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CNR-IRET (Firenze, Italy)

Soil quality: from chemical indicators to biodiversity

12 July 2022

National Research Council of Italy

CNR IRET

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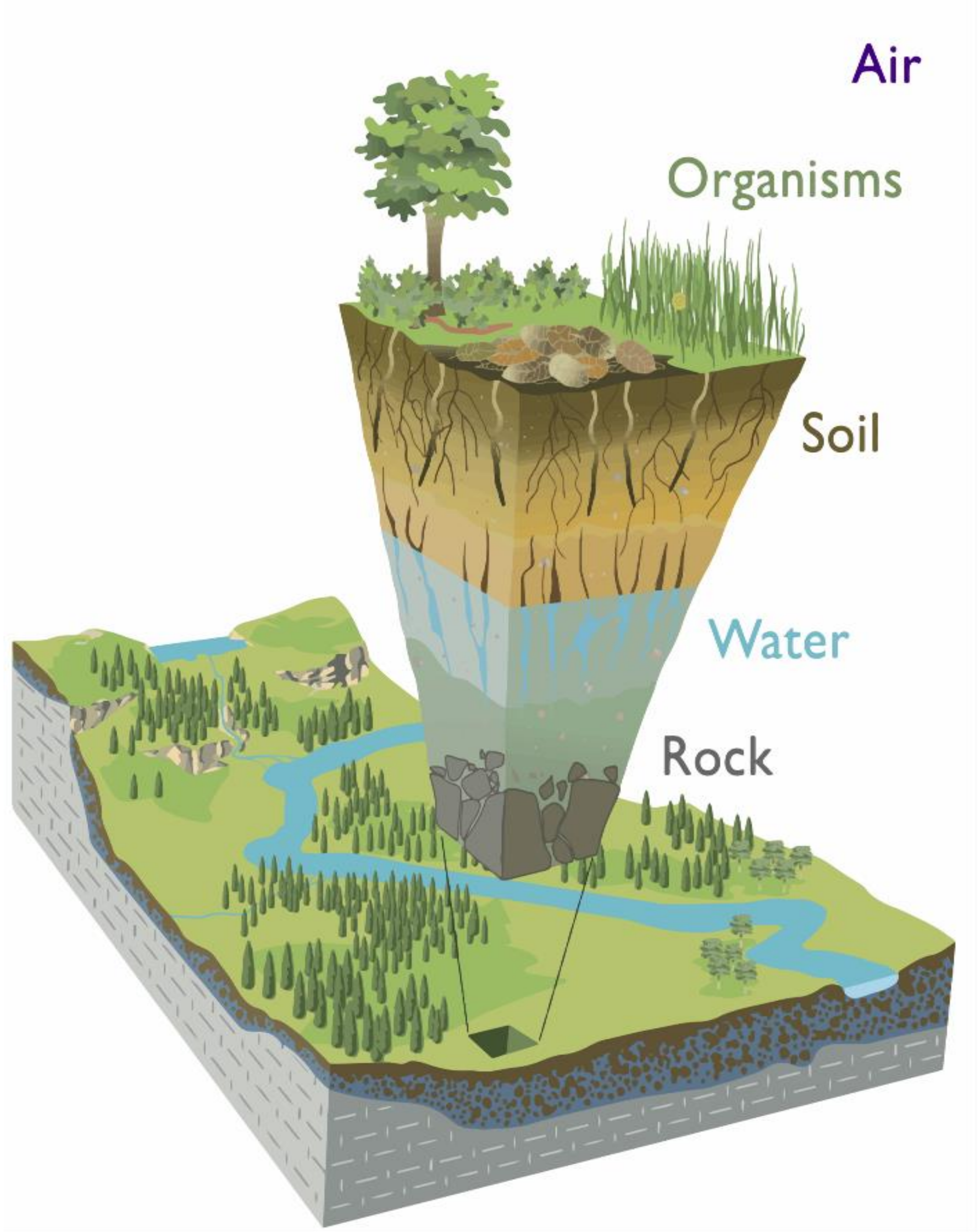
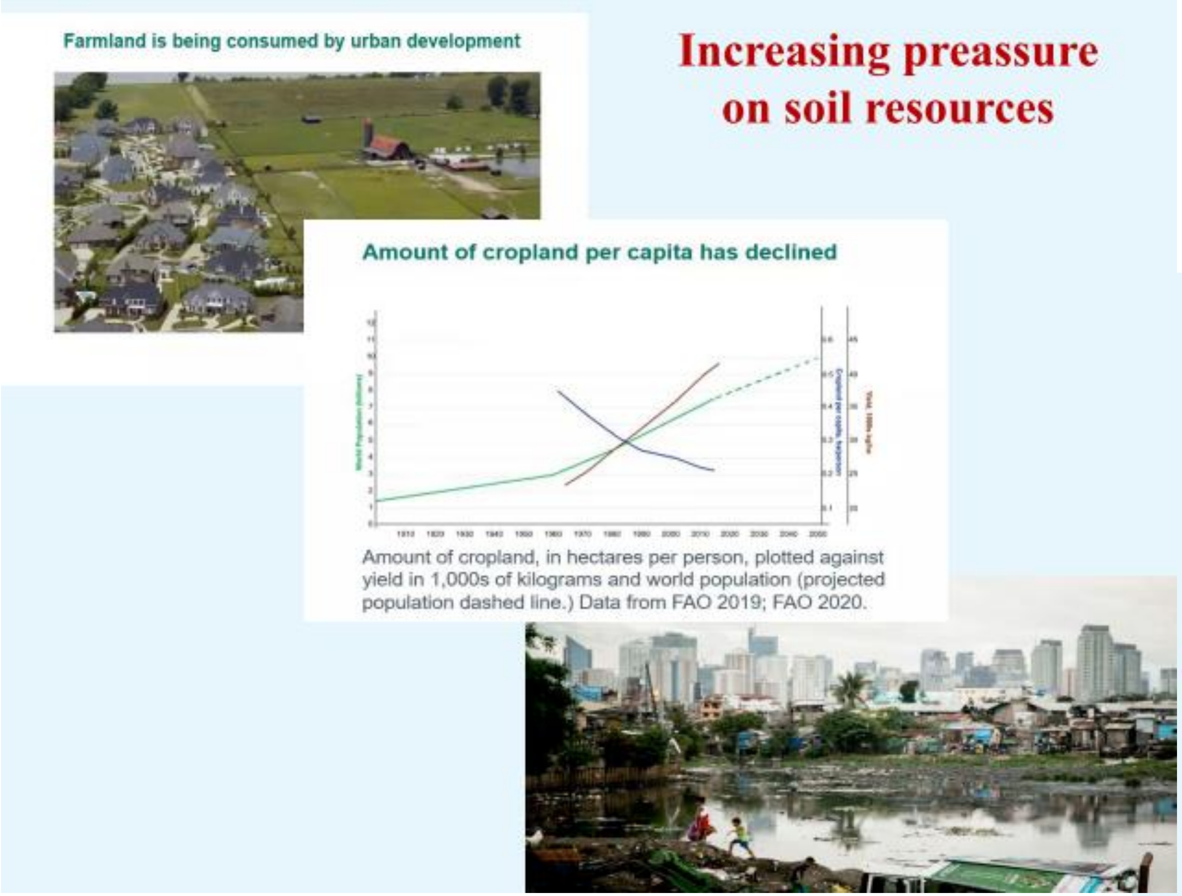
WHY SOIL??

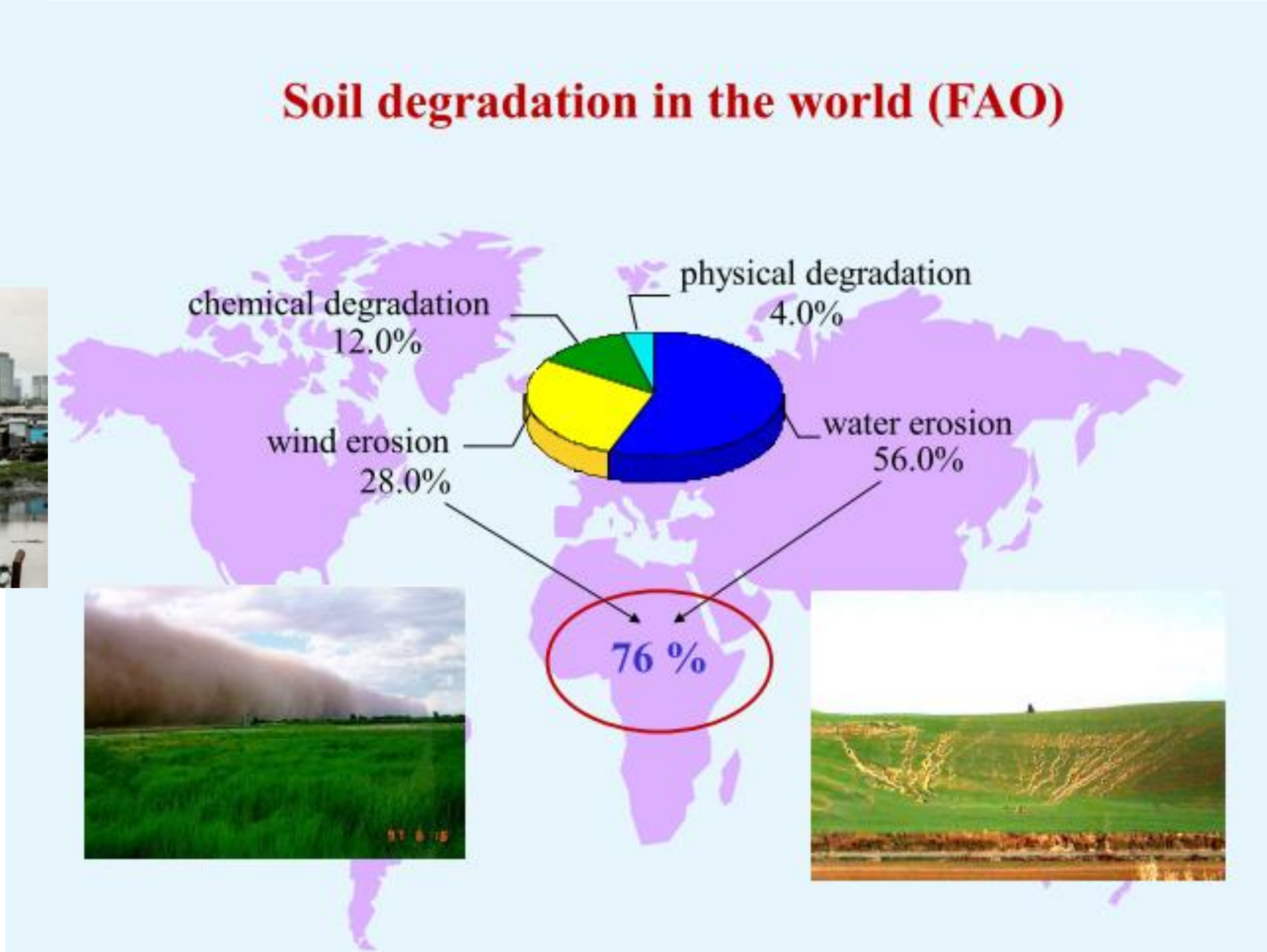
From an anthropocentric point of view..
-it sustains our life
-it allows us to have food and water

In general..
It sustains life.

Soil gives us clean air and water, bountiful crops and forests, productive grazing lands, diverse wildlife, and beautiful landscapes.

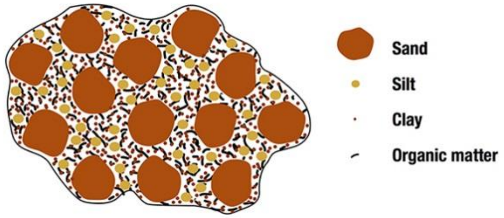


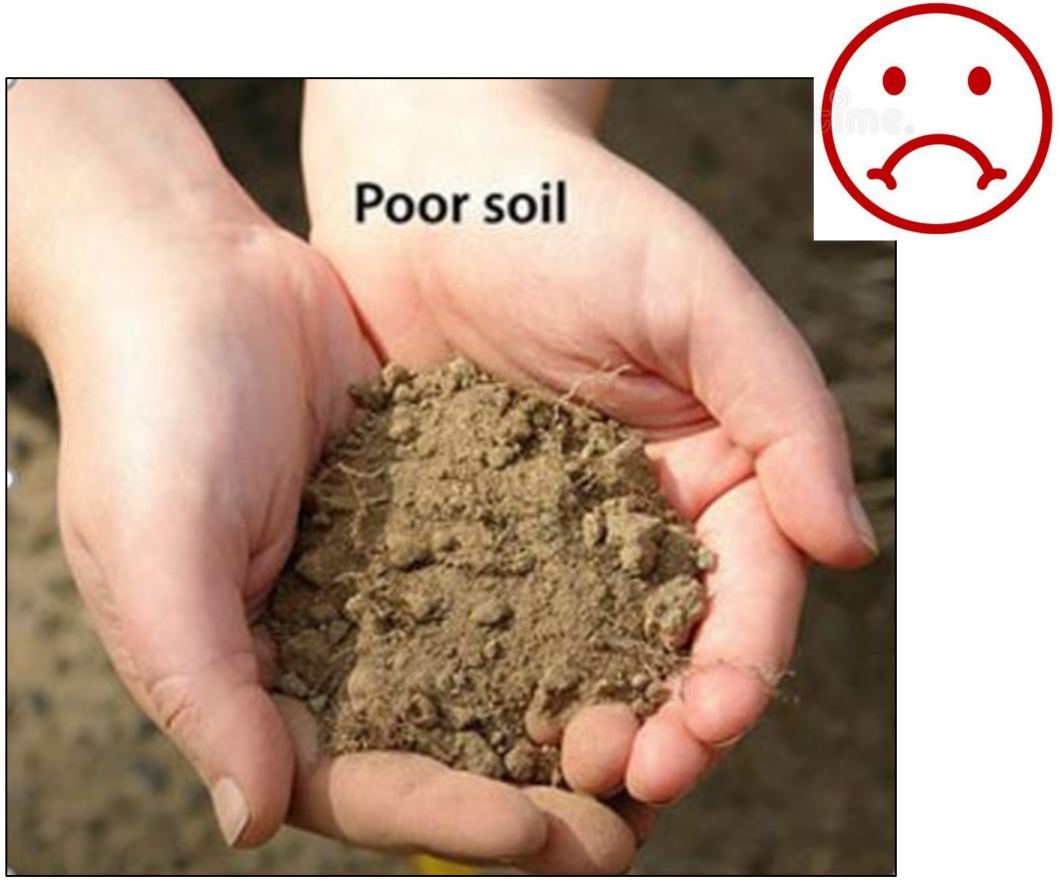

Increasing preassure on soil resources
Farmland is being consumed by urban development
Amount of cropland per capita has declined
Amount of cropland, in hectares per person, plotted against yield in 1,000s of kilograms and world population (projected population dashed line.) Data from FAO 2019; FAO 2020.


Soil degradation in the world (FAO)
physical degradation
4.0%
chemical degradation
12.0%
wind erosion
28.0%
water erosion
56.0%
76 %

Healthy soil vs Unhealthy soil

Healthy soil has got a nice, dark, black color. Soil with little to no life in it looks more like dirt: brown and dry. Poor soil will turn to brown mud when it gets wet. Healthy soil absorbs moisture beautifully and should not have a muddy feel.





Unhealthy soil doesn't have the moisture and nutrients needed to thrive, which makes it dry, crumbling, and cracked. When you pick up the dirt, it might crumble quickly in your hands or be difficult to break apart. Proper watering and irrigation would improve the soil's condition in these instances.

In general

Indicator: measure, generally quantitative, that can be used to illustrate and communicate complex phenomena simply, including trends and progress over time.

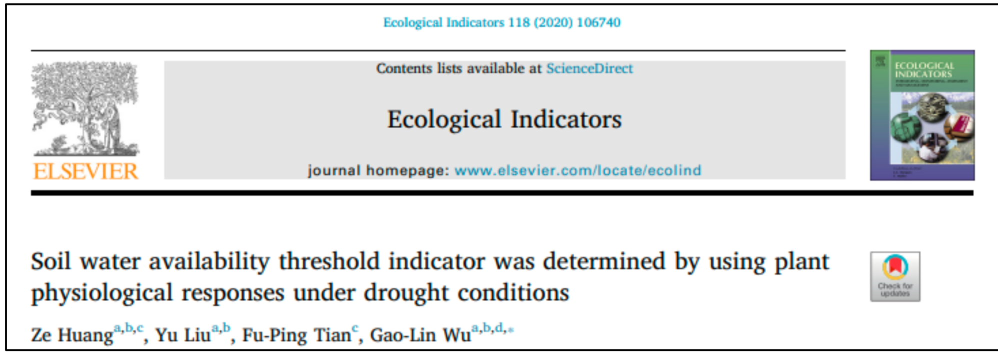
Thresholds are perceived as values above or below which a significant shift or a rapid negative change takes place.

Soil

Indicators provide relevant and meaningful information about the status and dynamic behavior of soil, with regard to its (multi-) functionality as well as impact on ecosystem services.

Beyond such values, soil would be considered as degraded, with restoring action needed.

An example..



Ecological Indicators 118 (2020) 106740

Contents lists available at ScienceDirect

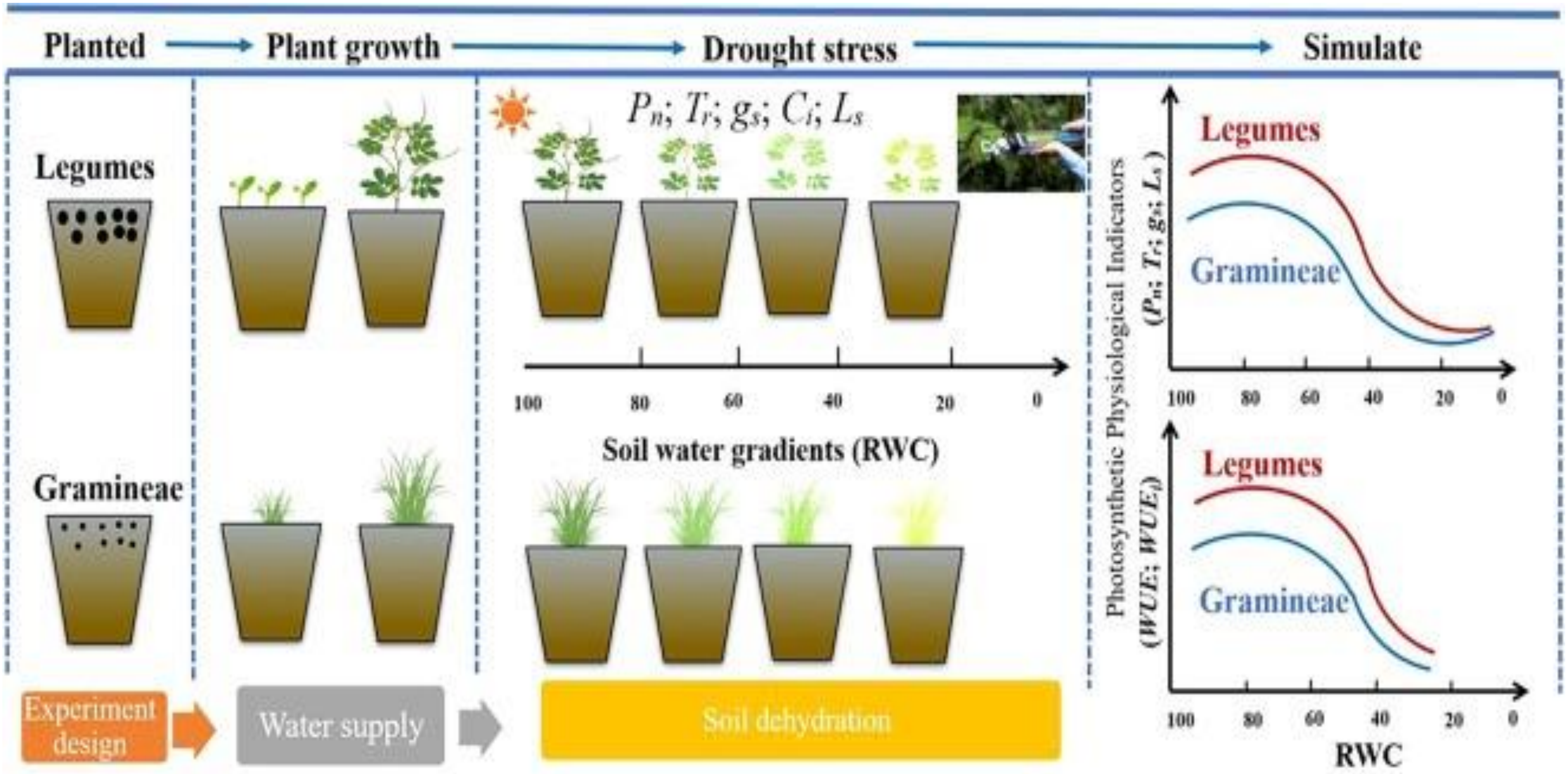
Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

ELSEVIER

Soil water availability threshold indicator was determined by using plant physiological responses under drought conditions

Ze Huang[a,b,c], Yu Liu[a,b], Fu-Ping Tian[c], Gao-Lin Wu[a,b,d,*]



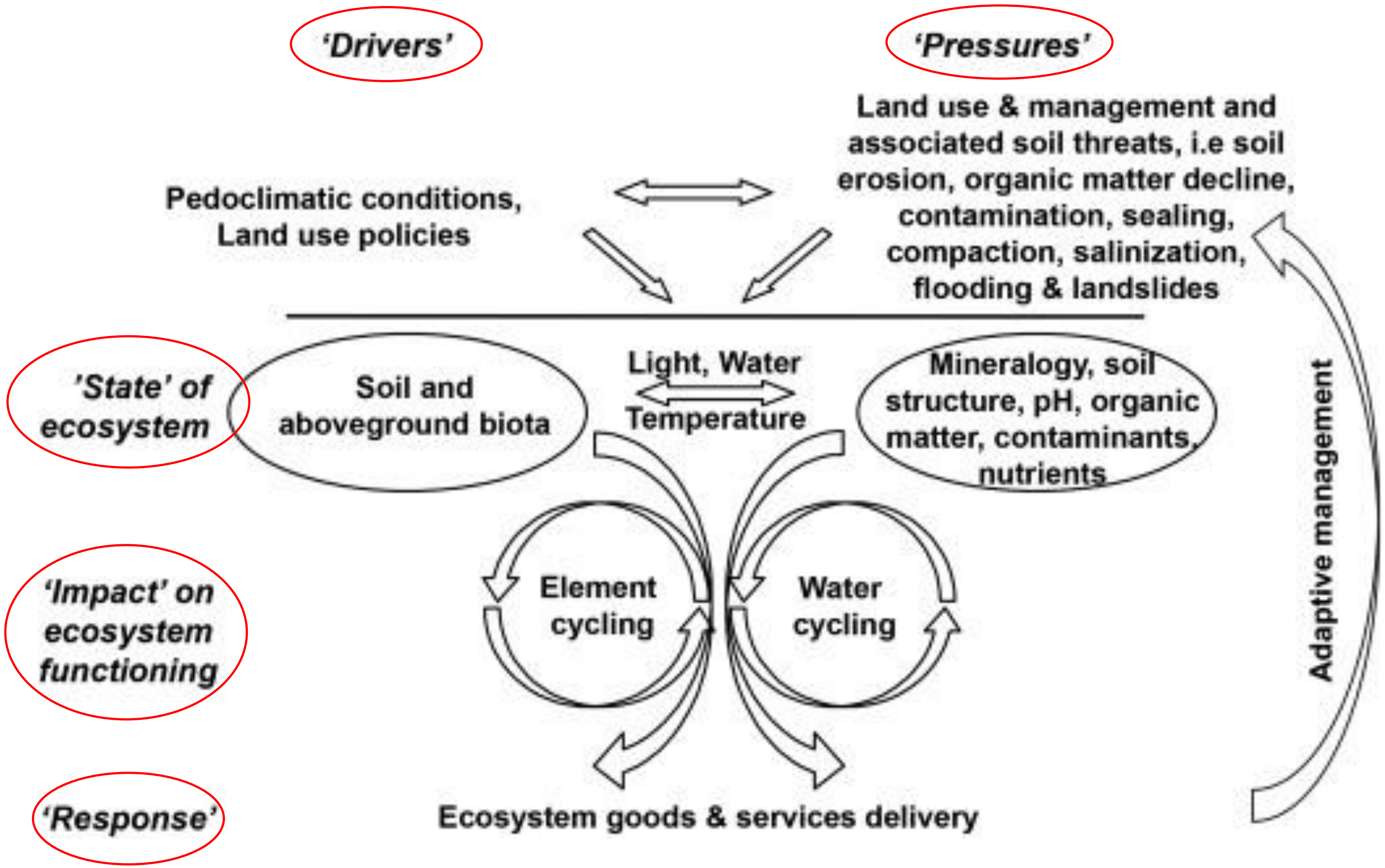
Parameters

P_n -> Net CO_2 assimilation rate
T_r -> Transpiration rate
g_s -> Stomatal conductance
C_i -> Intercellular CO_2 concentration
L_s -> The stomatal limitation value

RWC -> Relative soil water content

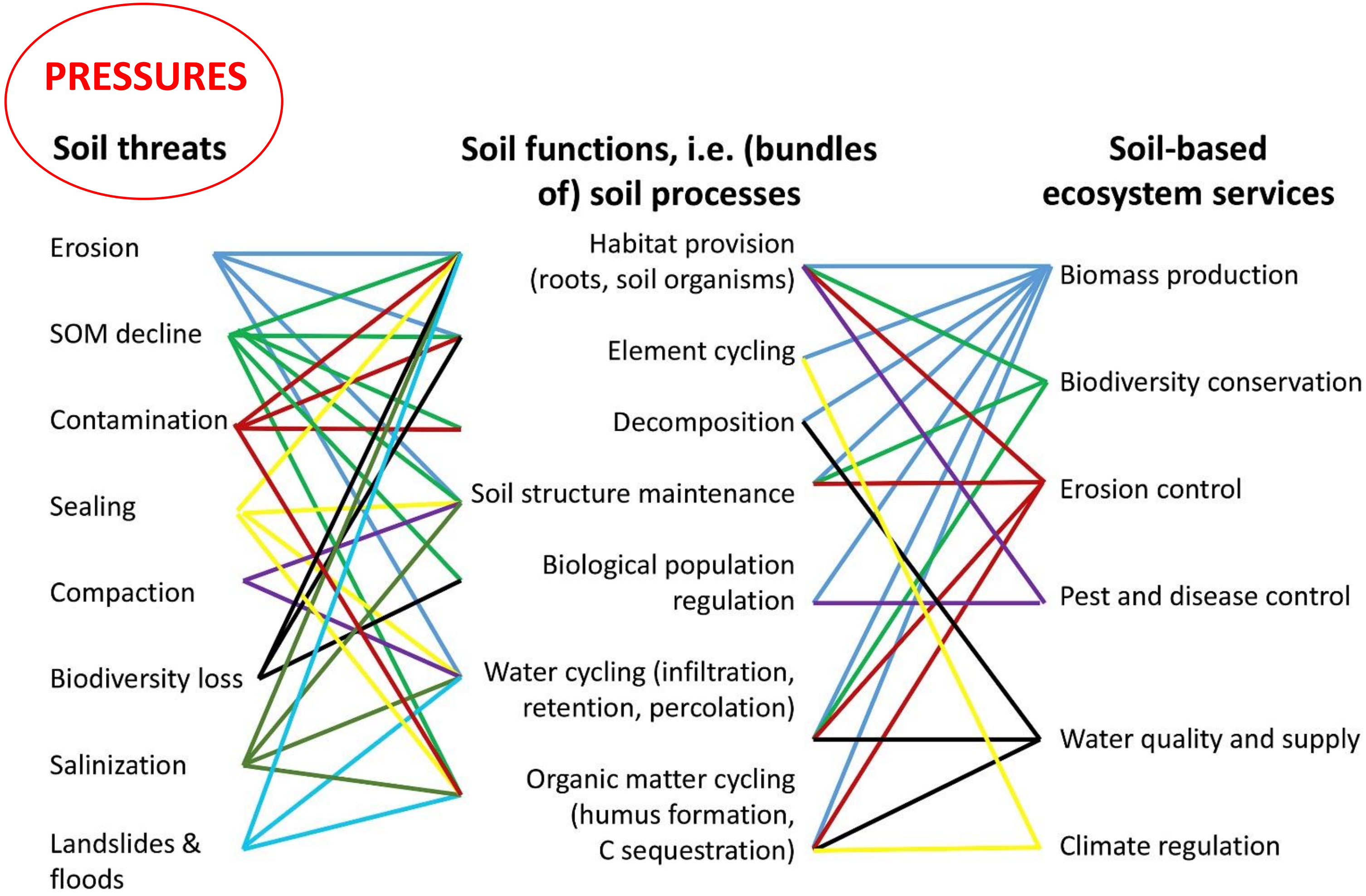
Legumes have higher capability to encounter drought resistance than grasses

The Driver-Pressure-State-Impact-Response framework applied to soil (in general, not considering each ecosystem)



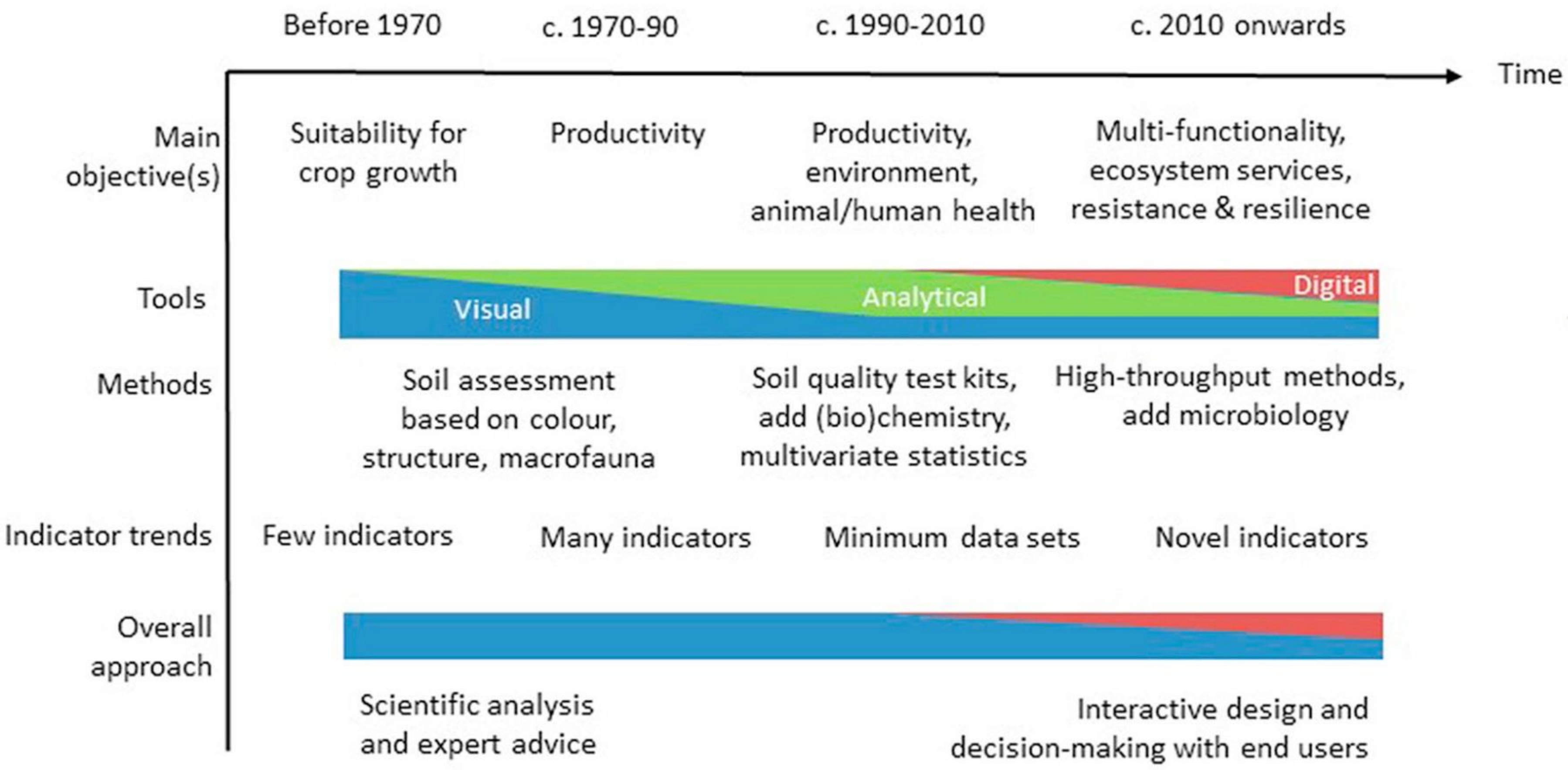
Brussaard et al. 2007. https://doi.org/10.1016/j.pedobi.2006.10.007

Linkages between soil threats, soil functions, and soil-based ecosystem services



Brussaard et al. 2012.
https://www.doi.org/10.1093/acprof:oso/9780199575923.003.0005

Indicators for soil health..and changes along the time!



Bünemann et al. 2018.
https://doi.org/10.1016/j.soilbio.2018.01.030

ENV PRO

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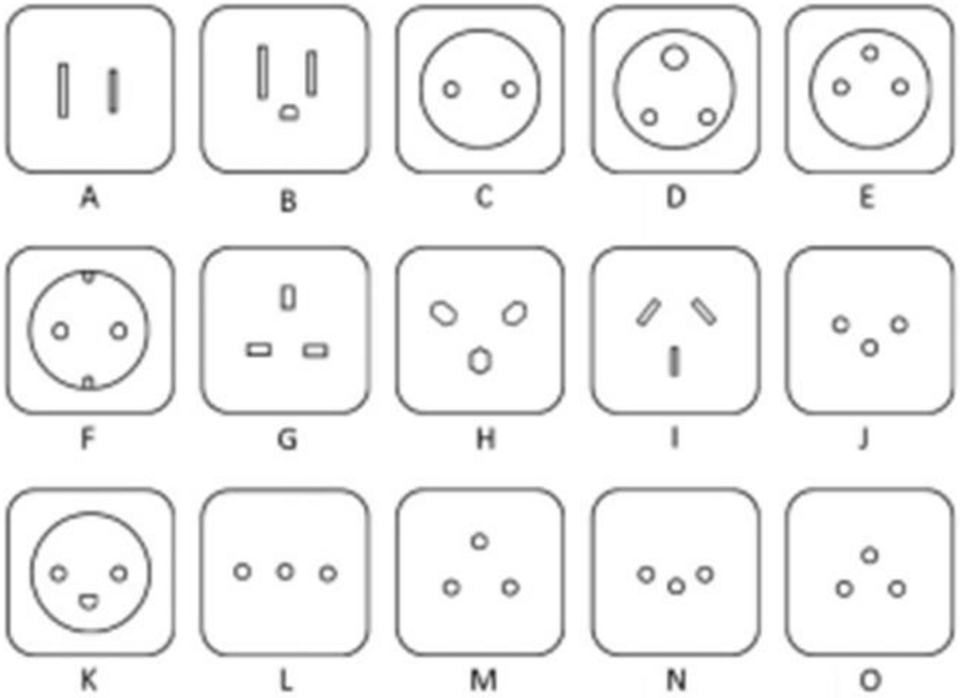
But…how to choose type of measurements, harmonise data ..and then indicators to monitor the status of soils?

What about standardization and harmonisation?

In general..

STANDARDISED DATA IS STILL NOT HARMONISED DATA

STANDARDISED DATA
explicit data = FAIR



HARMONISED DATA
transformed data to a common standard

Standardisation is describing data in the same way (agreed definitions, structure, format)
Harmonisation is translating data to the same units, lab methods, definitions, etc.

If we search for forest soils..

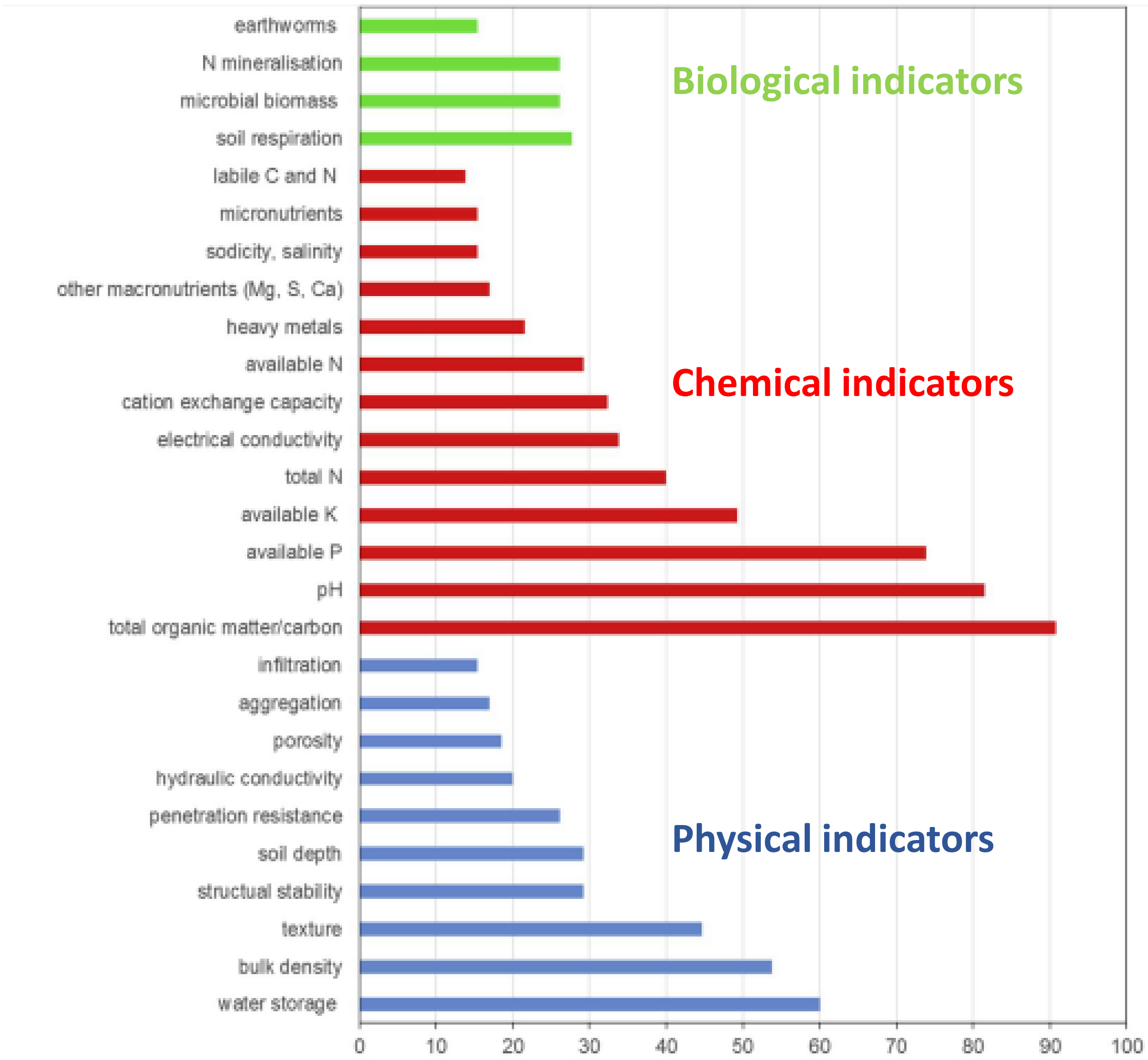


Fig. 4. Frequency of different indicators (min. 10%) in all reviewed soil quality assessment approaches (n = 65). Soil biological, chemical and physical indicators shown in green, red and blue, respectively. For further details on indicators see Supplementary Table 3. Publications dealing exclusively with forest soils (e.g. Schoenholtz et al., 2000; Zhang, 1992) or focusing on biological indicators only, without also looking at chemical and/or physical indicators (Filip, 2002; Parisi et al., 2005; Ritz et al., 2009), were not included in this compilation. If the same authors proposed the same set of indicators in more than one publication, then only the first was considered. In two publications (Andrews et al., 2002; Biswas et al., 2017), two different sets of indicator were proposed. Thus, the total number of reviewed publications was 62 while the total number of indicator sets was 65.

Are we sure they are measured and analysed with the same method?

Review by Brussaard et al. 2018.
https://doi.org/10.1016/j.soilbio.2018.01.030

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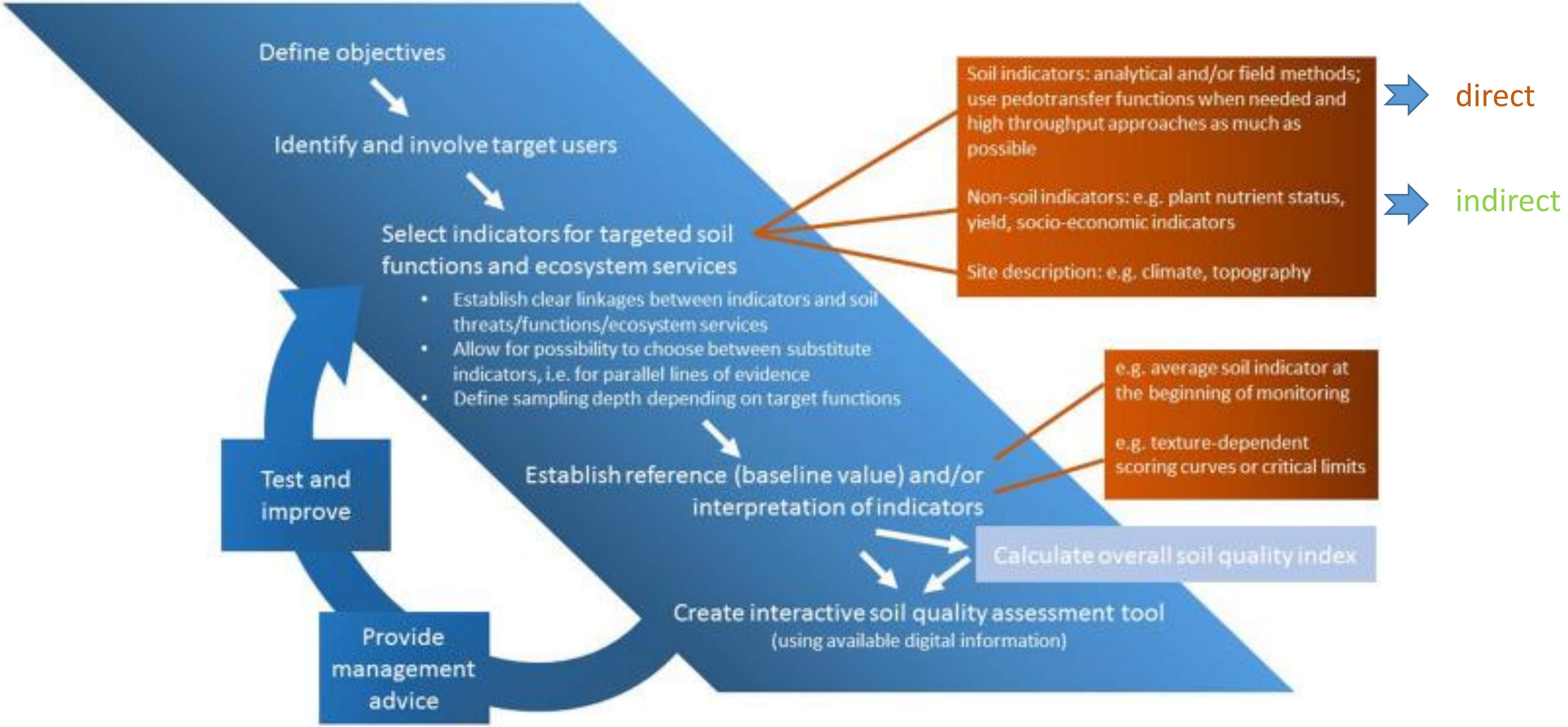
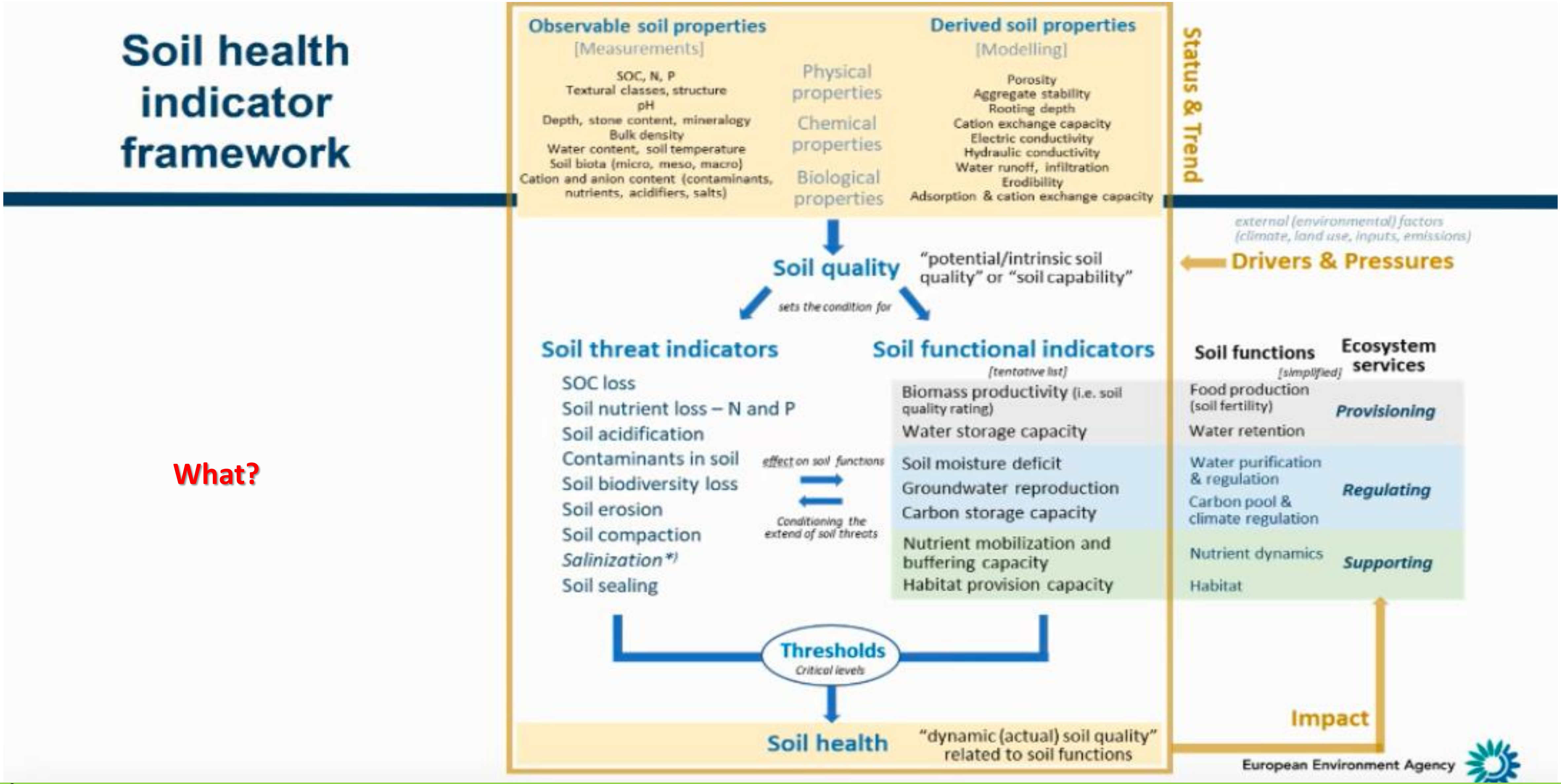
Main steps in the development of a soil quality assessment approach



Brussaard et al. 2012.
https://www.doi.org/10.1093/acprof:oso/9780199575923.003.0005

From research level to policy and.. viceversa!

AN EXAMPLE: EUROPEAN COMMISSION



What?

Soil status and trend, impact

Indicators

(Policy) Assessments

Status of the World's Soil Resources (FAO and ITPS, 2015, 2025, ff)

State and Outlook of the Environment (SOER 2020, 2025, 2030, ff)

National and European Soil Condition Assessments (ca. 10 cycles, 2020 ongoing)

Reginal and local soil management

Global Summary of Threats to Soil Functions

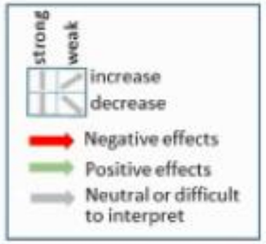
Region	Soil erosion	Organic carbon change	Nutrient imbalance	Salinization	Soil sealing	Loss of biodiversity	Soil pollution	Acidification	Compaction	Water-logging	Comments
Europe and Eurasia	Fair	Poor	Poor	Poor	Poor	Fair	Poor	Poor	Fair	Fair	In densely populated Western Europe, soil ealing is one of the most threatening phenomena. Salinization is a widespread threat in Central Asia and in some areas in Spain, Hungary, Turkey, and Russia.

Soil Threats

- Soil Sealing
- Erosion
- Loss of organic matter
- Decline in Biodiversity
- Contamination
- Compaction
- Landslides
- Salinization
- Eutrophication/ Acidification

Soil Functions

- Biomass production
- Storage and Filter
- Hosting Biodiversity
- Platform for human activities
- Provision raw materials
- Carbon Pool
- Archaeological heritage



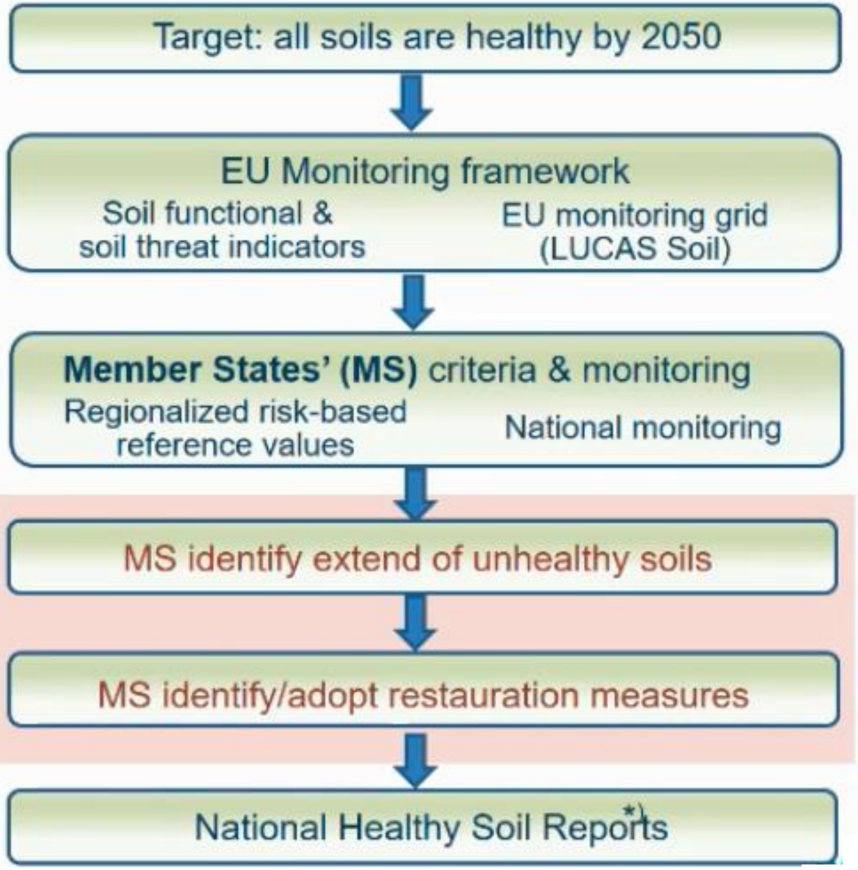
AN EXAMPLE: EUROPEAN COMMISSION

Conceptual basis of the EU Healthy Soil Law

Member states

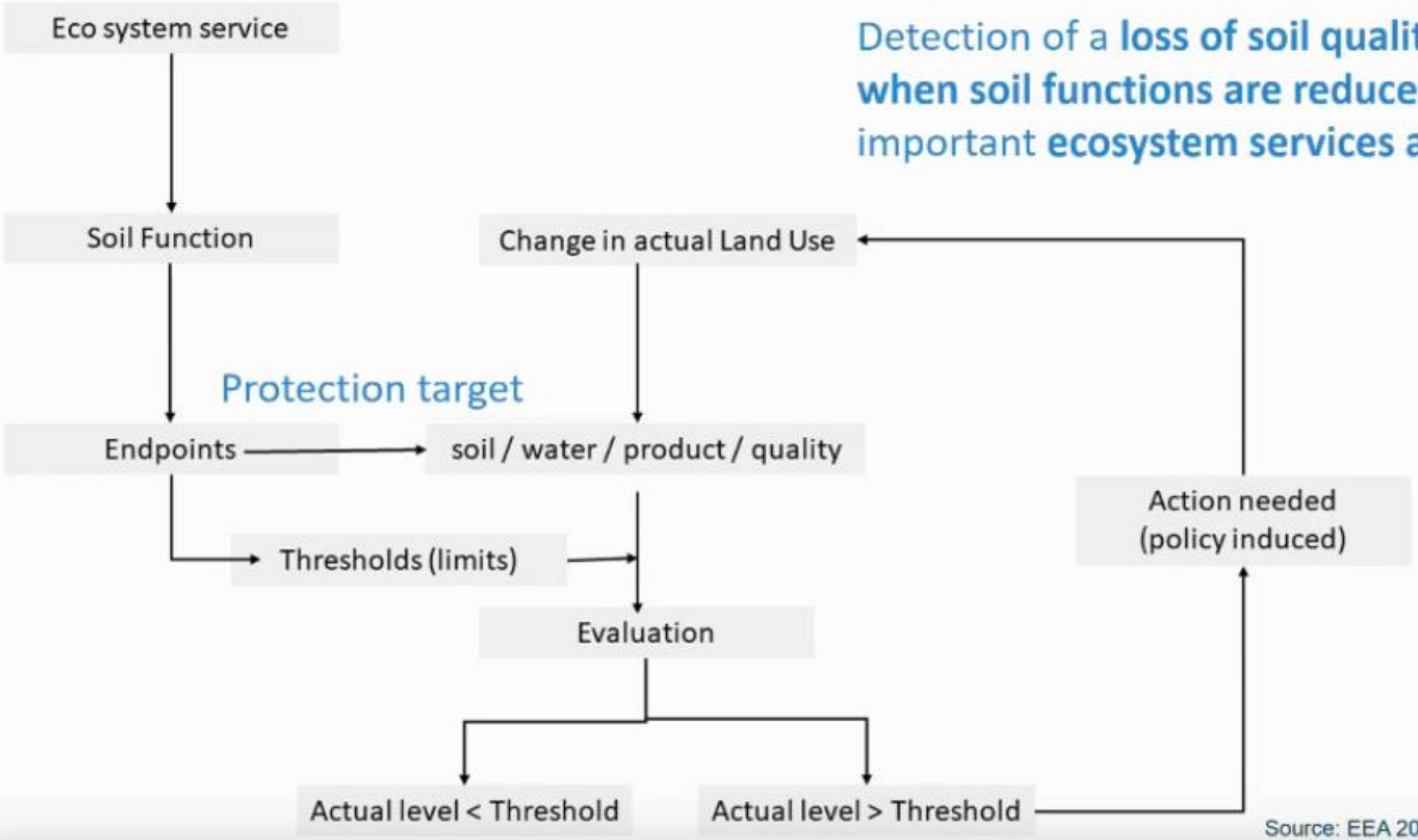
- To **identify unhealthy soils** as locations for restauration measures
- To monitor and report about the health of soils, in response to management plans

Where?



Healthy soils/degraded soils: risk-based approach

Detection of a **loss of soil quality** to a level **when soil functions are reduced** so that important **ecosystem services are affected**.

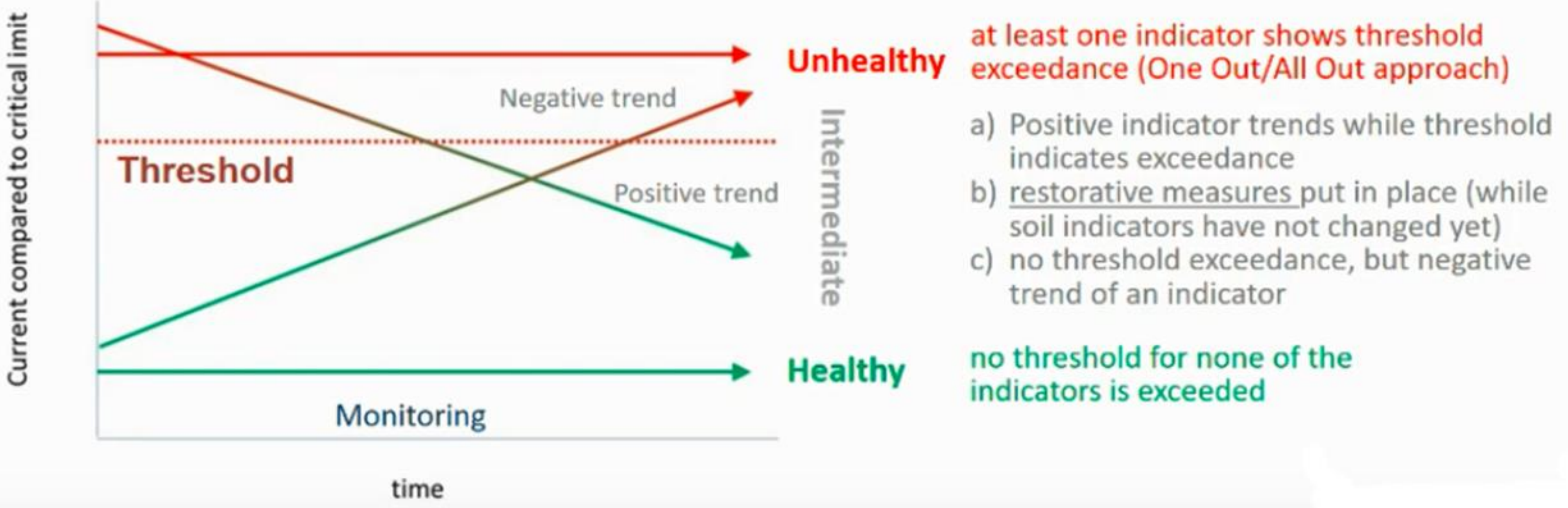


Source: EEA 2021 (Figure by P. Roemkens)

Dynamic assessment of soil degradation

Thresholds

- **indicate** a critical limit beyond which soil functions are "significantly" reduced or even lost: degraded/not degraded
- **serve** as orientation for the trend of soil recovery/degradation
- **prevent** harm from protection targets (water quality biodiversity, income, etc.)



Soil indicators and thresholds: state of the art

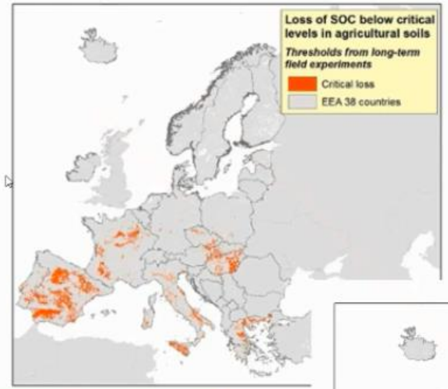
Soil threat	Land use	Indicator	Thresholds
Soil organic carbon loss	Agriculture	Deceedance of optimal SOC	Sand: 1,5 (1,0-2,0) [% SOC] Silt: 1,9 (1,4-2,4) Loam and clay: 1,6 (1,0-2,8)
Nutrient loss	Agriculture	Exceedance of critical levels of mineral nitrogen	NH_3 in air: 1 – 3 [mg NH_3 m^{-3}] NO_3 in ground water: 50 [mg NO_3 l^{-1}] N in surface water: 1.0 to 2.5 [mg N l^{-1}]
	Forest	N limitation based on exceedance of C/N ratio	C/N 20-25 leakage from forests: 1 [mg N l^{-1}]
	Agriculture	Deceedance of optimal phosphorus	P concentration 25-35 (optimal P fertility class)
	Forest	P limitation based on exceedance of N/P ratio	N/P ratio > 18 (coniferous forests) N/P ratio > 25 (deciduous forests)
Acidification	Agriculture	Critical pH levels	pH < 4.5 - 4.7
	Forest	Critical inorganic Al levels	base cation/aluminium ratio = 1 (0.5-2.0)
Soil pollution	Agriculture	Exceedance of screening values for critical risk from heavy metal pollution	Cd, Cu, Pb and Zn by country [mg/kg] (Arsenic still to be added; review of organic pollutants ongoing)
Soil erosion	Agriculture	Actual rate of soil loss by water erosion	2 [t ha^{-1} yr^{-1}] (soil loss tolerance)
Soil biodiversity loss		Loss of soil biodiversity (subindicators) *to be developed*	a) safe minimum standard of conservation b) Operating Ranges (OR) for specific soil animals and microorganisms
Soil compaction	Agriculture	Harmful subsoil compaction (subindicators) *priority (sub) indicators*	Saturated hydraulic conductivity (Ks) < 10 [cm/d] Air capacity (AC) < 5 [%]
Soil sealing		Sealed area per total area	National targets to achieve No Net Land Take

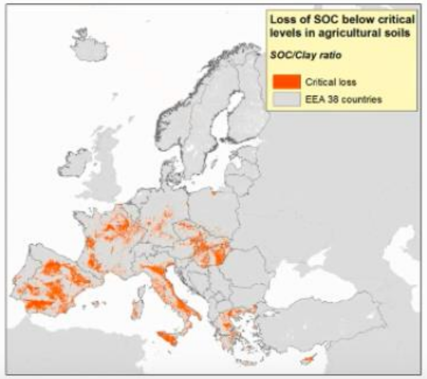
Soil indicators and thresholds: soil organic carbon (SOC)

	Definition
Reference values	Site-specific, typical SOC or SOM values under current management
	Benchmark SOC values
	– Natural soils (forest soils with low historic disturbance)
	– 25 quartile of the SOC median for permanent grassland
	– Modelled SOC steady state (25 yrs) for grassland
	Optimal SOC content for soil functioning (based on the role of SOC in soil functional PTF, combined with data from long term field experiments)
Soil vulnerability index based on the SOC/clay ratio	
Reciprocal SOC sequestration potential	
Thresholds from long-term field experiments	
Farmers perspective on deficient SOC	

AN EXAMPLE: EUROPEAN COMMISSION

Indicator "Functional SOC deficiency" for arable land





Climatic regions	Long-term field experiments	SOC/Clay ratio
Alpine	1,5%	13,9%
Atlantic	12,3%	27,3%
Boreal	0,0%	0,2%
Continental	13,6%	23,8%
Mediterranean	59,7%	75,9%
EU25	25,2%	37,1%

Soil erosion functional indicators

Define target soil quality: minimum good status of potential ecosystem service supply

Threshold: site-specific limits for tolerable erosion rates are needed

Steinhoff-Knopp et al. (2020)

Ecosystem service	Indicator	Specification	Status ecosystem service supply					
			0 no	1 very low	2 low	3 medium	4 high	5 very high
Crop provision	potential arable yield	Potential yield winter barley [t/ha]	0	≤ 2500	2500 - 2875	2875 - 3250	3250 - 3625	≥ 3625
Water filtration	Nitrate leaching vulnerability	Water exchange rate [%/a]	0	≥ 250	150 - 250	100 - 150	70 - 100	< 70
Water flow regulation	Water storage capacity	potential storable water [mm]	0	< 50	50 - 90	90 - 140	140 - 200	≥ 200
Fresh water provision	Percolation rate	Percolated water [mm/a]	0	< 200	200 to < 250	250 to < 300	300 to < 350	≥ 350

..other open questions in soil monitoring:

1) chemical and physical indicators: harmonization?

2) biological indicators: where we are?

3) what about new threats?

1) Chemical and physical indicators: harmonization?

What about new measurement methods?

Quantitative vs qualitative, for example

Proximal and remote sensors for soil quality

European Journal of **Soil Science**

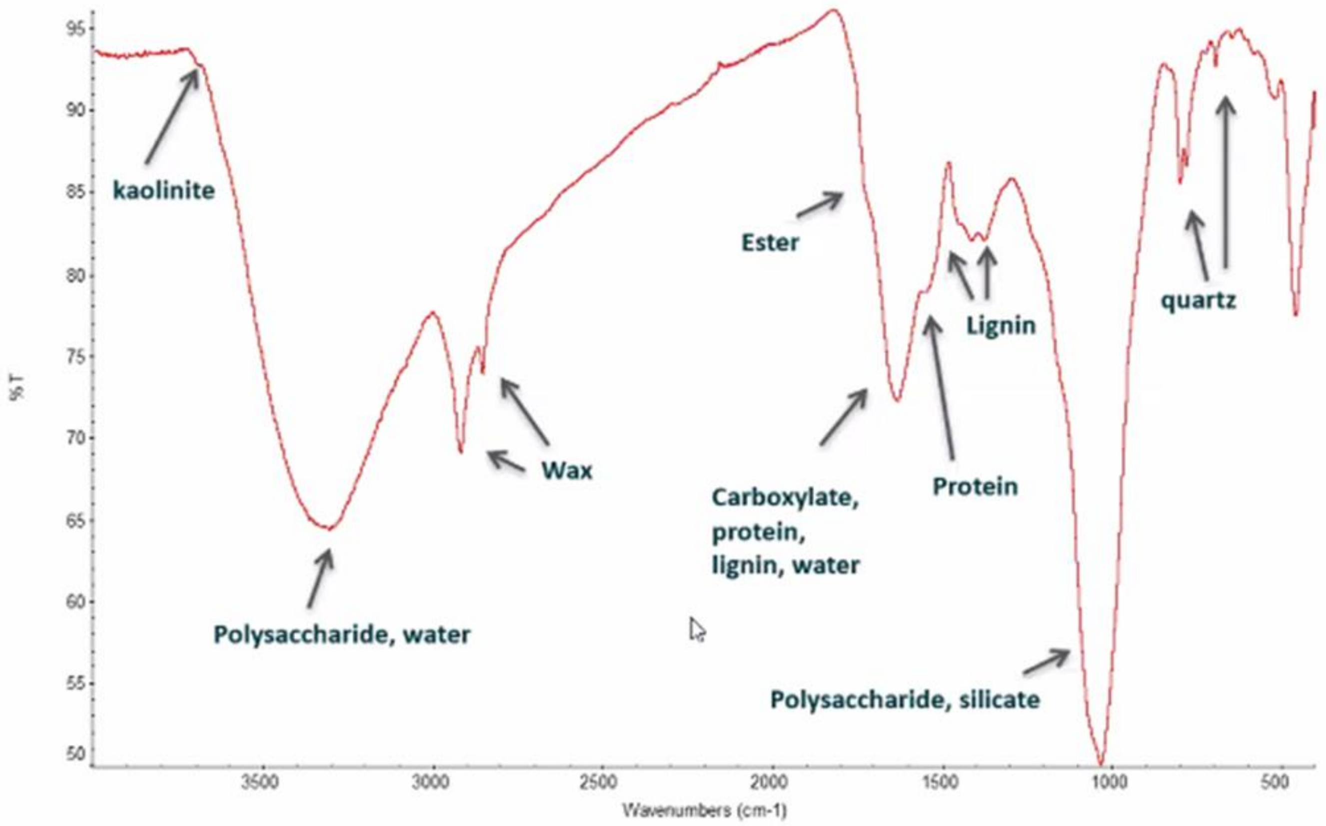
European Journal of Soil Science, December 2010, **61**, 865–876 doi: 10.1111/j.1365-2389.2010.01301.x

Soil properties prediction of western Mediterranean islands with similar climatic environments by means of mid-infrared diffuse reflectance spectroscopy

L. P. D'Acqui[a], A. Pucci[a] & L. J. Janik[b]

The IR Spectrum of an Organic Soil

The James Hutton Institute



Artz et al. (2008) Soil Biol. Biochem. 40, 515–527 doi: http://dx.doi.org/10.1016/j.soilbio.2007.09.019

2) Biological indicators: where we are?

Soil biodiversity and policy…

By Orgiazzi 2022

2) Biological indicators: where we are?

CSIRO PUBLISHING

Soil Research, 2020, **58**, 1–20
https://doi.org/10.1071/SR19067

Review

Soil biodiversity and biogeochemical function in managed ecosystems

X. D. Chen[A,F,G], *K. E. Dunfield*[B], *T. D. Fraser*[C], *S. A. Wakelin*[D], *A. E. Richardson*[E], and *L. M. Condron*[F,H]

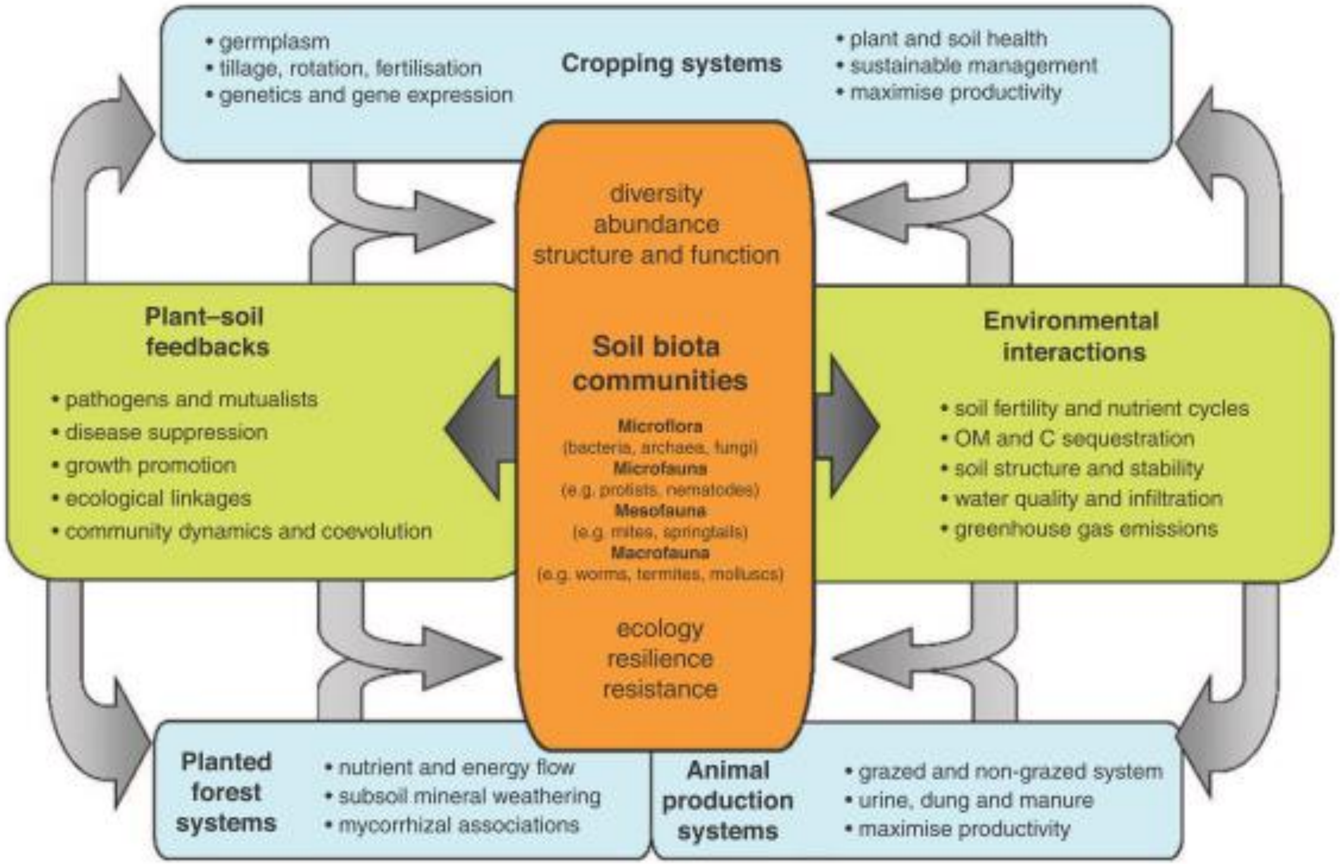


Fig. 1. Schematic representation of major links between soil biota and functional processes in managed ecosystems represented by intensive cropping, animal production, and planted forest systems.

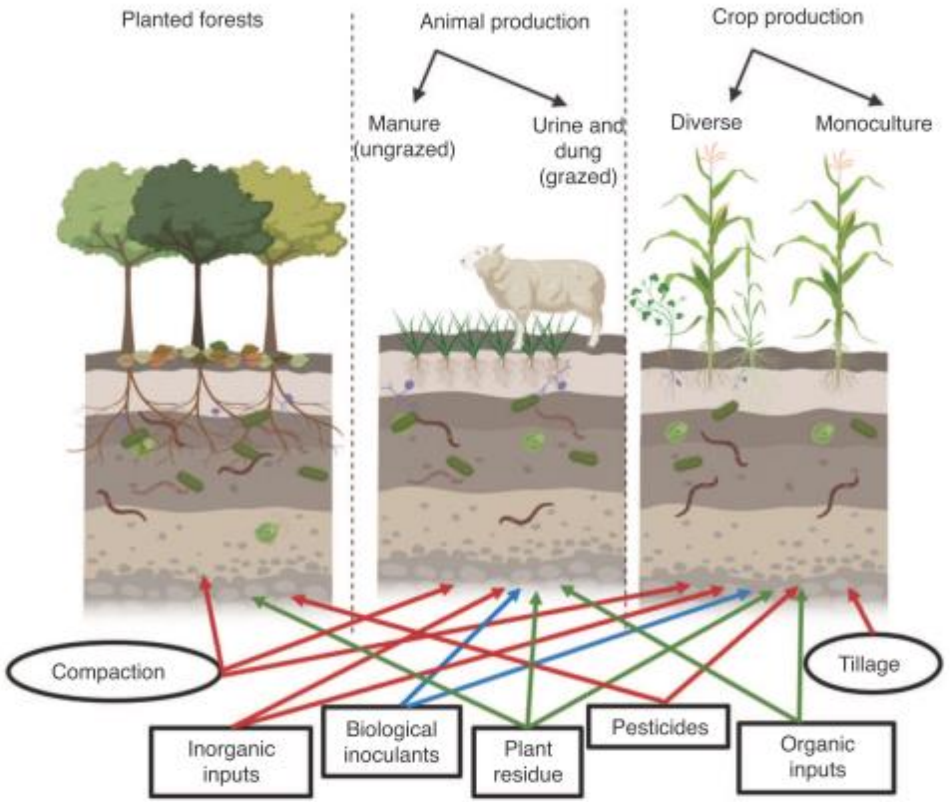


Fig. 2. Main inputs (rectangles) and disturbance (circles) identified in managed ecosystems (planted forests, animal production, and crop production) that influence microbial diversity and function. The generalised impact on soil biodiversity by each is depicted by green (positive), blue (neutral/unknown), and red (negative) arrows. Drawing is not to scale.

2) Biological indicators: where we are?

..a proposed approach..

..sometimes impossible..

Received: 6 July 2017 | Revised: 11 December 2017 | Accepted: 13 December 2017

DOI: 10.1111/mec.14478

INVITED REVIEWS AND SYNTHESES

WILEY MOLECULAR ECOLOGY

Scaling up: A guide to high-throughput genomic approaches for biodiversity analysis

Teresita M. Porter[1,2] | Mehrdad Hajibabaei[1]

Biomonitoring
Repeated biodiversity measurements across time and space

Biodiversity
Measurement of alpha, beta, and gamma diversity for community analyses
Integration of DNA-based, biological and environmental ecological indicators

DNA-based indicators

Includes ESVs, OTUs, taxa, genes, genomes, metagenomes, metatranscriptomes, or metabolic activity predicted from sequence analysis.

Identification of sequences by comparison with reference databases according to predefined cut-offs.

Biological indicators

Includes species, indicator assemblages, communities, trophic guilds, biomass, density or metabolic activity derived from direct measurement.

Identification of species largely based on morphological characters and manual comparison with taxonomic keys.

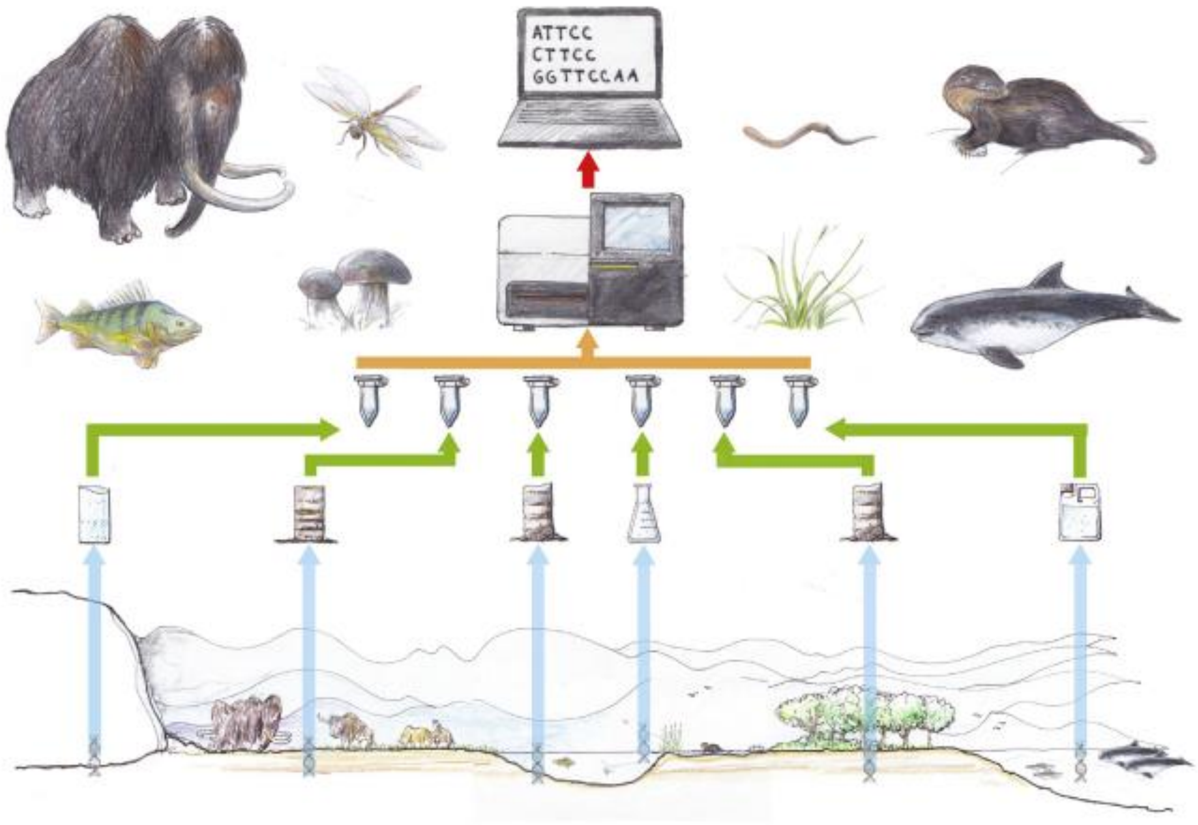
Environmental indicators

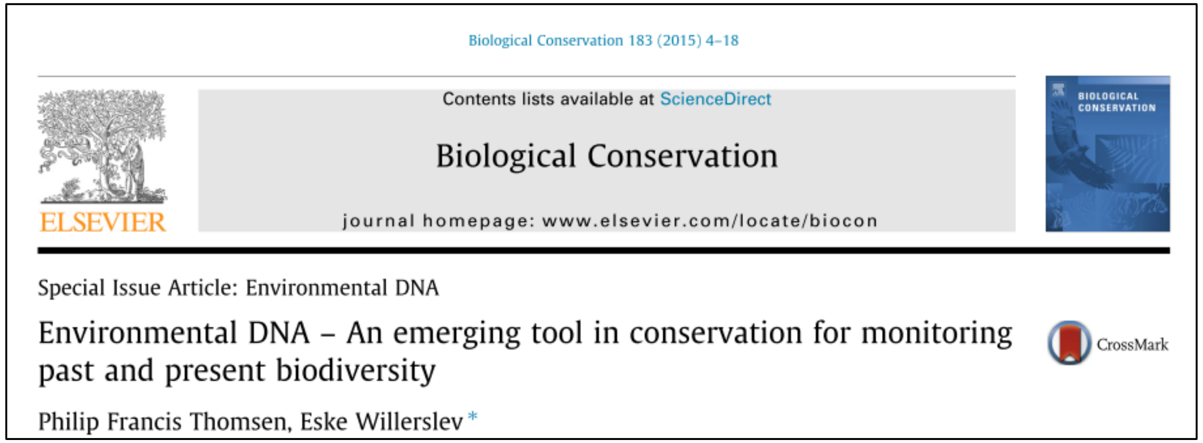
Site characteristics such as nutrient levels, moisture, temperature or other structural measures.

Earth observation data such as numerical weather data, photograph radar or sonar imagery.

FIGURE 1 Integration of data types in biodiversity genomics. Boxes outline the various ways biodiversity can be sampled using DNA-based or traditional methods that use biological and environmental ecological indicators

2) Biological indicators: where we are?




Biological Conservation 183 (2015) 4–18
Contents lists available at ScienceDirect
Biological Conservation
journal homepage: www.elsevier.com/locate/biocon

Special Issue Article: Environmental DNA

Environmental DNA – An emerging tool in conservation for monitoring past and present biodiversity

Philip Francis Thomsen, Eske Willerslev *

eDNA

Genetic material obtained directly from environmental samples (soil, sediment, water, etc.) without any obvious signs of biological source material

2) Biological indicators: where we are?

Science of the Total Environment 749 (2020) 142262

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

ELSEVIER

Changes in soil microbial communities in post mine ecological restoration: Implications for monitoring using high throughput DNA sequencing

M. van der Heyde [a,b,*], M. Bunce [b,c], K. Dixon [a], G. Wardell-Johnson [a], N.E. White [b], P. Nevill [a,b]

Biological Conservation 217 (2018) 113–120

Contents lists available at ScienceDirect

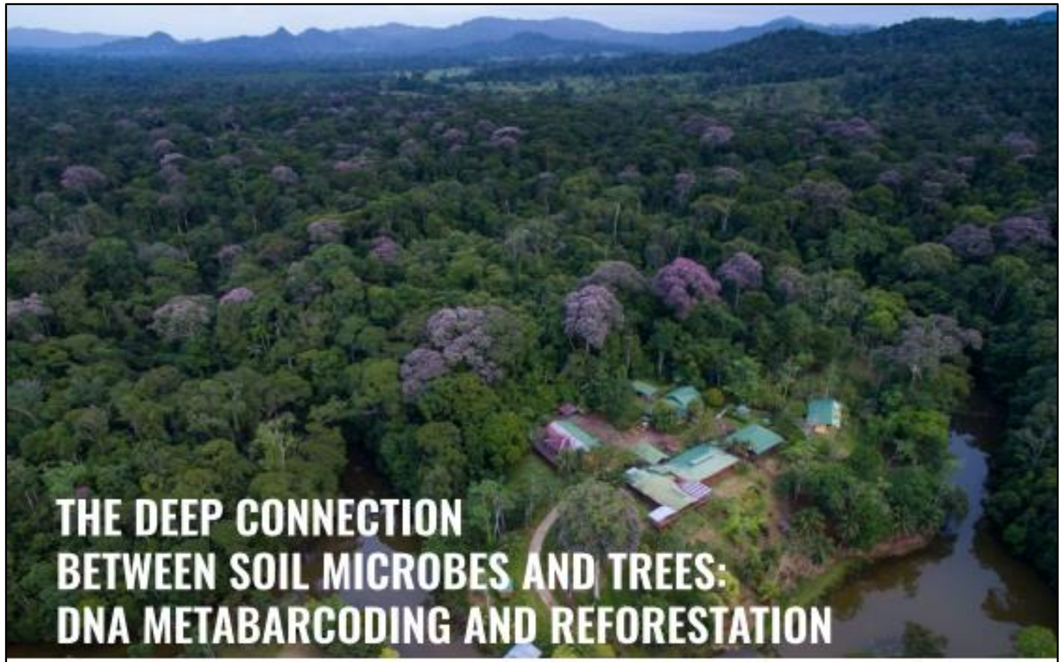
Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

ELSEVIER

High-throughput eDNA monitoring of fungi to track functional recovery in ecological restoration

DongFeng Yan[a,b], Jacob G. Mills[a], Nicholas J.C. Gellie[a], Andrew Bissett[c], Andrew J. Lowe[a,*], Martin F. Breed[a,*]



by KATIE M. MCGEE and MEHRDAD HAJIBABAEI

2) Biological indicators: where we are?

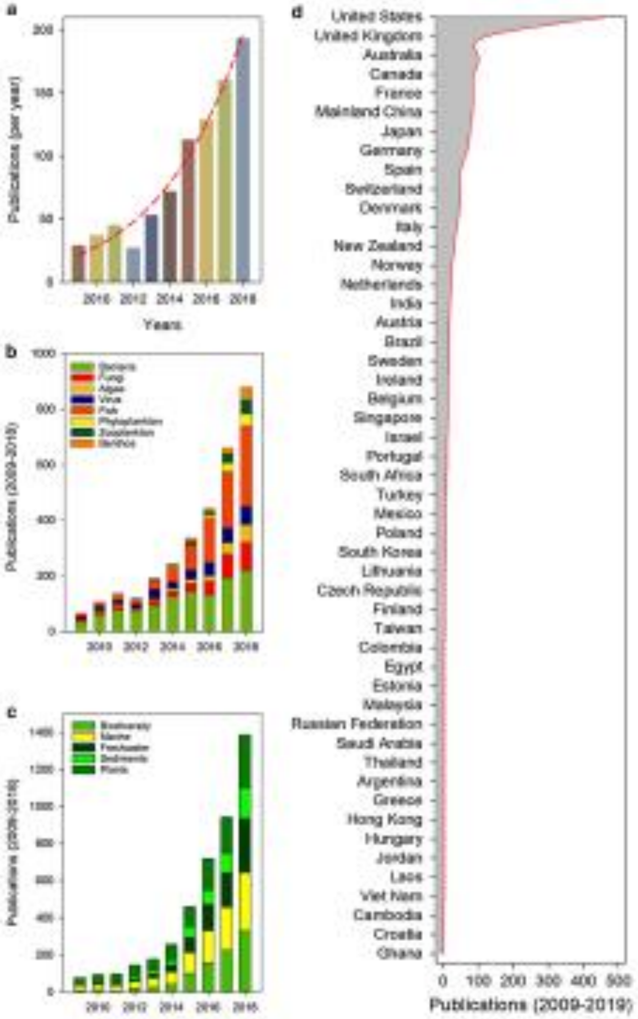


Fig. 1 a Publication trends of eDNA from 2009 to 2019 Jan retrieved from the publication database using the search term 'eDNA'. b–d eDNA analysis based on area of utilization and publications from different countries (top 50 countries in terms of publications from 2009 to 2019). a Source: https://www.ncbi.nlm.nih.gov/pubmed. b–d Source: https://www.scopus.com

Rev Environ Sci Biotechnol (2019) 18:389–411
https://doi.org/10.1007/s11157-019-09501-4

MINI REVIEW

A review on the applications and recent advances in environmental DNA (eDNA) metagenomics

Deviram Garlapati · B. Charankumar · K. Ramu · P. Madeswaran · M. V. Ramana Murthy

Table 1 Literature-based search (PubMed and Scopus)

Search word	Search fields	Number of hits in major databases		Last updated
		PubMed	Scopus	
"eDNA*"	Article title, Abstract, Keywords	1066	1444	16/01/2019
"eDNA AND aquatic*"	Article title, Abstract, Keywords	241	141	16/01/2019
"eDNA AND marine*"	Article title, Abstract, Keywords	94	93	16/01/2019
"eDNA AND freshwater*"	Article title, Abstract, Keywords	111	122	16/01/2019
"eDNA AND sediments*"	Article title, Abstract, Keywords	29	57	16/01/2019
"eDNA AND diversity*"	Article title, Abstract, Keywords	97	140	16/01/2019
"eDNA AND soil*"	Article title, Abstract, Keywords	59	92	16/01/2019

2) Biological indicators: where we are?

forests

MDPI

Article

Evaluation of Soil Biodiversity in Alpine Habitats through eDNA Metabarcoding and Relationships with Environmental Features

Noemi Rota [1,*], Claudia Canedoli [1], Chiara Ferrè [1], Gentile Francesco Ficetola [2,3], Alessia Guerrieri [2] and Emilio Padoa-Schioppa [1]

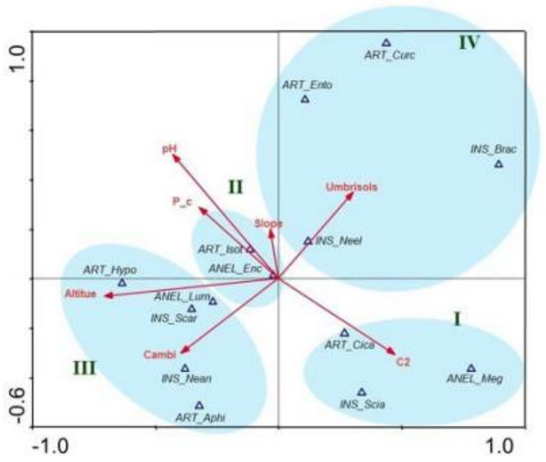


Figure 5. Biplot of grassland environmental features and soil communities resulting from CCA analysis (environmental features are indicated in red, soil communities are indicated in black with a blue triangle, and blue circles with the Roman numeral indicate clusters). The suffixes ART, ANEL, and INS refer to the targets: arthropods, annelids, and insects.

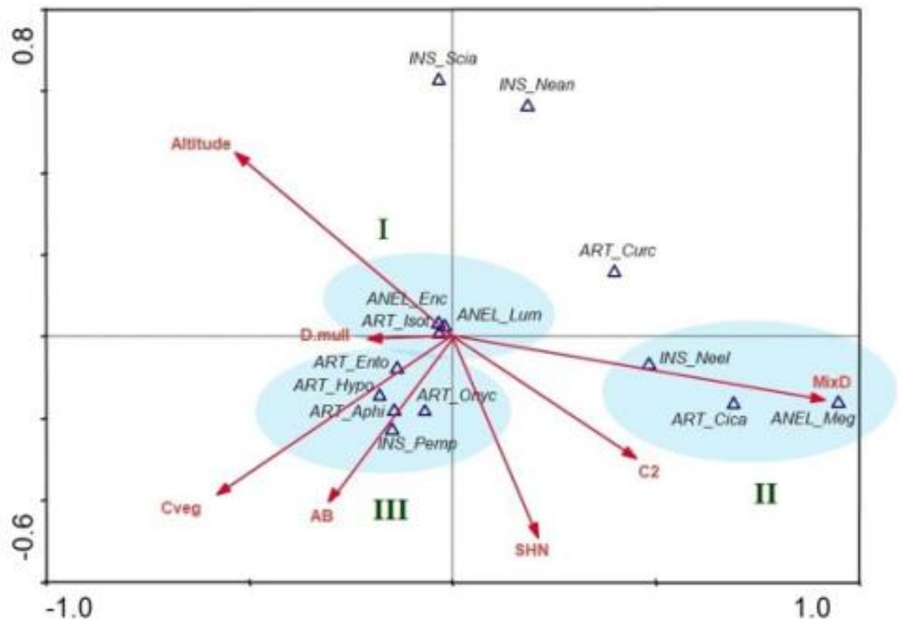
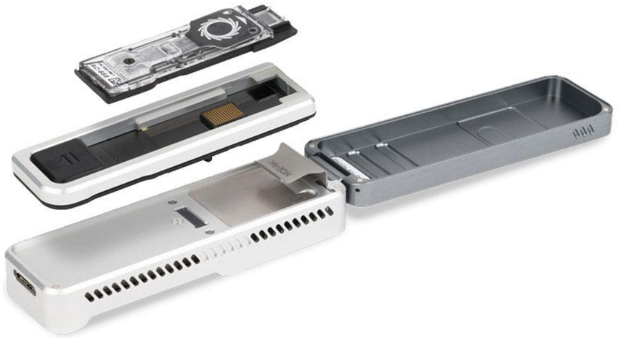


Figure 4. Biplot of forests environmental features and soil communities resulting from CCA analysis (environmental features are indicated in red, soil communities are indicated in black with a blue triangle, and blue circles with Roman numeral indicate clusters). The suffixes ART, ANEL, and INS refer to the targets: arthropods, annelids, and insects.

2) Biological indicators: where we are?

Equipment?



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Methodology article | Open Access | Published: 29 September 2021

ONTbarcoder and MinION barcodes aid biodiversity discovery and identification by everyone, for everyone

Amrita Srivathsan, Leshon Lee, Kazutaka Katoh, Emily Hartop, Sujatha Narayanan Kutty, Johnathan Wong, Darren Yeo & Rudolf Meier

BMC Biology **19**, Article number: 217 (2021) | Cite this article

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It was developed via “innovation through subtraction” and thus requires **minimal lab equipment**, can be **learned within days**, reduces the barcode sequencing **cost to < 10 cents**, and allows **fast turnaround from specimen to sequence** by using the portable MinION sequencer.

2) Biological indicators: where we are?

Equipment?

Key points
(why I like this paper)

- Decentralizes sequencing
- Reverse workflow (i.e. sequence all specimens)
- Engage community and stakeholders
- Provides extensive methods section
- Suggest simpler lab protocols
- New tool for bioinformatics
- Made possible by technological improvements
- Can be used for projects of different sizes (up to 10 000 amplicons)

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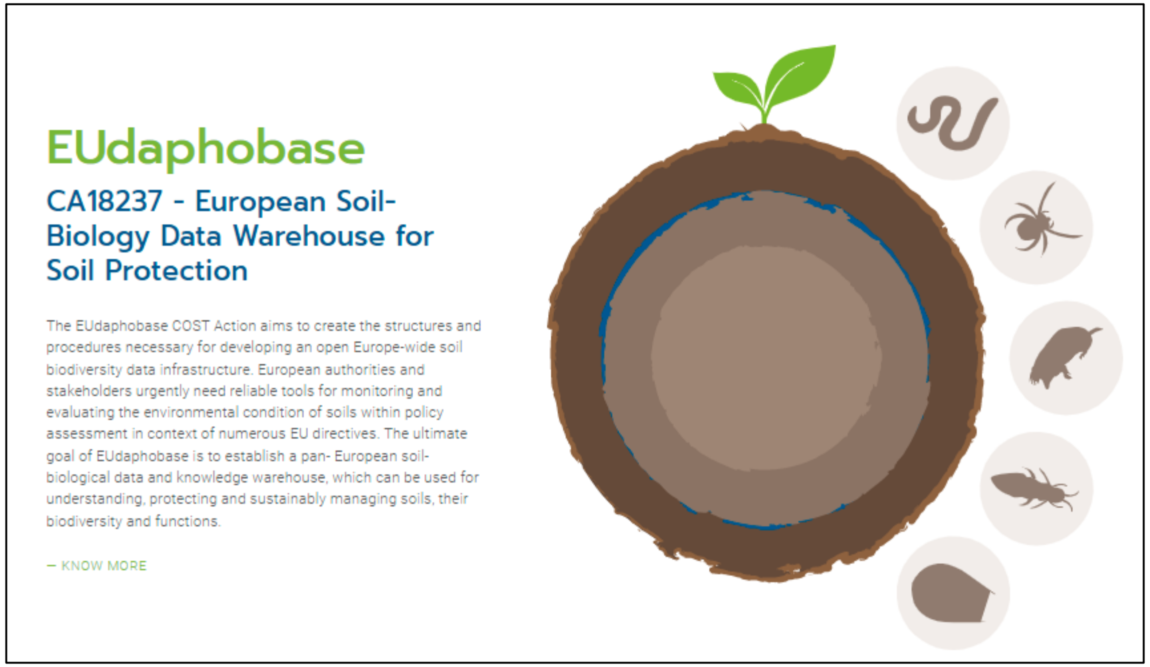
Step 1: DNA Extraction with hotSHOT

Sett 480 ganger • 25. mar. 2021 • This video shows DNA ext Vis mer | 8 | Liker ikke | Del | Lagre

ENV PRO CNR IRET

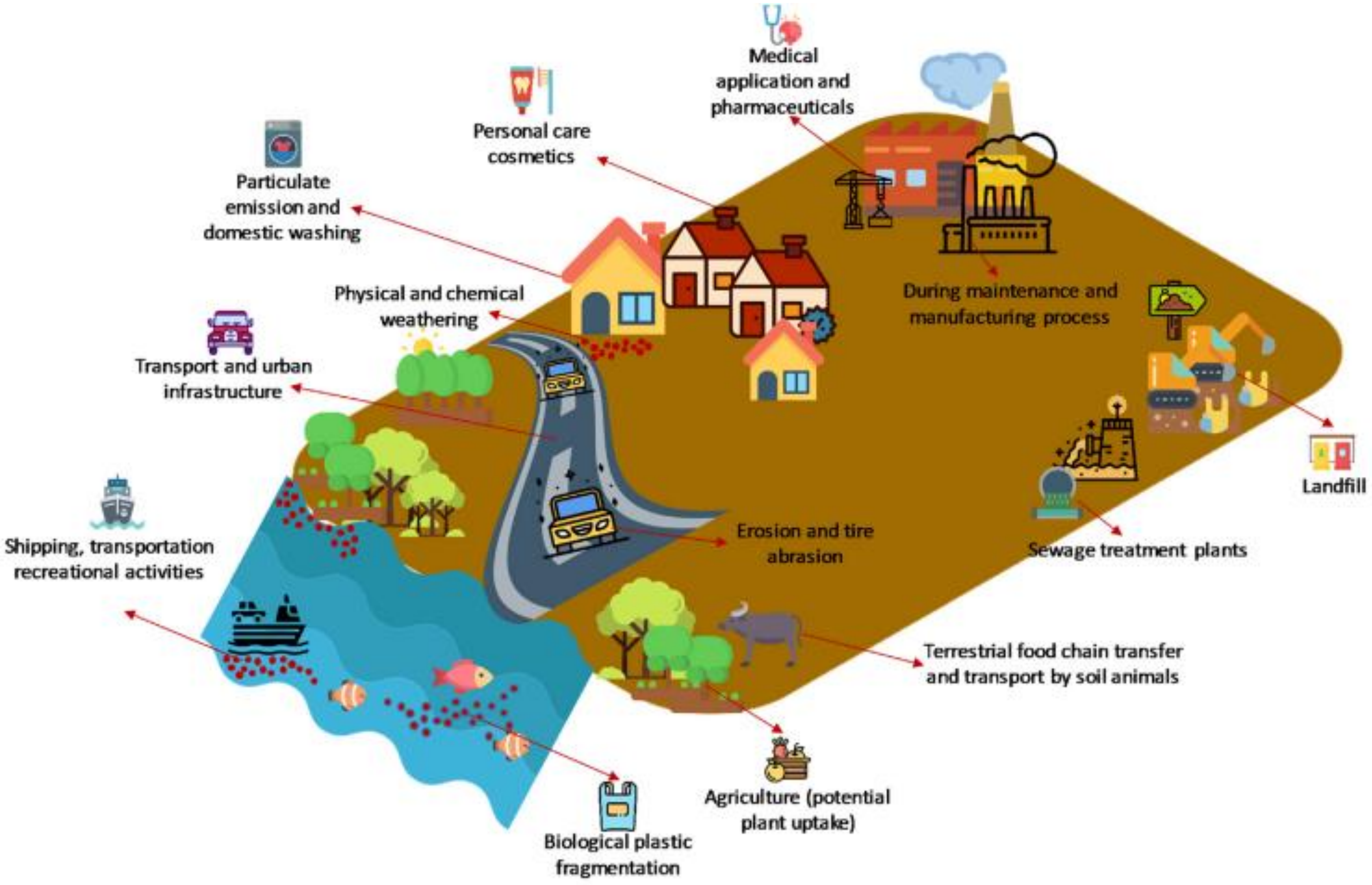
2) Biological indicators: where we are?

..some suggestions..



3) what about new threats?

An example……microplastics and terrestrial environments (thanks to urban compost!)

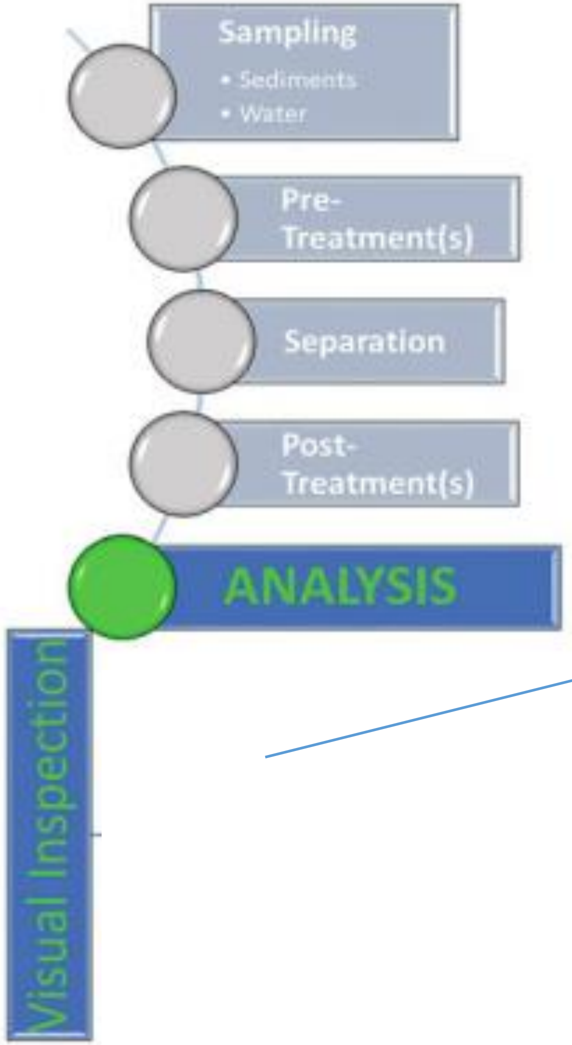


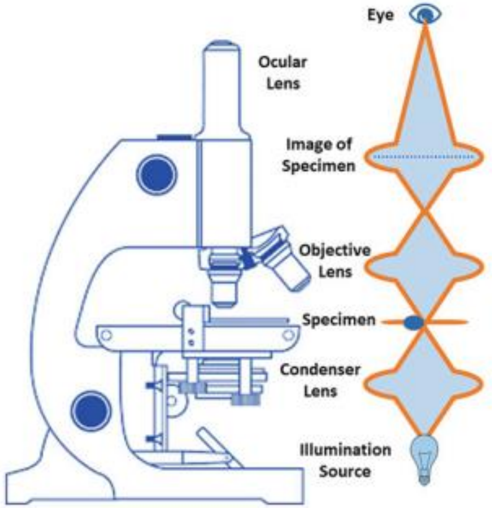
Generation and dispersion of microplastics in terrestrial environments (adapted and modified from Karbalaei et al., 2018).

3) what about new threats?

Development of a pipeline for microplastic analysis in IRET

Schematic representation of microplastics analysis
using microscopy and spectroscopy

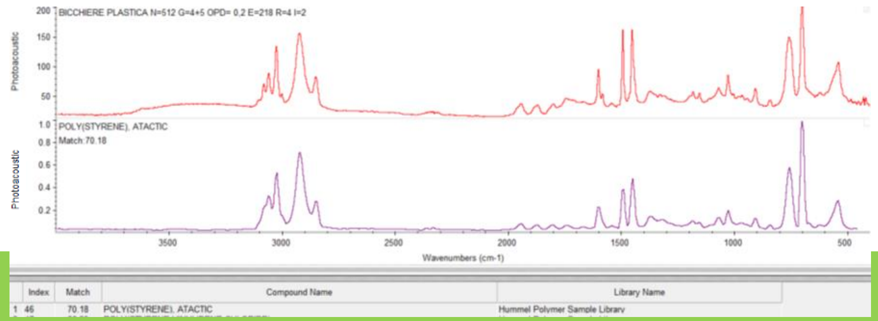




FTIR-PAS to identify microplastics

- versatile
- time-costing
- sensible

Promising tool for the identification of microplastics in complex matrices

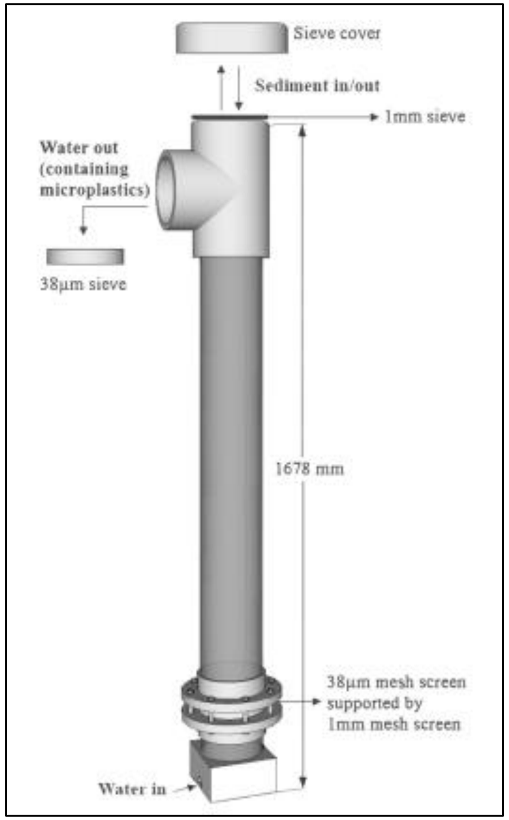


3) what about new threats?

A novel approach to extract, quantify and identify microplastics in soils; a farmland case study in Mediterranean area ☆☆

Luigi Paolo D'Acqui[b,1], Sara Di Lonardo[1,1], Alessandro Dodero[1,1], Alessandra Bonetti[1,1], Fabrizio Filindassi[1,1], Ottorino-Luca Pantani[a,1]

The device used by Claessens et al. 2013



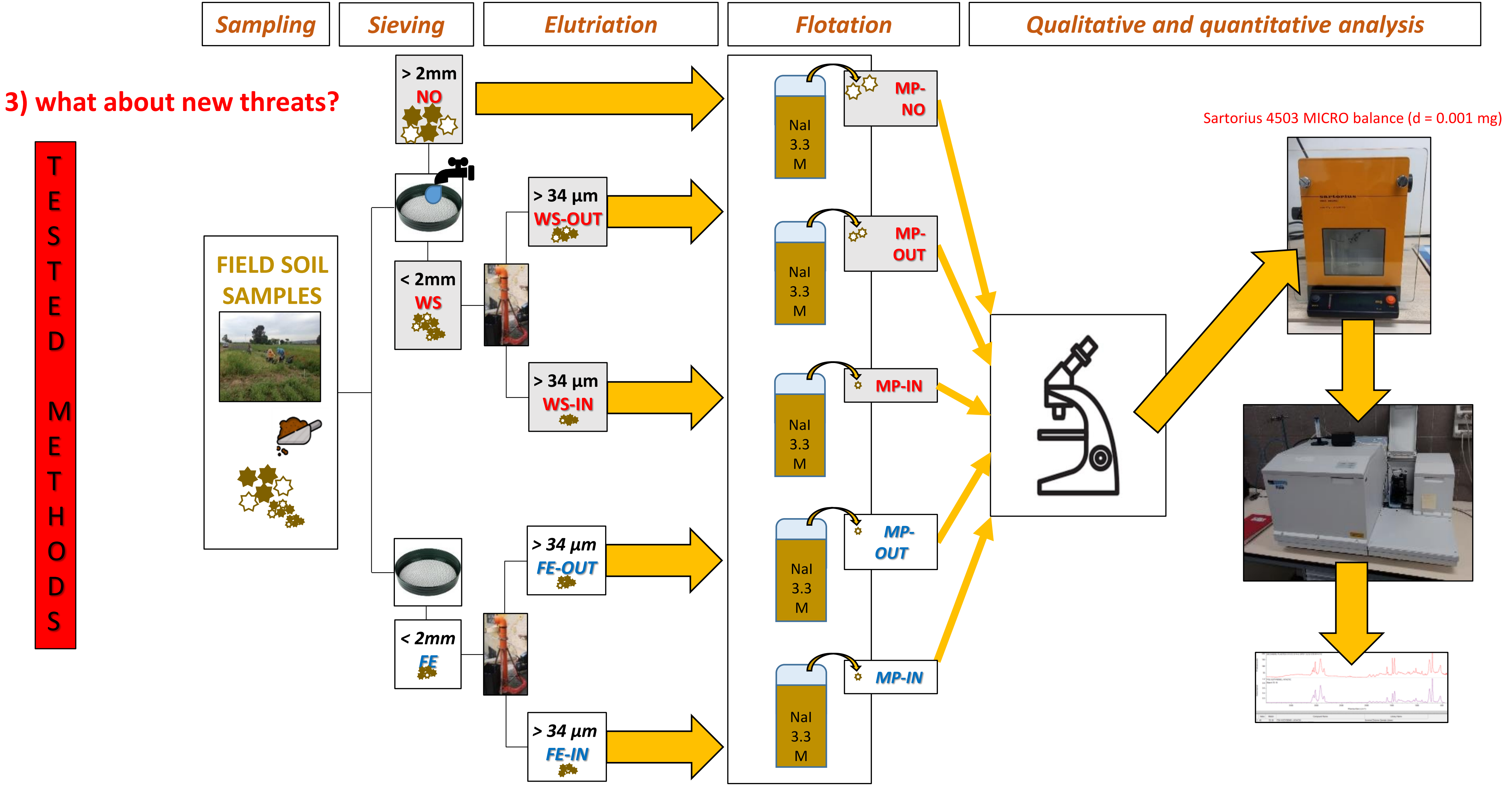
The device used in our exp

Aims:

(1) developing a protocol to identify plastic residues as found along the soil particle size distribution;

(2) monitoring the contribution of urban composts in agricultural soils to MPs contamination.

We investigated compost from recycled urban waste as possible vehicle for the entry of MPs into the environment and we adapted some sediment fractionation procedures to separate and identify MPs. We investigated agricultural soils in inland hilly areas of Italy, where municipal solid waste composts were applied since 2005.

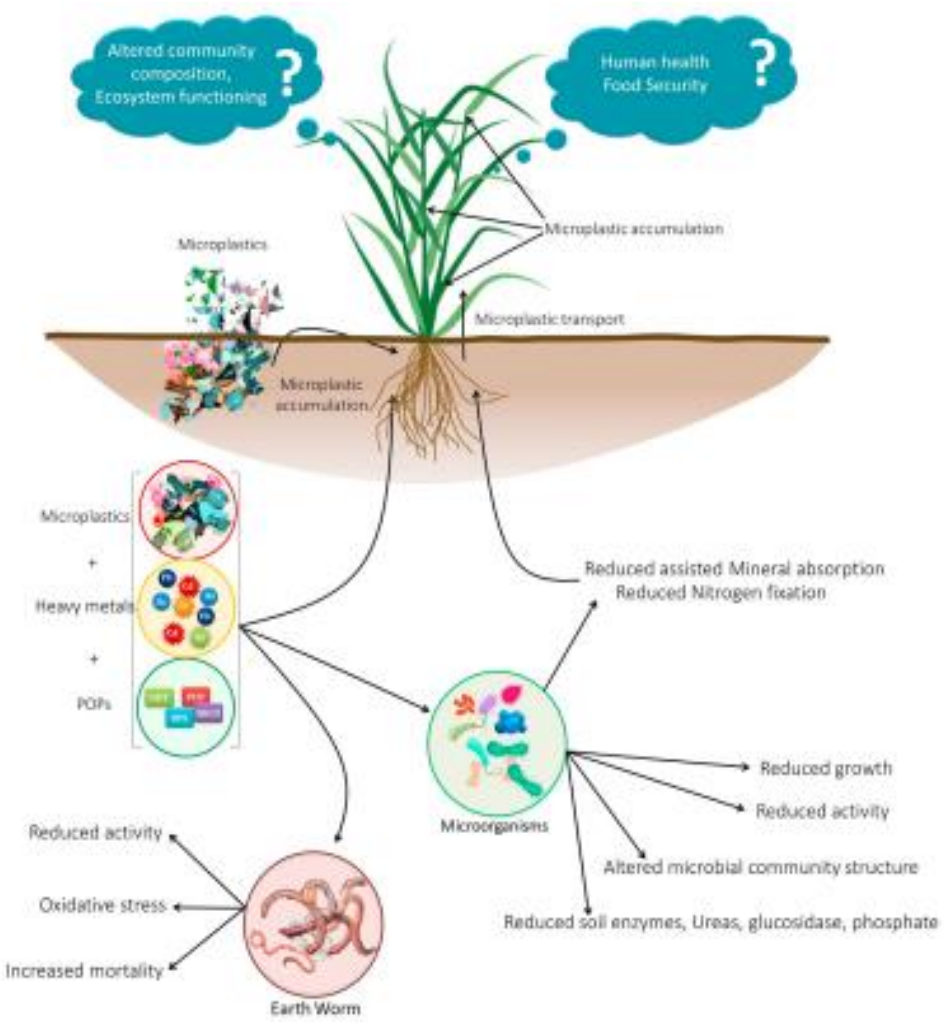


3) what about new threats?
TESTED METHODS
Sampling
Sieving
Elutriation
Flotation
Qualitative and quantitative analysis
FIELD SOIL SAMPLES
> 2mm
NO
< 2mm
WS
> 34 µm
WS-OUT
> 34 µm
WS-IN
< 2mm
FE
> 34 µm
FE-OUT
> 34 µm
FE-IN
NaI 3.3 M
MP-NO
MP-OUT
MP-IN
MP-OUT
MP-IN
Sartorius 4503 MICRO balance (d = 0.001 mg)

3) what about new threats?

Urban compost…..Microplastics and terrestrial ecosystems

Other issues!



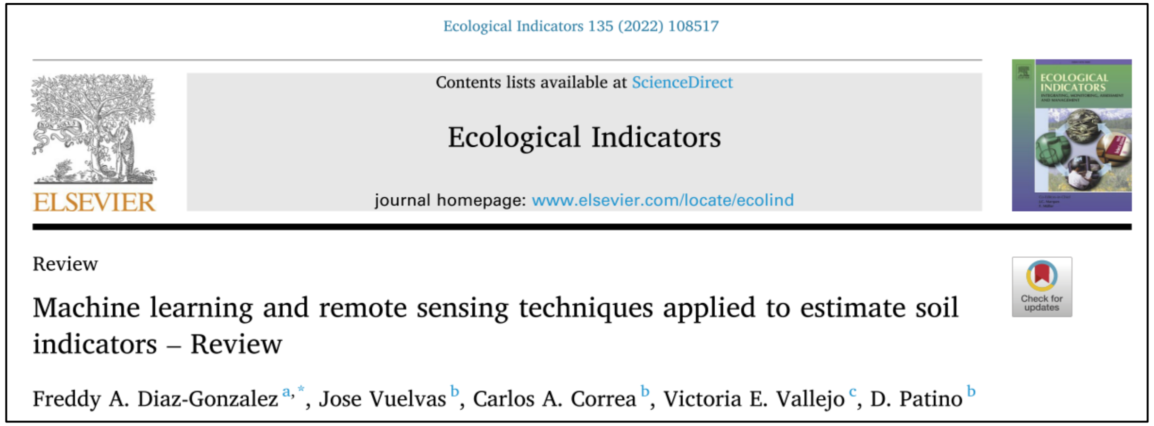
MPs in the soil affect plant growth directly or indirectly by impacting the growth of soil-dwelling organisms.

What about plants and microrganisms?
And other organic pollutants?

The never ending story..FINAL remarks

- Soil functional indicators require conceptional refinement (while remaining simple) and maturity
- Thresholds: they depends from various parameters (ecosystems, country/regions, etc)
- Impacts on end-points are needed
- SOC: may be the most important parameter for the production
- Data source and methodologies (harmonisation) need to be revised

The future..in the present!



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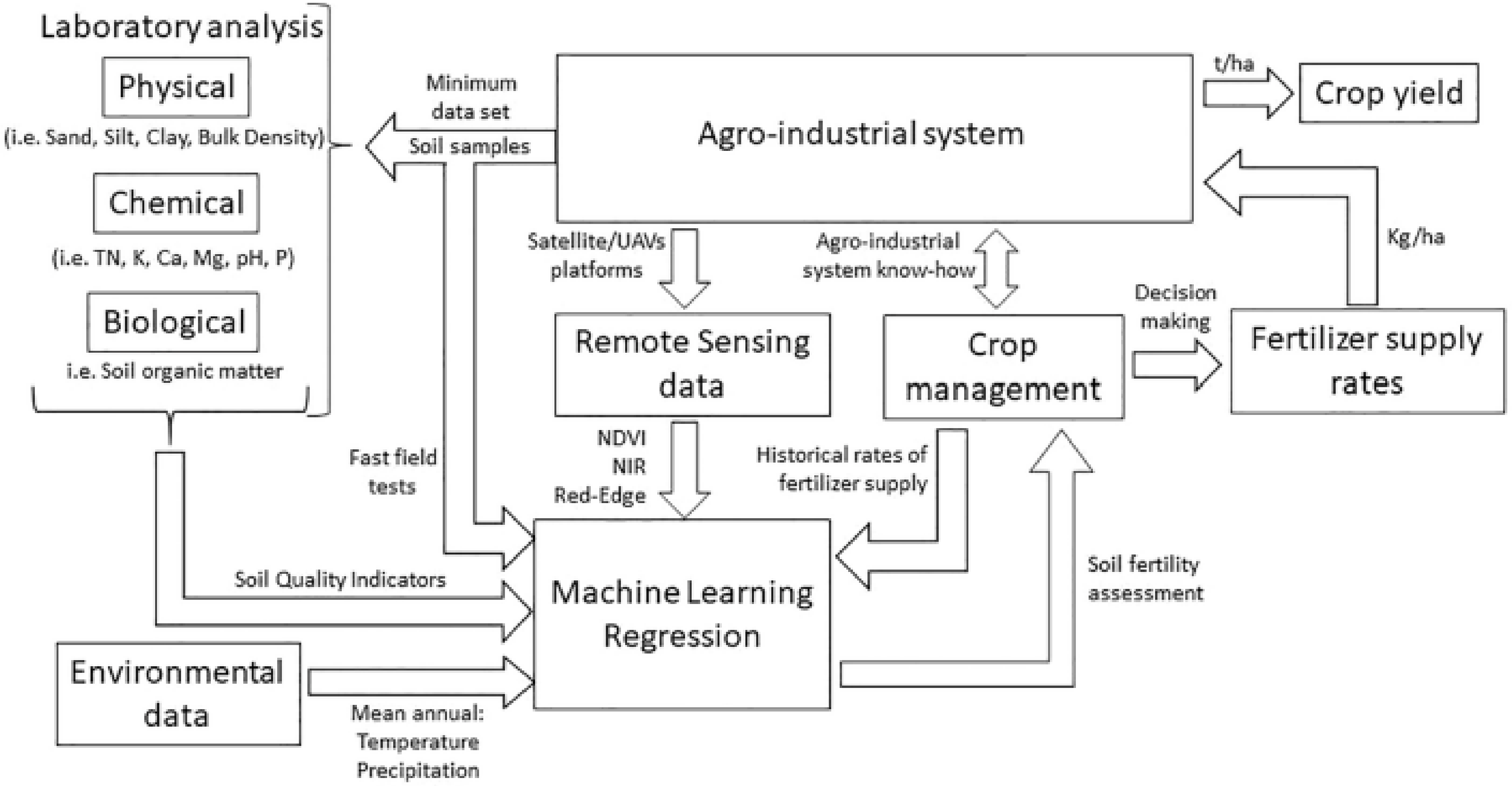
Review

Machine learning and remote sensing techniques applied to estimate soil indicators – Review

Freddy A. Diaz-Gonzalez [a,*], Jose Vuelvas [b], Carlos A. Correa [b], Victoria E. Vallejo [c], D. Patino [b]



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Take home message

As humans, we can't make soil.

Only soil organisms (plants, microbes, earthworms) can make healthy soil!

We can only provide the environment!

Sara Di Lonardo
CNR-IRET (Firenze, Italy)

Soil quality: from chemical indicators to biodiversity

Thanks for your attention!

12 July 2022