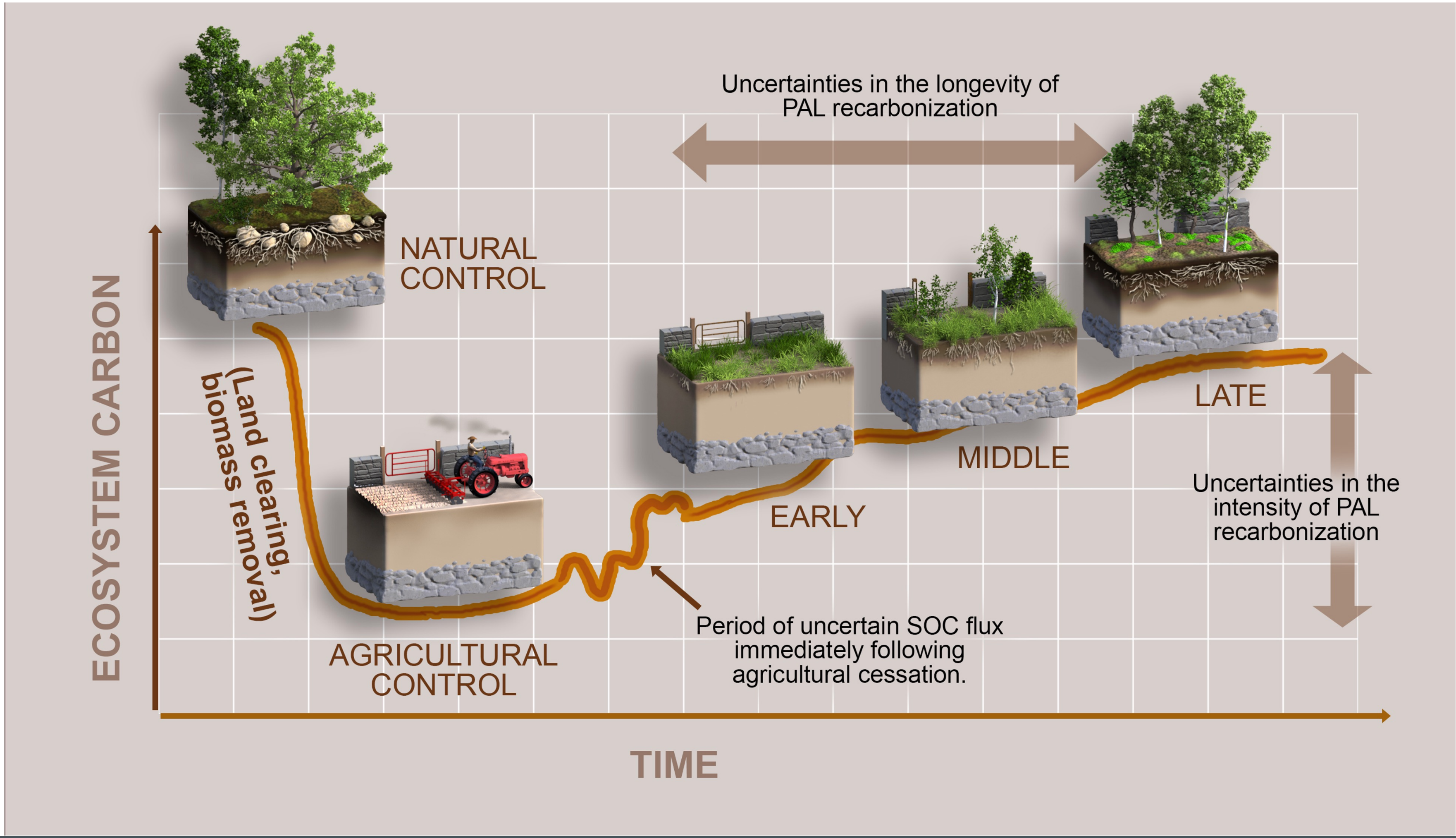


Mahmoudi et al, 2021 Geoderma

Soil multifunctionality in drylands can be improved by management practices that promote organic matter accumulation and favour native plant species that 'mycorrhize more'



- Sustainable technologies are compatible with different cultivation modes (conventional, organic, agroecological)
- Reconcile several sustainable technologies to maximize ecosystem services provided by the soil



- Unlocking Carbon Sequestration in Abandoned Croplands with Satellites and AI.

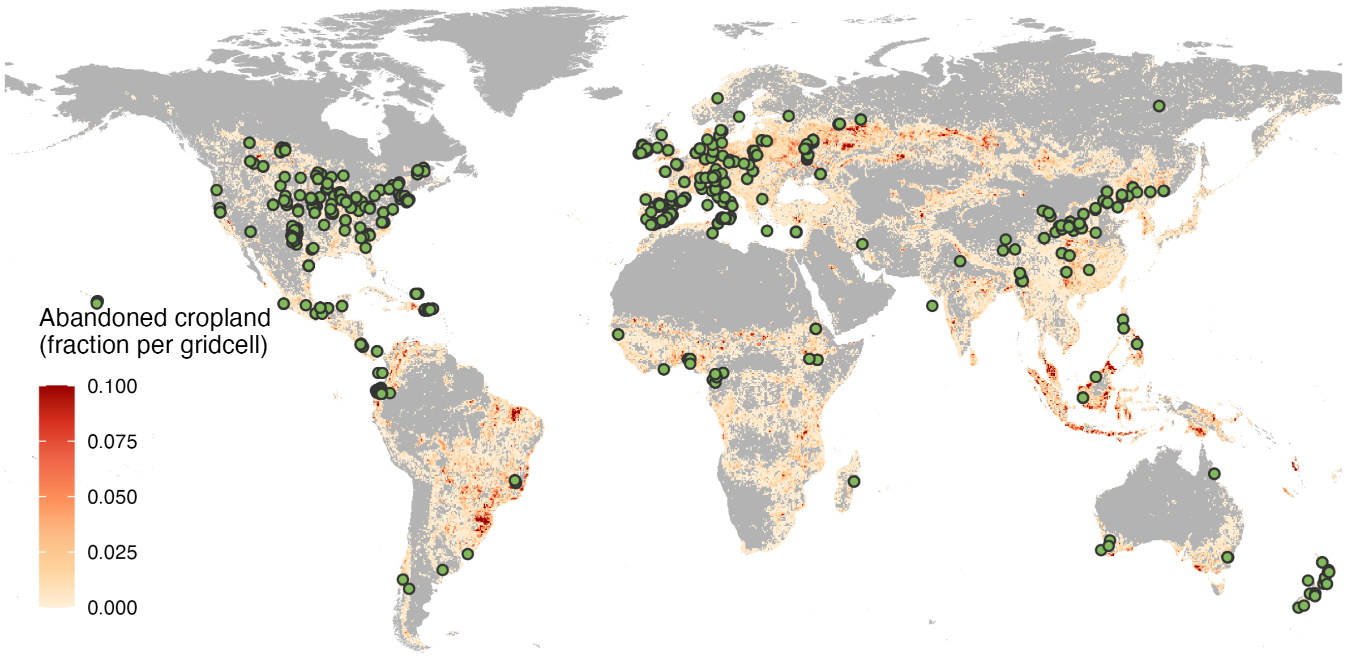


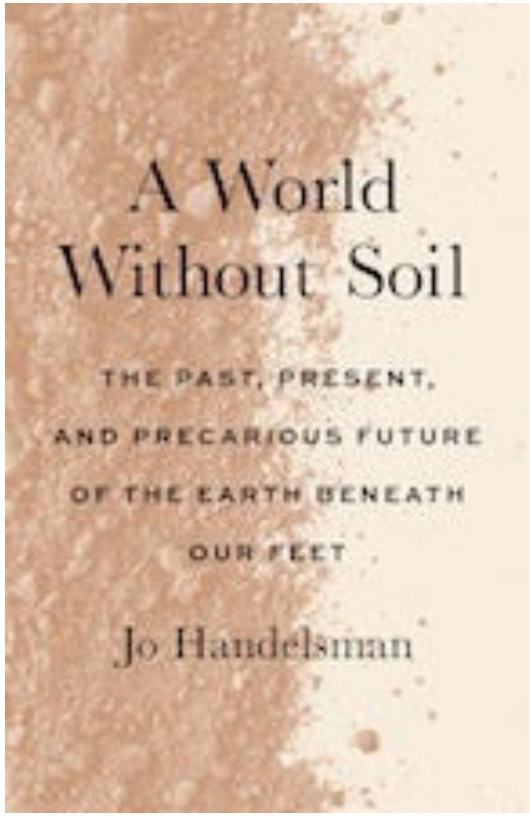
Figure 1. *The background color illustrates the distribution of abandoned croplands in 2019, based on satellite data from the European Space Agency (ESA). Green dots indicate the locations of soil carbon data from abandoned croplands, gathered from existing literature, which will be used to determine soil carbon accrual rates and identify the factors influencing carbon sequestration in these areas.*

- Unlocking Carbon Sequestration in Abandoned Croplands with Satellites and AI.

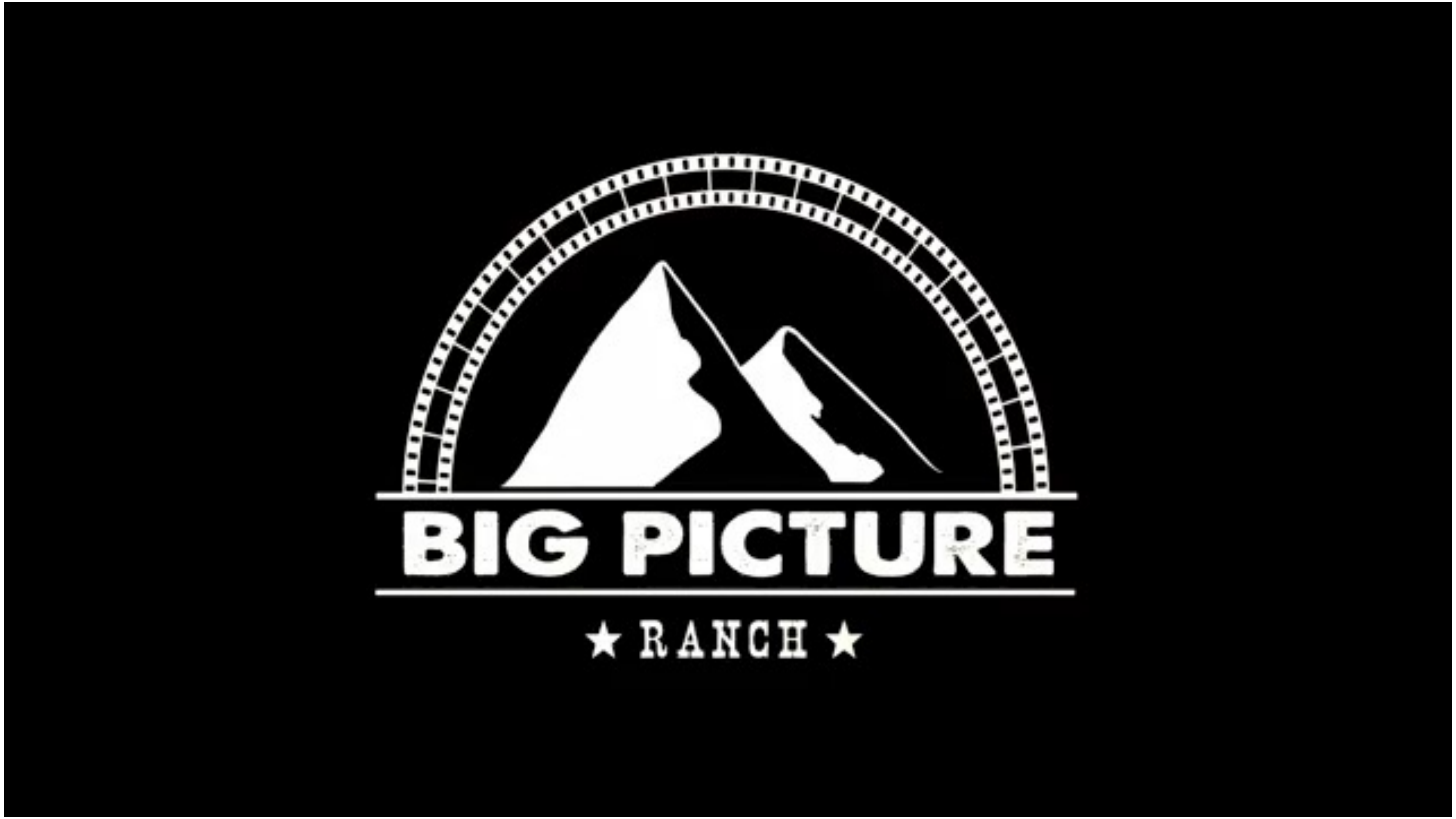
ONGOING PROJECTS in our group:

- SOILDARITY - https://www.soildarity.eu/
- BioClub - Designing biofertilizers by mimicking plants' recruitment of rhizospheric partners
- https://ce3c.ciencias.ulisboa.pt/research/projects/ver.php?id=64
- LxCrop - Production of functional foods in structures built using microbial hydroponics and LED light
- Ecossed
- PolRura - Políticas, Ruralidade, Diversidade e Desenvolvimento
- R3forest - Utilização de biomassa de exóticas para a recuperação pós-fogo: Reutilização, Regeneração e Reflorestação - **https://ce3c.ciencias.ulisboa.pt/research/projects/ver.php?id=239**
- Soill – A one stop shop for living labs
- Echo – Soil for citizens
- GoForest – Political recommendations for soil protection

- For more information, please check our website - https://ce3c.ciencias.ulisboa.pt/team/PSE



- For more information, please check our website - https://ce3c.ciencias.ulisboa.pt/team/PSE



Kiss the Ground Film trailer (2020)