

FACULDADE DE CIÊNCIAS · UNIVERSIDADE DE LISBOA



Sustainable Use of Soil

A transversal lecture on soil as a living, finite resource

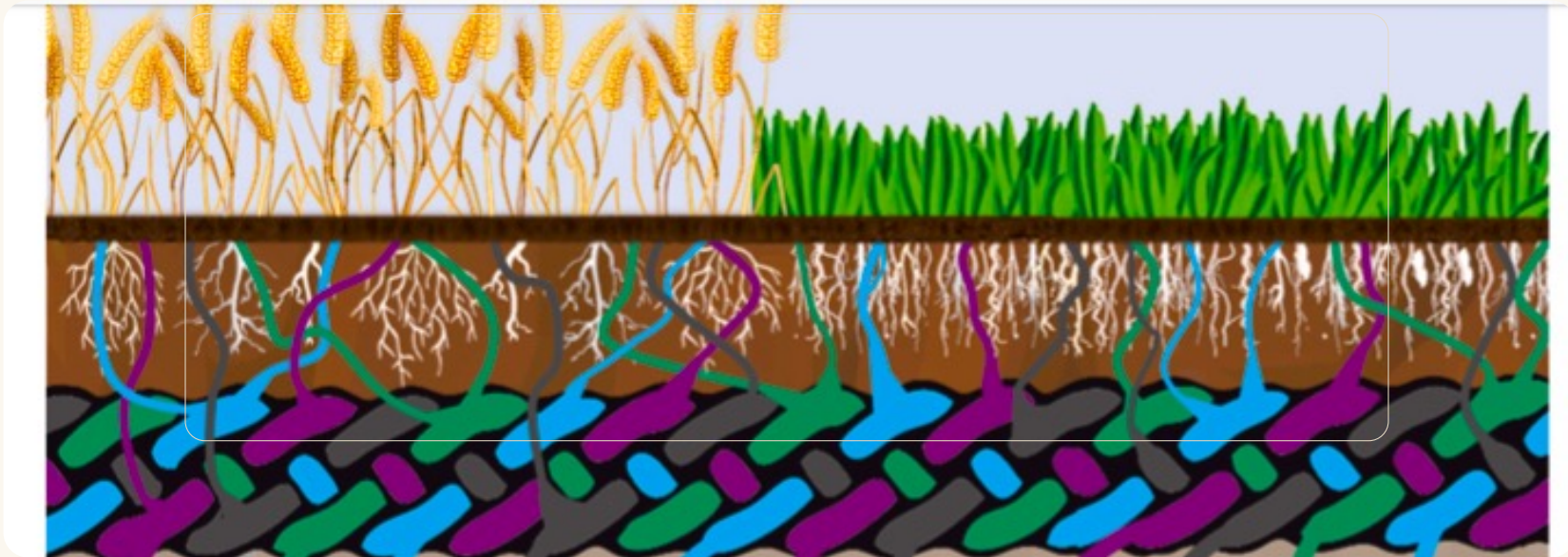
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50 min



PART I • SOIL: AN INVISIBLE RESOURCE?



What would happen if soils stopped functioning?

Image adapted from Creamer et al. 2022, Soil Biology & Biochemistry

PART I • SOIL: AN INVISIBLE RESOURCE?

A living, slow, and fragile system

01

A living system

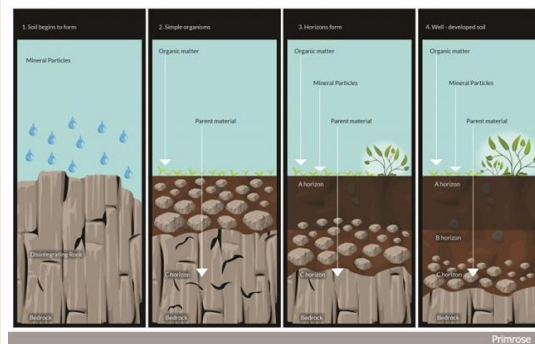
Soil is not inert mineral matter — it is home to an immense diversity of organisms whose activity sustains its every function.



02

Extremely slow to form

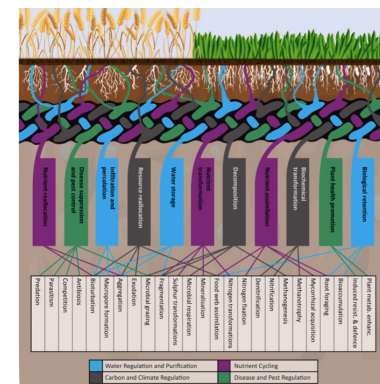
Centuries to millennia are needed to build a few centimetres of fertile soil — on our timescale, it behaves as a non-renewable resource.



03

Many functions, one failure

Because so many services depend on the same soil, degrading it can compromise food, water, climate and biodiversity all at once.



PART II • WHY DO WE NEED HEALTHY SOILS?

Soil ecosystem services

Soils sustain all terrestrial ecosystems. Every category of ecosystem service — provisioning, regulating, supporting and cultural — depends on soil, directly or indirectly.

Food, clean water, climate regulation, flood control, even recreation and cultural value: soil is the quiet link underneath each one.



EU Soil Observatory, after Baveye et al. 2016; Creamer et al. 2022

Four functions, one resource



Food & biomass production

The physical and biological basis of almost all terrestrial food production.



Water & nutrient regulation

Soil filters water, buffers floods, and cycles the nutrients every ecosystem depends on.



Carbon storage & climate regulation

Soils hold more carbon than the atmosphere and all vegetation combined.



Habitat & biodiversity conservation

Soil hosts a quarter of all species on Earth — most of them still undescribed.

A QUESTION

'Who' is responsible for the ecosystem services provided by soils?

Not a single organism, and not us alone: a dense web of interacting actors and processes, below ground, does the work.

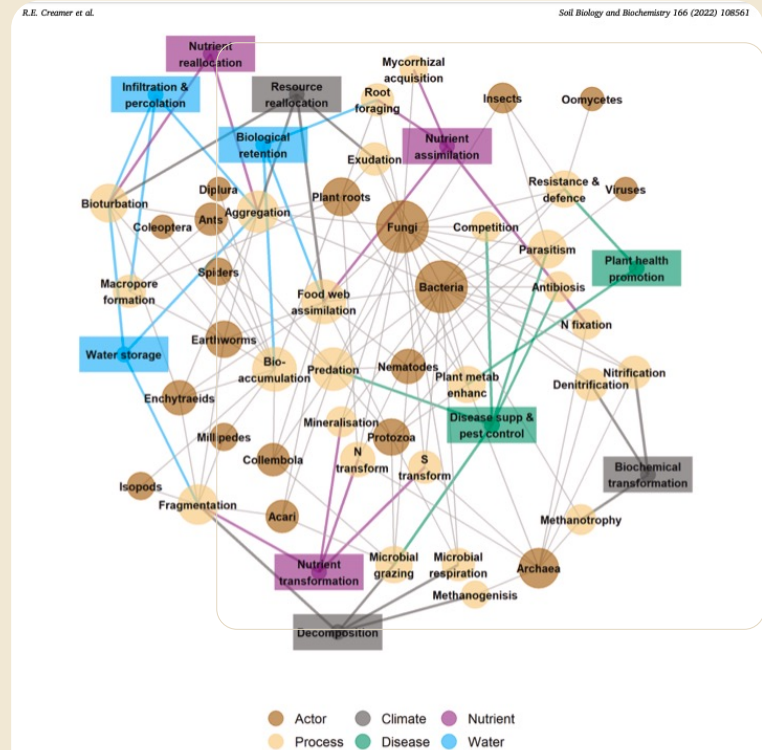


Fig. 6. Network visualisation of the connections between actors, processes and sub-functions. The size of the actor nodes represents the number of processes that they contribute to. The size of the process nodes represents the number of soil functions that they support. Sub-functions are indicated by rectangular boxes and colours refer to the different soil functions: Carbon and Climate Regulation (dark grey), Water Regulation & Purification (blue), Nutrient Cycling (purple) and Disease and

Biodiversity does the work

Microorganisms, soil fauna and plant roots carry out the processes — decomposition, nutrient cycling, aggregation, etc. — that add up to every ecosystem service in previous slides.

Microorganisms

Bacteria, fungi and protists driving decomposition and nutrient transformation.



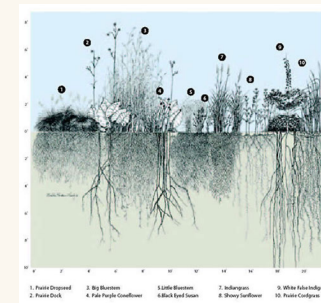
Soil fauna

Earthworms, mites and other invertebrates shaping soil structure.



Plant roots

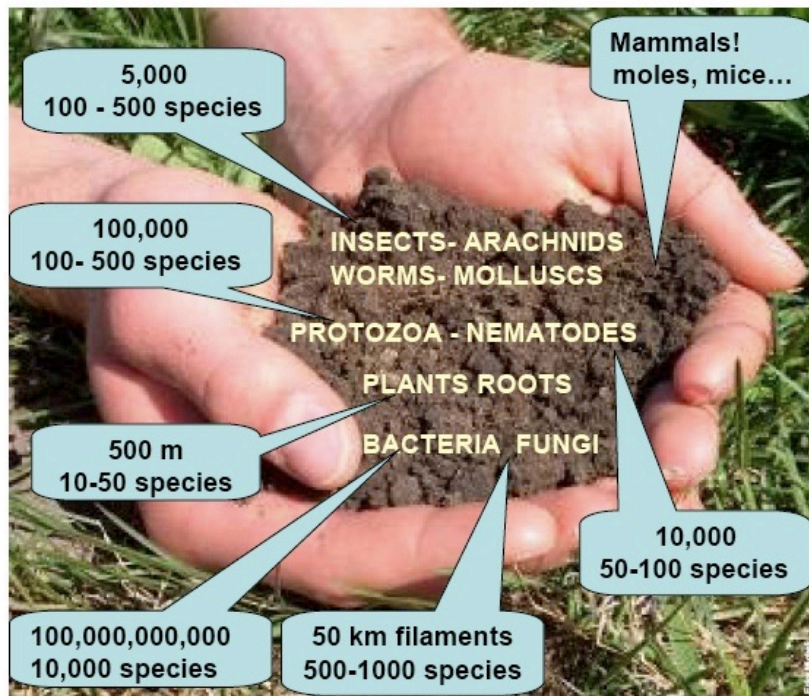
Exuding carbon, building aggregates, partnering with mycorrhizal fungi.



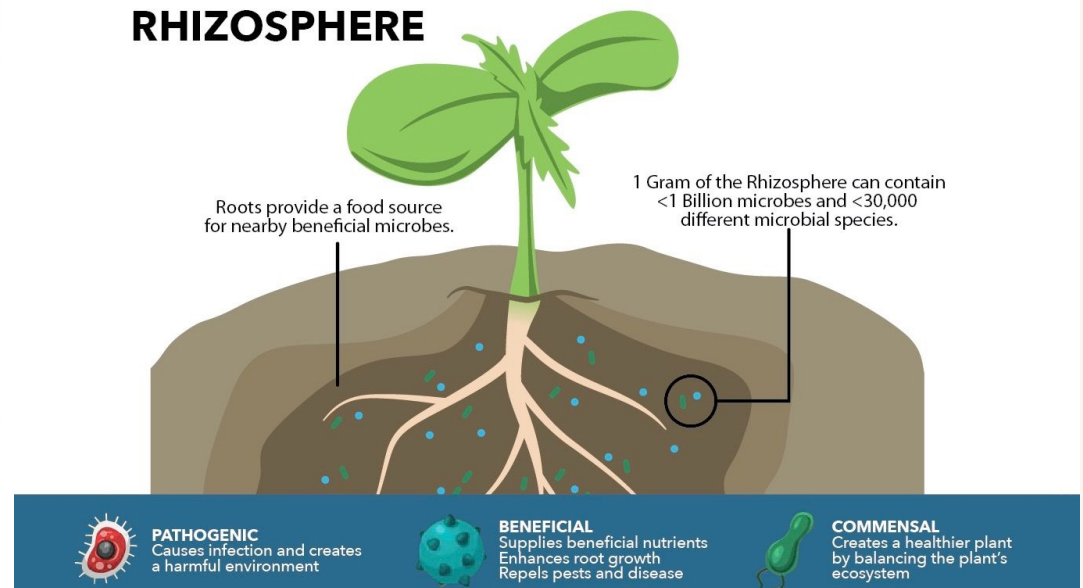
What matters most for sustainability is not memorising every taxonomic group, but recognising that these biological processes are essential to soil functioning.

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Microorganisms, soil fauna and plant roots carry out the processes — decomposition, nutrient cycling, aggregation, etc. — that add up to every ecosystem service in previous slides.



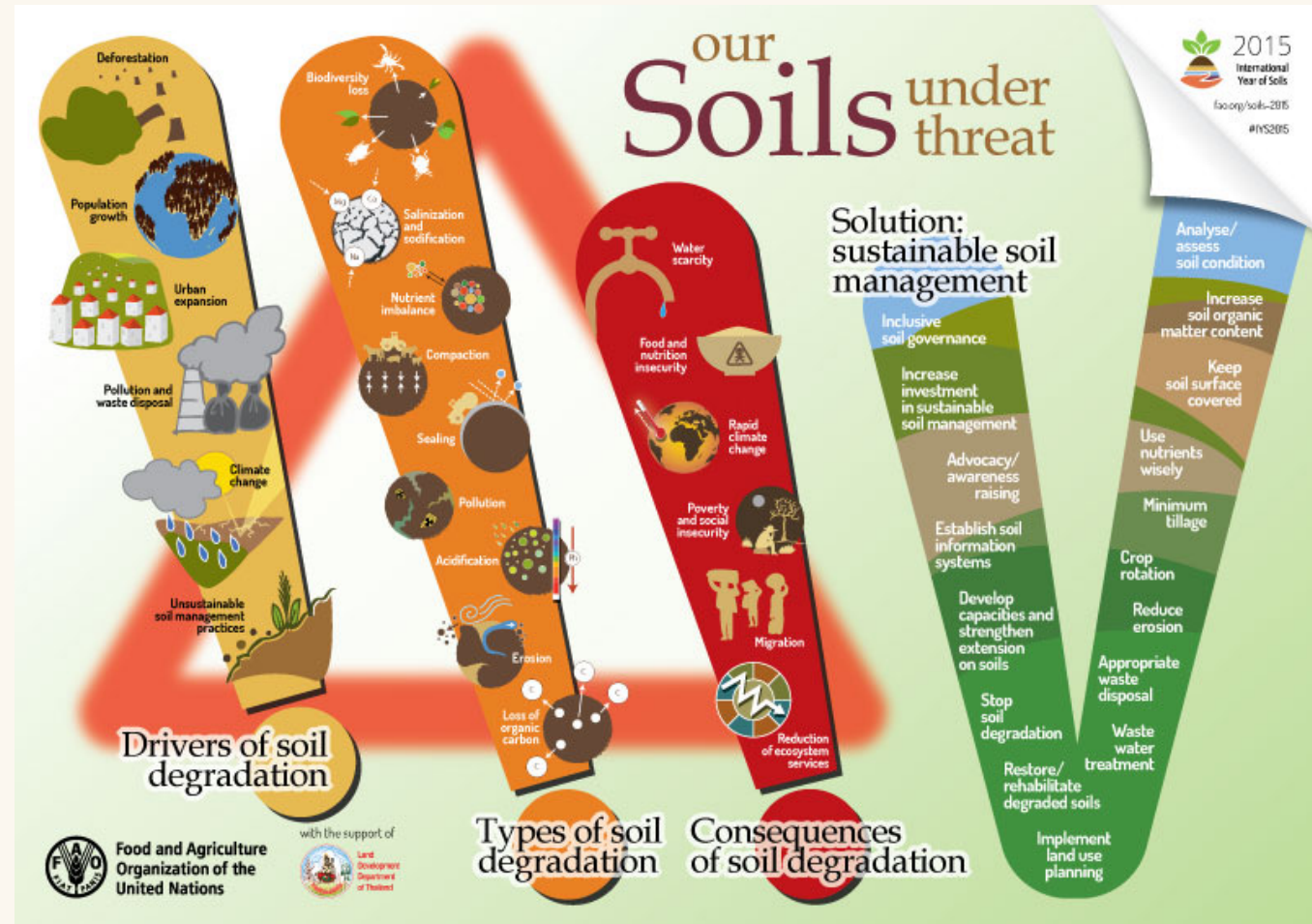
RHIZOSPHERE



*A productive, living system — but an extremely
fragile one.*

PART III • HOW ARE WE
DEGRADING SOIL?

A diversity of pressures



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A diversity of pressures

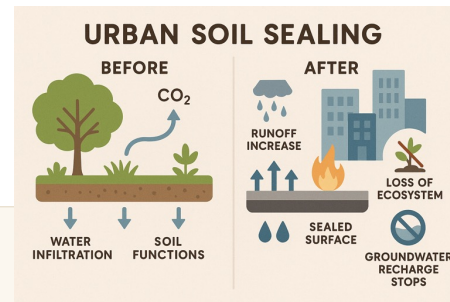
Erosion & soil loss

Removal of the topsoil, loss of organic matter, and a shrinking capacity to produce.



Sealing & urbanisation

Loss of ecological function, and disrupted infiltration and runoff.



Climate change & desertification

Greater vulnerability to drought, erosion and carbon loss.



Add to this contamination and the excessive or poorly matched use of fertilisers — a pressure important enough to look at on its own.

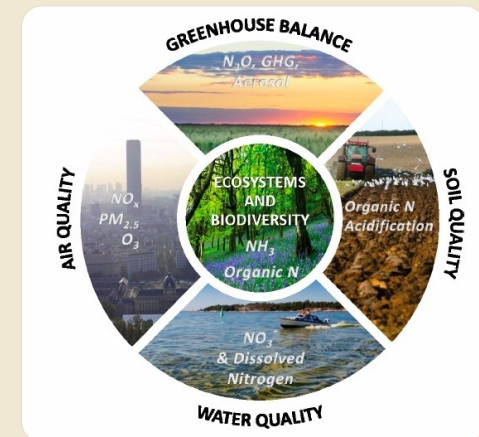
PART III • DEGRADATION

Too much of a good thing: nitrogen

Excess or mismatched fertiliser use does not only waste money — it leaks into air, water and soil, with consequences far beyond the field. Nutrient-use efficiency is as much an economic and social question as an environmental one.

€70–320 billion / year

Estimated cost of nitrogen pollution in the EU — Sutton et al. 2011, European Nitrogen Assessment



European Nitrogen Assessment

Soil degradation: a planetary boundary

Soil degradation is not yet part of the planetary boundaries framework — but it arguably should be: it is a key process for Earth system stability, already affects 3.2 billion people, and is tightly linked to biodiversity loss, nutrient cycles and climate change.

Because soil restoration is so slow, degradation beyond a critical point behaves like crossing an irreversible threshold.

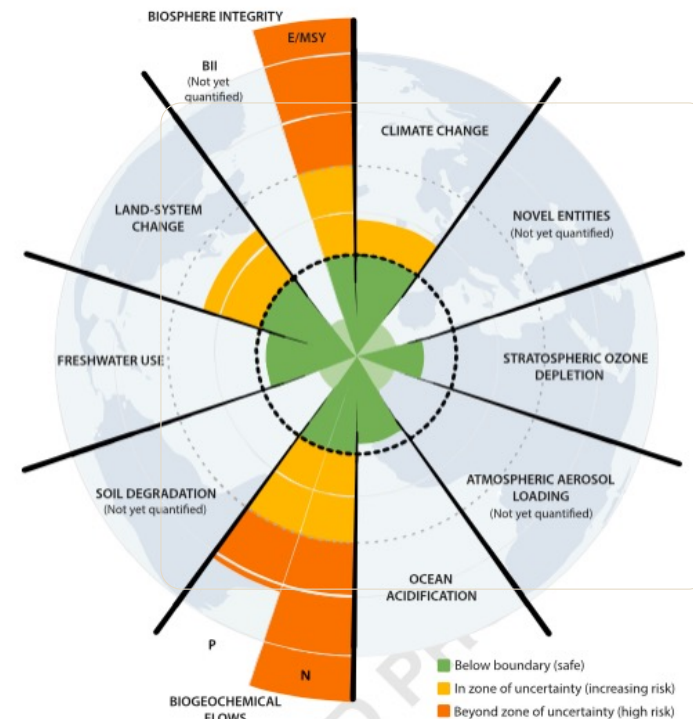


Fig. 2 Proposed new planetary boundaries framework. Updated version of the planetary boundaries framework portraying the current nine Earth system processes along with soil degradation as the 10th Earth system process. The small circle (bold dotted line) represents the planetary boundaries. The large circle (regular dotted line) portrays the thresholds. Adapted from the original image of the planetary boundaries framework constructed by J. Lokrantz/Azote based on Steffen et al.². Licensed under CC-BY.

CLOSER TO HOME

A Mediterranean vulnerability

Low organic matter

Naturally low organic-matter content leaves many Mediterranean soils with little buffering capacity.

Erosive rainfall

Intense rain concentrated after long, dry summers drives episodic but severe erosion.

Desertification risk

Southern and interior Portugal are mapped as vulnerable under the national programme to combat desertification (PANCD).

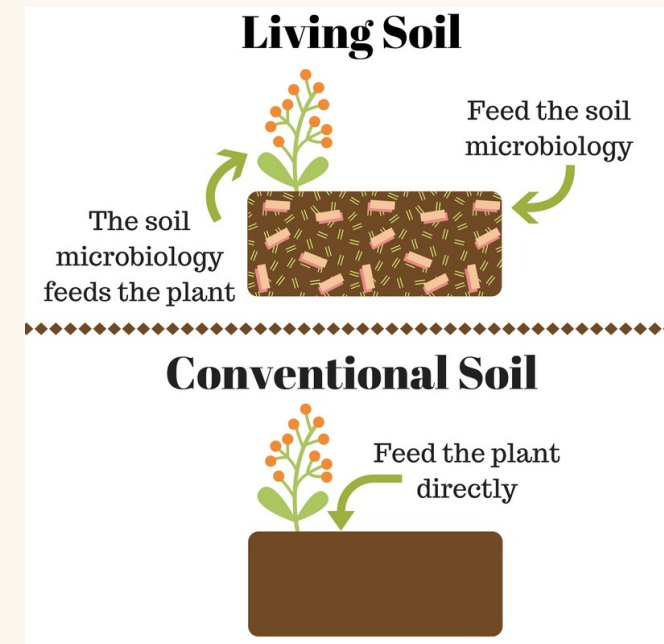


These are not only distant or abstract problems. Mediterranean soils, including much of Portugal, are structurally more exposed to degradation than soils in temperate, wetter climates.

PART IV · USING SOIL SUSTAINABLY

Four objectives, many strategies

Objective	Example strategies
Protect soil	Vegetation cover, reduced tillage, erosion prevention
Recover functions	Organic matter inputs, ecological restoration
Use resources efficiently	Precision agriculture, adjusted fertilisation
Favour biological processes	Rotations, plant diversity, mycorrhizae and other beneficial microorganisms



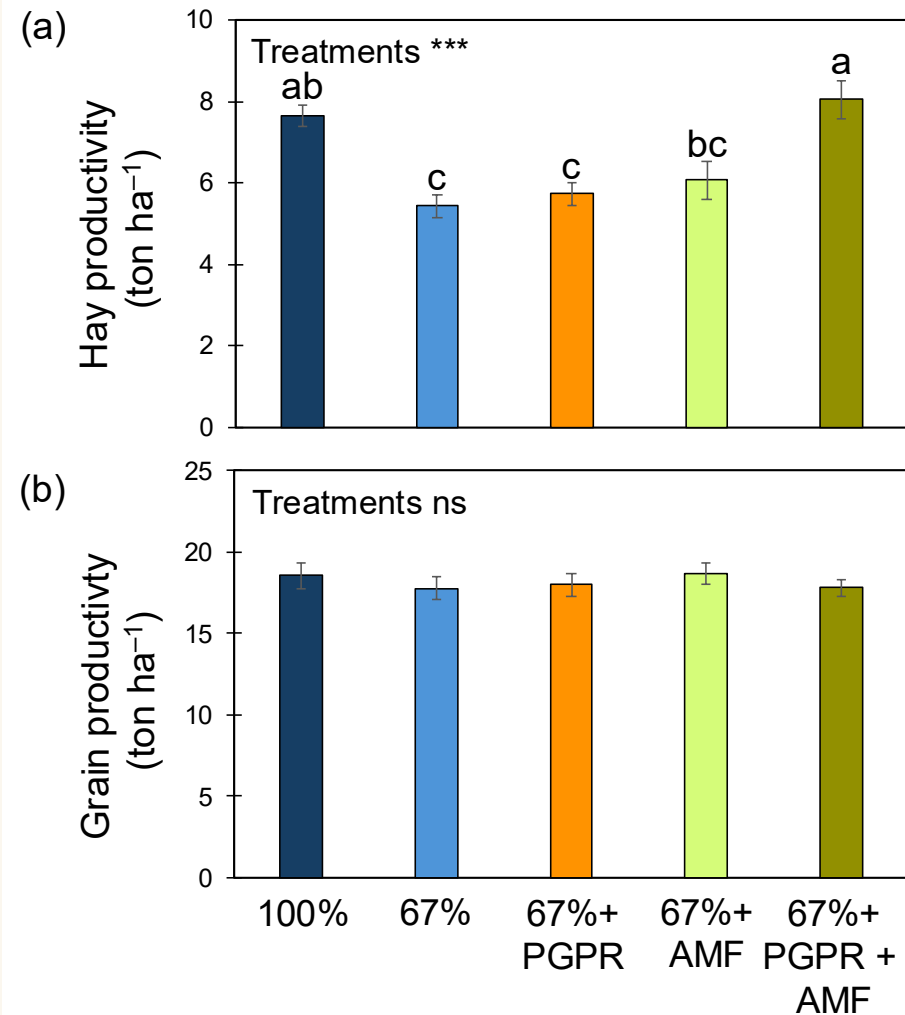
Sustainability is not a property of a technology — it depends on its effects on soil function, in a given context.

EXAMPLE 1

Biofertilizers: can we do more with less?



Dias et al., 2026, Sustainability



EXAMPLE 1

Biofertilizers: can we do more with less?



CE3C — Plant-Soil Ecology, Faculdade de Ciências, Universidade de Lisboa

Inoculating crops with a microbial consortium offset a **one-third reduction** in mineral fertiliser — with no loss in plant biomass.

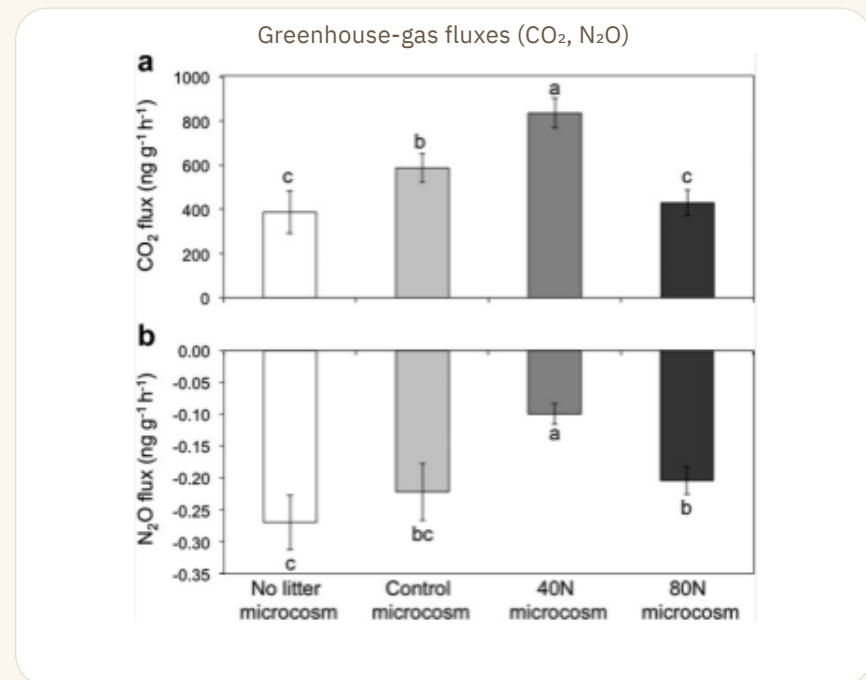
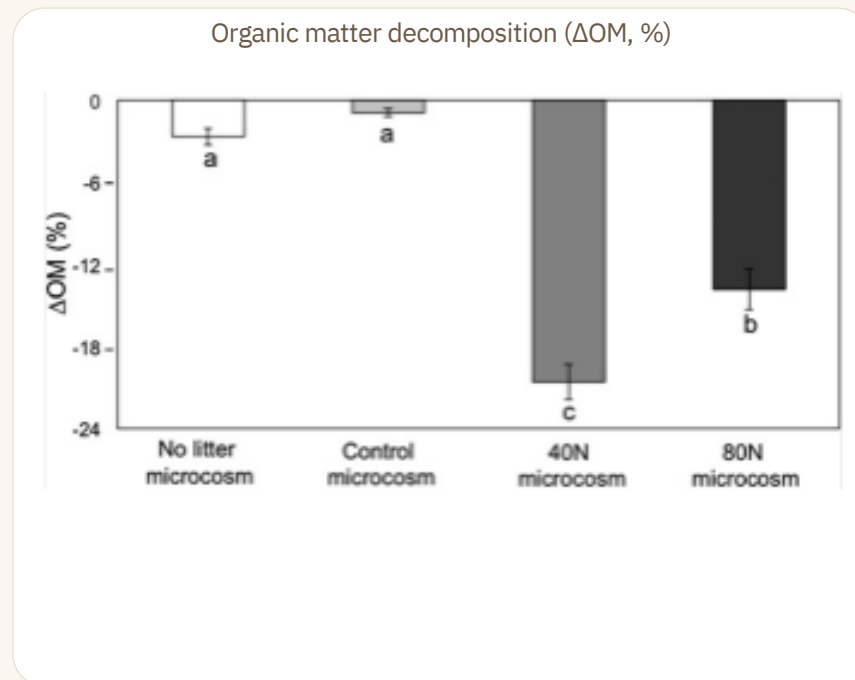
Can we produce the same amount of food using fewer external inputs?

This is a clear demonstration of the potential of functional biodiversity — microbial partners doing part of the work that synthetic fertiliser would otherwise have to do.

EXAMPLE 2

Is organic matter always a sustainable solution?

One amendment, two opposite effects



A practice that improves one soil function may negatively affect another – the composition and quality of the amendment matter.

Dias et al. 2013, Soil Biology and Biochemistry

1-2 MINUTE DISCUSSION

The compost dilemma

A farmer applies compost to increase soil fertility. Crop productivity increases by 20%, but soil greenhouse-gas emissions also increase. Is this a sustainable practice?

A

Yes — because production increased.

B

No — because emissions increased.

C

It depends on an integrated assessment of benefits and impacts.

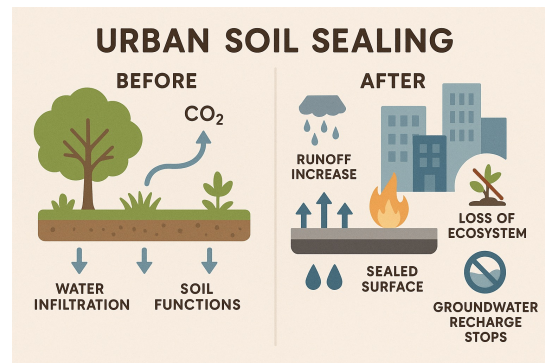
A TRANSVERSAL LECTURE

Beyond the farm

The lecture so far has leaned on agriculture — understandably, since that is where most research sits. But the topic is the sustainable use of soil as a resource, relevant well beyond agronomy.

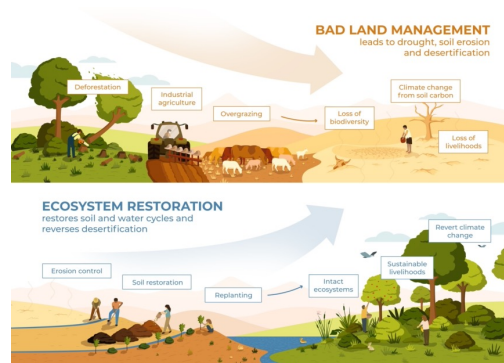
Urban sealing

Impervious surfaces cut off infiltration and the ecological functions of urban soils.



Ecological restoration

Degraded land can recover functions through deliberate restoration of soil and plant communities.



Land-use planning

Conserving natural soils is, at heart, a planning and policy decision.

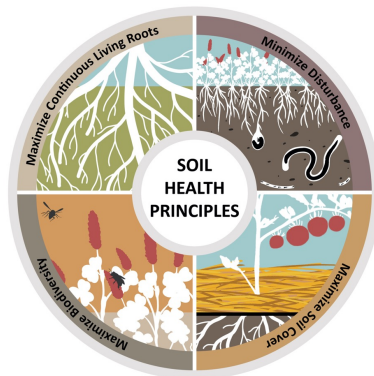


PART V · HOW DO WE KNOW WE ARE BEING SUSTAINABLE?

Three concepts we need

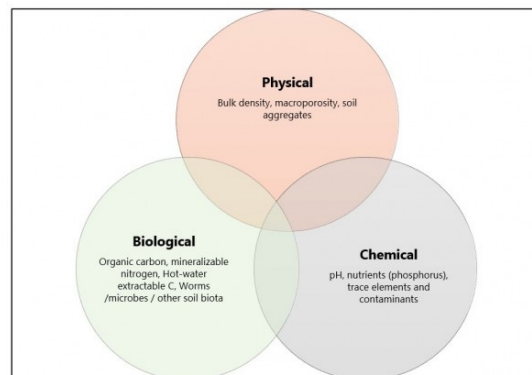
Soil health

The capacity of a soil to function, within its ecosystem, to sustain life and productivity.



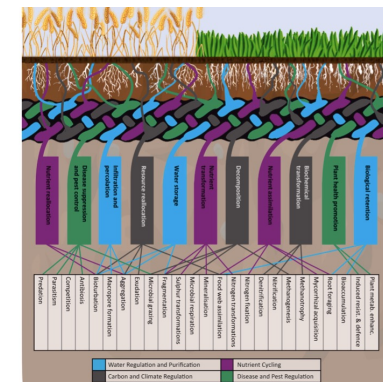
Indicators

Physical, chemical and biological measurements that let us track that capacity over time.

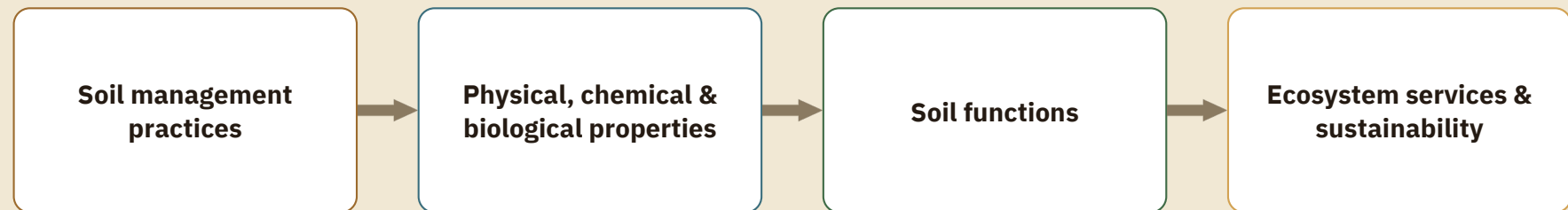


Multifunctionality

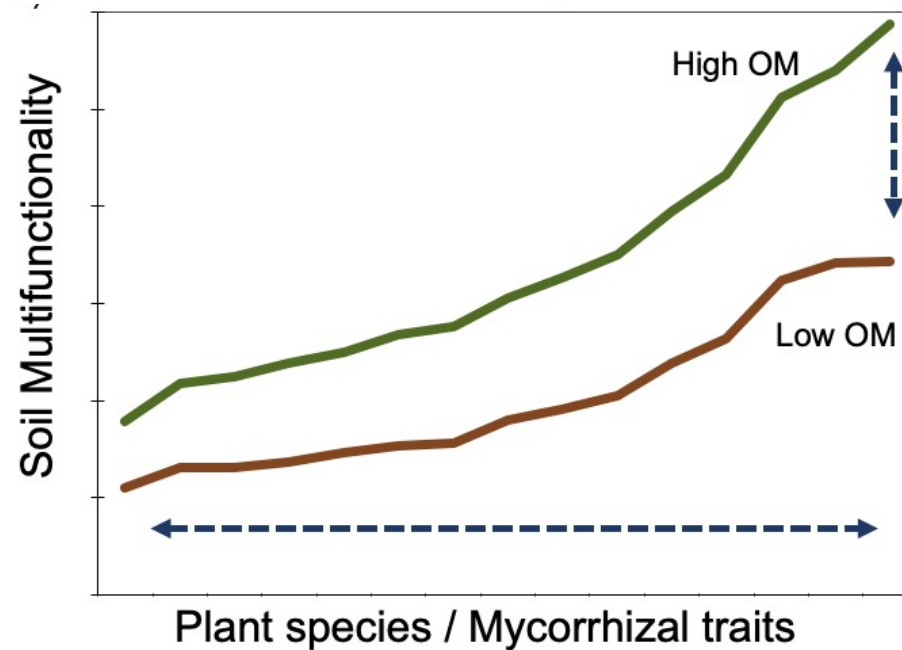
A soil rarely performs only one function — sustainability means weighing several functions at once.



From practices to ecosystem services



Productivity is not enough



Mahmoudi et al. 2021, Geoderma

Is higher crop productivity enough to conclude that a soil management practice is sustainable?

No — we need to evaluate different functions together, and consider effects over the medium and long term.

PART VI • CONCLUSION

Soil and the Sustainable Development Goals

02

Zero Hunger

06

Clean Water & Sanitation

13

Climate Action

15

Life on Land

Soil conservation contributes to several goals at once — but trade-offs between them, as we have seen, are also possible.

Three things to remember

1. Soil is a living and finite resource.
2. Sustainable soil management must preserve multiple ecosystem functions at once.
3. There is no universally sustainable practice — context, trade-offs and long-term outcomes matter.



Can we feed a growing population while restoring soil health?



Kiss the Ground Film trailer (2020)

ONGOING PROJECTS in our group:

- DroughtResist – Consórcio de biofábricas bacterianas: um bioestimulante para o aumento da tolerância das plantas ao stress hídrico face à crise climática
- GroundWork – Regenerative living labs to improve soil ecosystem functions by adapting agricultural land use with livestock integration
- NITROSCOPE – Scoping European N fluxes for sustainable N management and conservation practices
- INTERESH – INnovation for TERitorial CohEision around Soil Health
- SAVE water – GeoSpatial and Artificial intelligence technologies: Innovative approach for water resources management
- ECHO – Engaging Citizens in soil science: the road to Healthier sOils

An illustration showing a cross-section of the soil surface. On the left, there are yellow, dried-out plant stalks. On the right, there are green, healthy plant stalks. Below the surface, the soil is brown, and numerous roots of various colors (blue, green, purple, grey) are shown extending downwards into the soil, illustrating the root systems of the plants above.

For more information, please check our website - <https://www.ce3c.pt/research/research-groups/towards-sustainable-and-resilient-ecosystems/plant-soil-ecology>