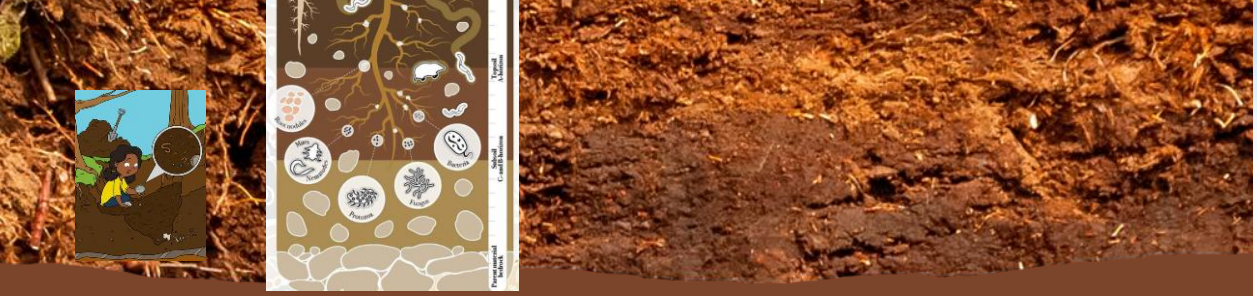
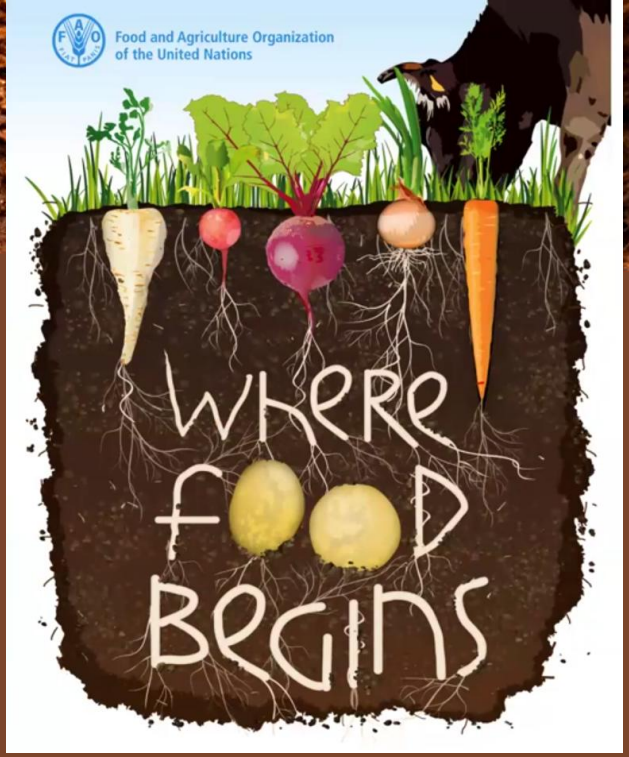




Soil health indicators and monitoring
relevant scientific findings from EJP SOIL

Rajasekaran Murugan, Antonio Bispo, Claire Chenu, Cristina Aponte, Stefano Mocali, Jack Faber, Guénola Pérès, Maria Fantappiè

EJP SOIL
European Joint Programme

Soils for Europe 30.04.2025, Brussels

EJP SOIL has received funding from the European Union's Horizon 2020 research and innovation programme: Grant agreement No 862695

Why soil health monitoring is relevant?

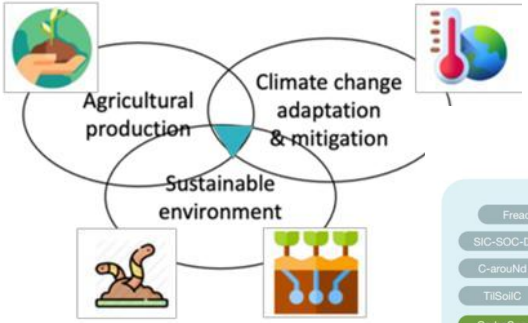
- Soils are a finite source and are evolving due to soil degradation

Panagos et al.2024

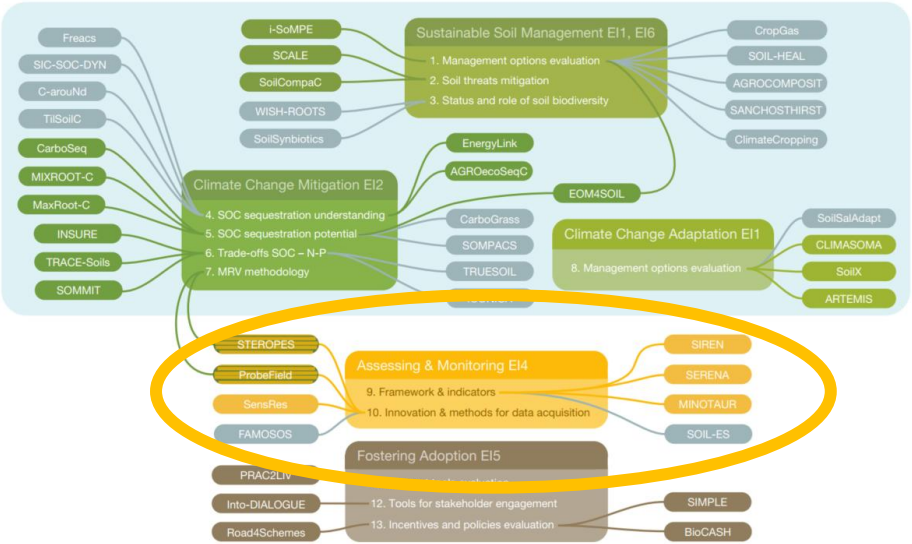
- **Soil** monitoring programms are necessary to
  - Define reference states of soil quality and/soil health
  - Monitor changes
  - Detect degradation at an early stage
  - Assess policies impact
  - Support research for the development and validation of new methods, models and tools

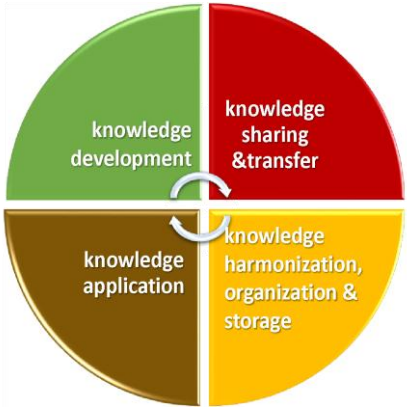
- **Where do we stand on soil health indicators, soil data and monitoring in Europe?**

EJP SOIL: A European Joint research Programme “Towards climate-smart and sustainable management of agricultural soils”



2020-2025; 24 MS; 1200 researchers





EU Directive on Soil Monitoring and Resilience - Identified needs

The needs for the SML

1. **Definitions**
2. **Soil data and monitoring scheme**
3. **Indicators and thresholds**
4. Mapping and reporting tools

EUROPEAN COMMISSION

Brussels, 5.7.2023
COM(2023) 416 final

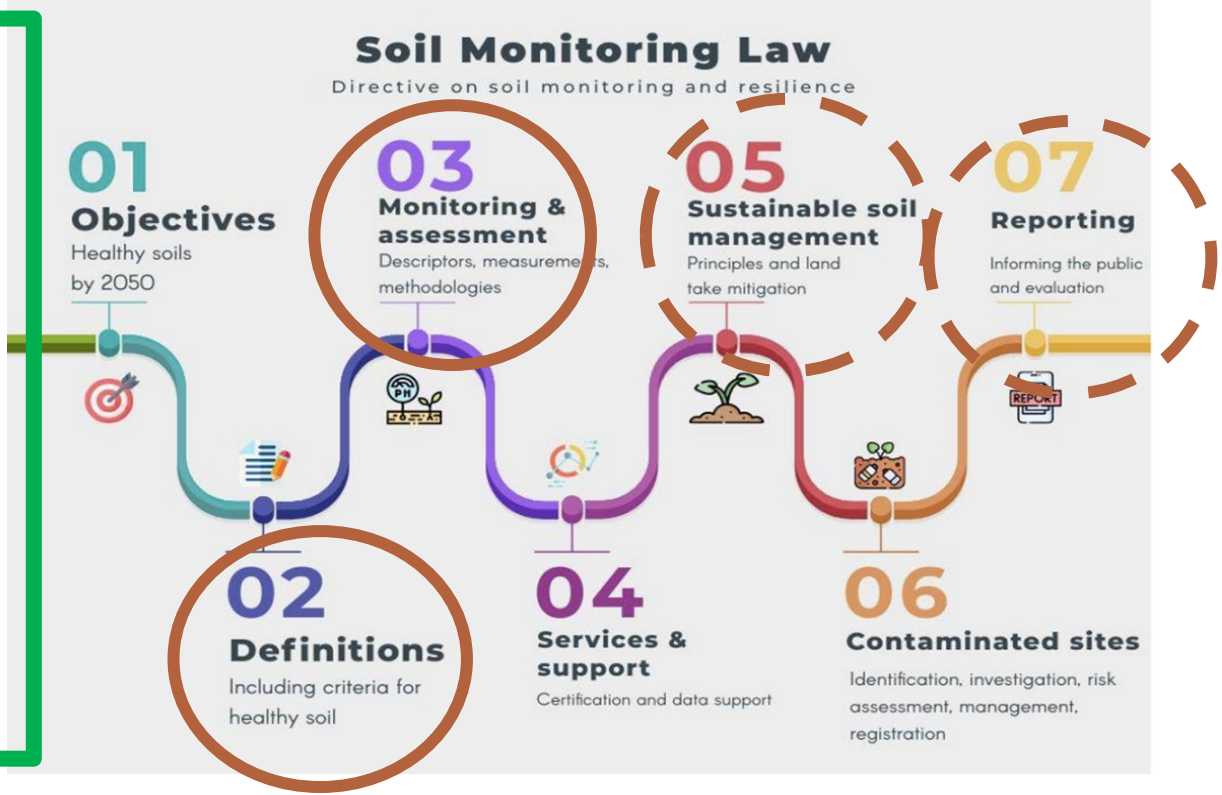
2023/0232 (COD)

Proposal for a

DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

on Soil Monitoring and Resilience (Soil Monitoring Law)

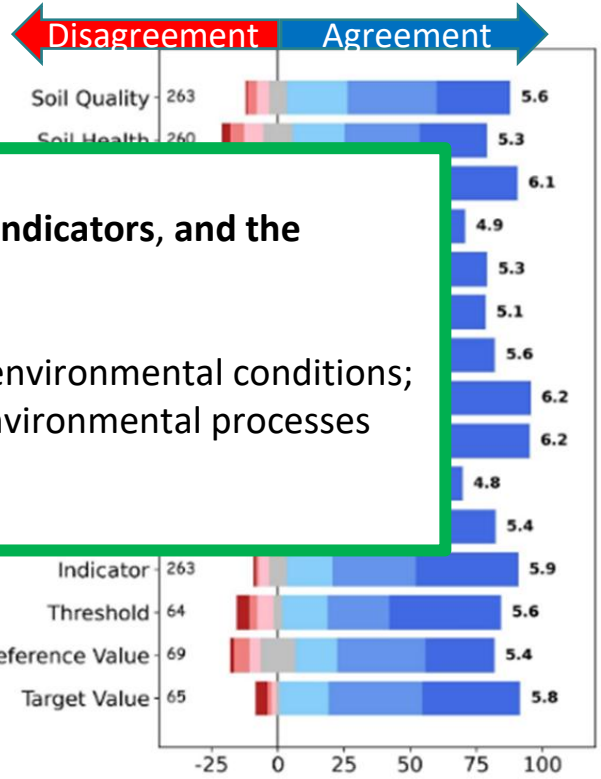
{SEC(2023) 416 final} - {SWD(2023) 416 final} - {SWD(2023) 417 final} - {SWD(2023) 418 final} - {SWD(2023) 423 final}

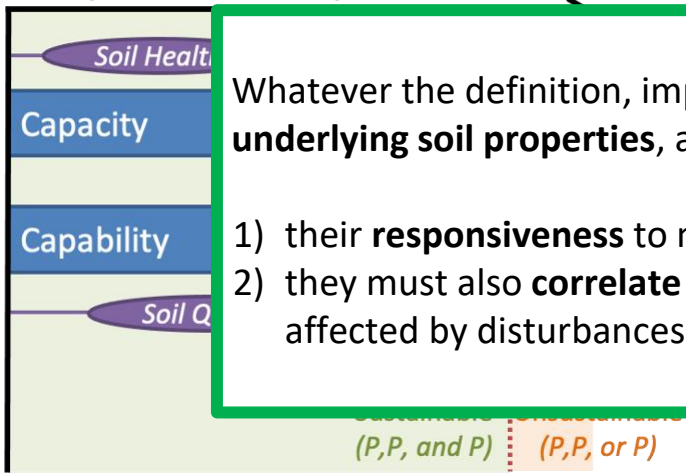


Need 1.Harmonize definitions on soil health and indicators

EJP SOIL proposal: while soil quality is the potential capability of a soil in a given soil type and land use, **soil health is its actual capacity to supply goods and services** (Faber et al 2022).

Do we speak one language on the way to sustainable soil management in Europe? **A terminology check via an EU-wide survey** https://doi.org/10.1111/ejss.13476





Whatever the definition, important **selection criteria for indicators, and the underlying soil properties**, are:

1) their **responsiveness** to management and changes in environmental conditions;
2) they must also **correlate** with soil functions and the environmental processes affected by disturbances and change.

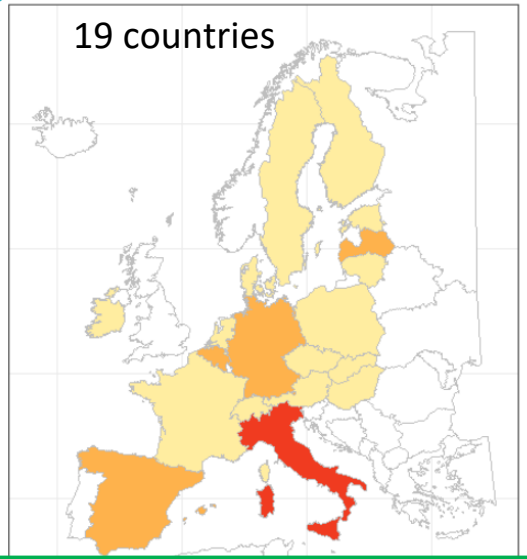
https://ejpsoil.eu/soil-research/siren

Need 2. Overview of **existing national soil data and monitoring programmes**

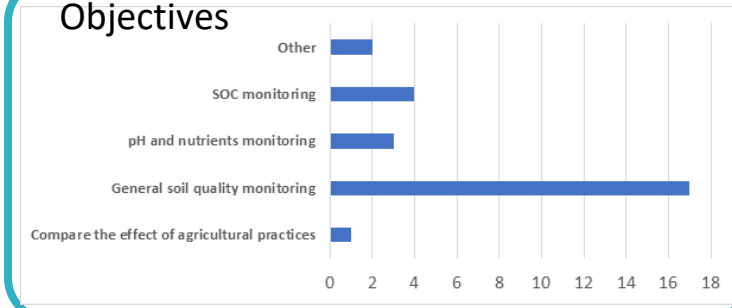
Data availability on **soil health indicators and laboratory methods vary** among MS

CORNU et al. 2024 ***Where do we stand on National Soil DATA in EU?*** *EJSS* *https://doi.org/10.1111/ejss.13398*

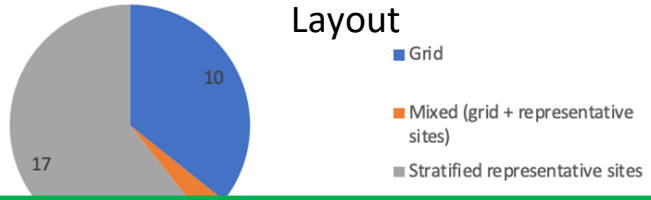
19 countries



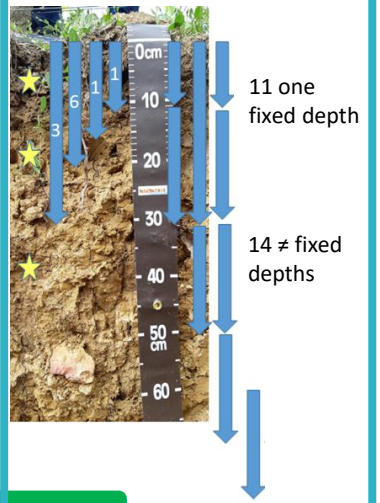
Objectives



Layout



Sampling depths



Soil monitoring systems with very diverse protocols and with different soil parameters monitored, and no willingness to change (but can be extended) **=> harmonization needed**

EJP SOIL A. Bispo et al. Deliverable D6.3, 2021

Mason et al. 2025, submitted

EJP SOIL
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Need 2. Double sampling exercise within LUCAS Soil 2022 to check the impact of sampling protocols and analytical methods and support the development and/or validation of transfer functions

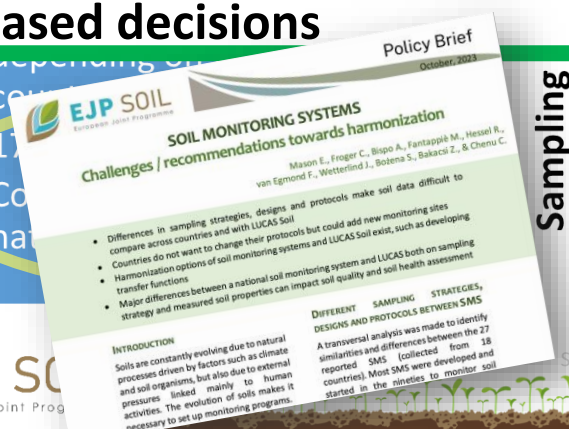
Analytical procedures

- Double samples
- Co
- 1

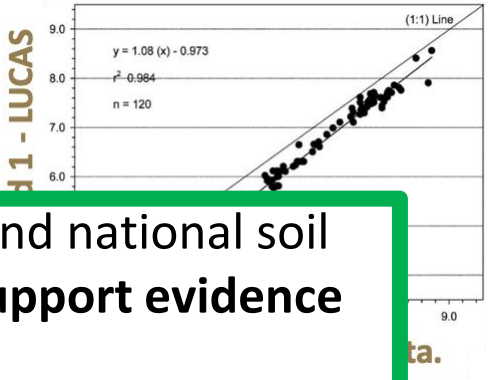
Sampling

- Sampling (on national
- Compare the overall process

Support harmonization and validation between LUCAS and national soil monitoring systems **=> enhanced data comparison to support evidence based decisions**



Transfer functions

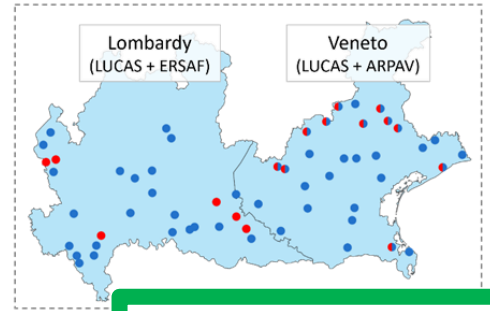


soil samples from 10 MS sent to EUROFINS for comparison

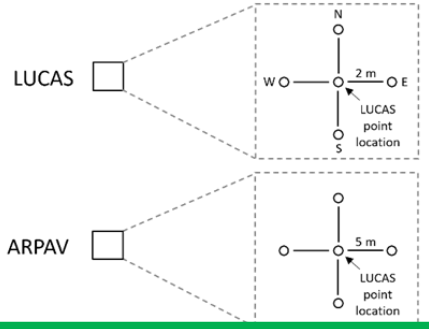
Del Duca et al., 2025. EJSS in press
On comparing sampling protocols.

Activity still ongoing

Need 2. Double sampling exercise within LUCAS Soil 2022 in Italy: effect of the sampling procedures



(A)



(B)

Strong differences between LUCAS and Italian Soil Monitoring protocols on various indicators and land use **=> highlighting the need to develop transfer functions, that enhances data comparison**

Two italian regions involved

Physicochemical soil properties analyzed in 52 sites by ARPAV

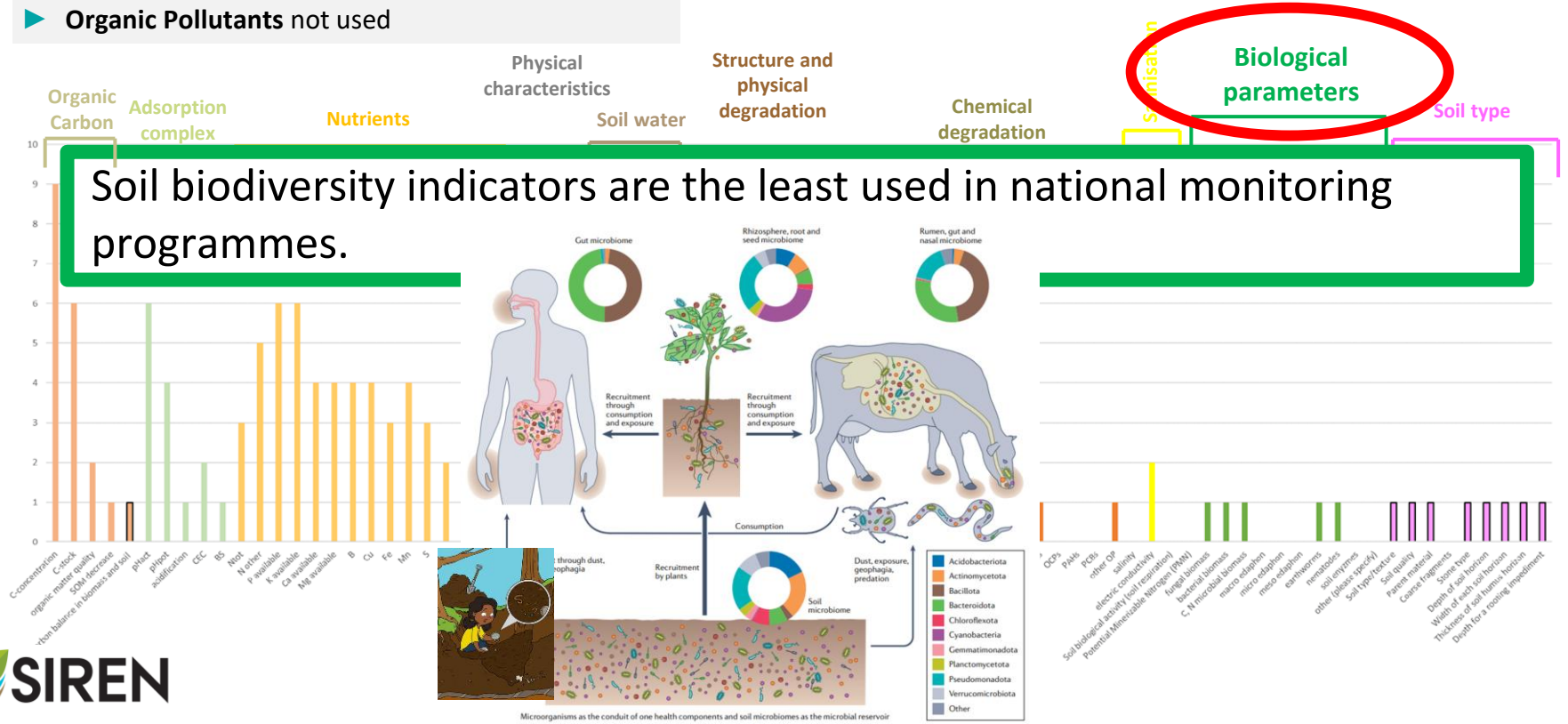
Microbiological soil properties analyzed in 17 sites by CREA

- Concordance among LUCAS and Italian sampling protocol varied depending on the physicochemical parameter being considered and on land use
- Overall , good concordance was ealth wed
- Biodiversity indices showed low concordance, but community composition was proved to be comparable among sampling strategies

Del Duca et al. 2025 EJSS in Press

Need 3. What do we know? Review of indicators used in EJPSOIL countries (20 MS)

- **68 indicators** to characterise soil Quality
- **Top 3** : [C], texture, [N], [P] and [Bulk density]
- **Biological indicators** still rarely used
- **Organic Pollutants** not used



SIREN

Need 3. Comparison of EU, EJP SOIL, FAO proposed indicators

Proposed by EU Commission	Changes by EJP SOIL (D6.5)	Proposed by FAO/GSP-ISAF WG
• SOC Content, SOC/clay • SOC Stock	• Delete: SOC/clay • Add: SOC/SOCexp and SOC/SOCmax	• SOC seq pot • SOC stock • SOC conc
Nutrients: Total N, Extractable P	Add : P stocks (not only available P) and C/N ratio (N pot. deliv.)	Av. Nutrient content (NPK), nutrient budget
	CEC and ESP to be added	Exch. Na or Na adsorp. rate
pH in Water		
Electr. Conductivity		
Available water capacity	Infiltration rate, permeability soil profile and/or the soil porosity and structure stability	Soil drainage classes
Biodiversity (soil respiration)	Biodiversity (functional and structural indicators)	Soil microbial biomass, soil respiration
Structure: Bulk density		
Contamination: Trace elements and selected organics		taminated sites, heavy metals cted/measured)
Soil sealing		
Soil erosion: loss rate		Water and tillage erosion, water erosion risk, susc to wind erosion

Agreement on main soil indicators (green color)
Changes/adaptations suggested (orange/red)

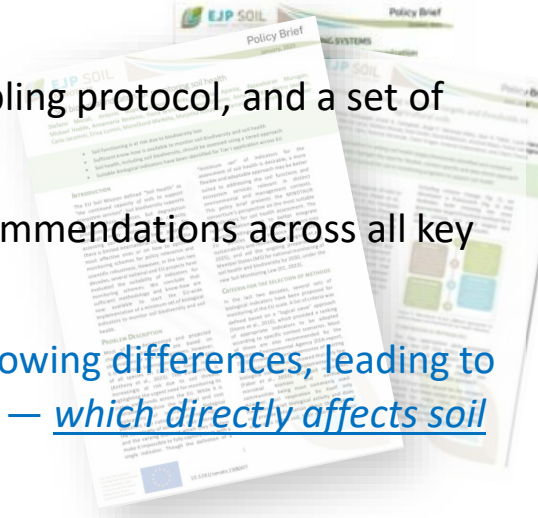
Need 3.Suggested set of biological indicators

Priority level	Recommended indicators	Brief description	Methodology	Cost
	Microbial biomass C	Amount of microbial biomass per gram soil	ISO 14 240-1 / -2 EN ISO 11 063	20-30€/sample
	Microbial respiration	Production of CO2 per amount of soil	ISO 16072:2002	20-30€
		Measurement of several	ISO 14 238	
	Biological regulators (Microfauna)	Structural and functional diversity (nematodes)	ISO 23611-4:2006	30-140€
	Chemical engineers (Microorganisms)	Structural diversity of soil microbiota (bacteria, archaea, fungi)	DNA metabarcoding (ISO 11063:2020) and Plassart et al., 2012	75-100€ for each target group

Minimum set of indicators to be used (less than 1,000 mple)

Use of a single bioindicator may lead to a wrong/misleading conclusion **=> A *set* of indicators (Tier I) should be used simultaneously to support evidence based management and policy decisions**

Take Home messages from EJP SOIL on soil health indicators and monitoring



- **A monitoring system** requires clear decisions on a sampling design, a sampling protocol, and a set of measurable parameters to calculate key soil health indicators.
- **EJP SOIL has provided guidance** through comprehensive reviews, and recommendations across all key aspects of monitoring:

1. **Monitoring strategies:** Comparison of national and LUCAS strategies showing differences, leading to potential over- or under-representation of certain landuse or soil types — *which directly affects soil health assessments*.
2. **Sampling and analytical protocols:** Long-established national systems vary widely with low possibility to change; thus, *data harmonization **(e.g., transfer functions)** is essential* — exemplified by the ongoing **double sampling exercise** linked to LUCAS 2022.
3. **Soil health Indicators to be measured:** Compared the proposed indicators of the SML with literature and made recommendations (D6.5), main changes were requested on biological indicators (Minotaur project).

www.ejpsoil.eu

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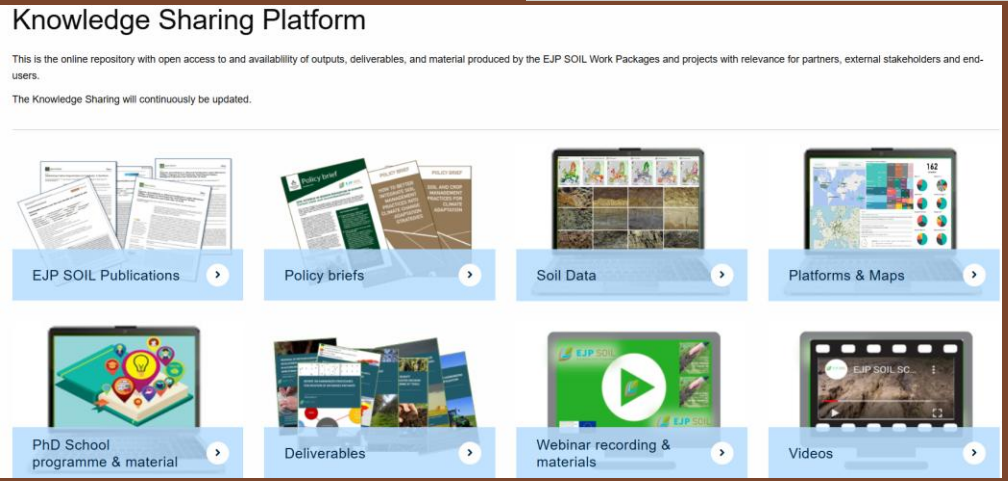

Thank you!

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Soils for Europe 30.04.2025, Brussels

EJP SOIL
European Joint Programme

EJP SOIL has received funding from the European Union's Horizon 2020 research and innovation programme: Grant agreement No 862695

N3. Sensitivity of Tier I indicators to tillage and fertilization.

Results obtained in 10 EJP SOIL long term experiments.

	Biological indicators (tier 1)	Metrics	TILLAGE		Fertilization	
			Effect size*	Rank#	Effect size*	Rank#
Functional indicators	Soil microbial respiration	Basal respiration	0.624	2	0.179	3
	Microbial biomass	Bacteria	0.568	3	0.112	8
	Microbial biomass	Fungi	0.189	11	0.040	14
	Enzyme activity	Beta-glucosidase	0.664	1	0.089	12
	Enzyme activity	Dehydrogenase	0.431	4	0.114	7
	Enzyme activity	Urease	0.404	5	0.146	6
	Enzyme activity	Arylsulphatase	0.198	10	0.206	2
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Structural indicators	Biological regulators (mesofauna)	n. eudaphic	0.226	9	0.013	16
	Biological regulators (mesofauna)	n. epigeic	0.161	13	0.171	5
	Biological regulators (nematodes)	Tot abundance	0.159	14	0.008	17
	Biological regulators (nematodes)	Fungivores	0.065	16	0.103	9
	Chemical engineers (microorganisms)	16SrRNA metabarcoding	0.238	8	0.098	10

They assess soil biological activity and the efficiency of nutrient cycling processes: **DO NOT MEASURE BIODIVERSITY**

trophic scales: **DO NOT MEASURE FUNCTIONS**

Use of a single bioindicator may lead to a wrong/misleading conclusion **=> A *set* of indicators (Tier I) should be used simultaneously to support evidence based management and policy decisions**

**Eta-squared (η^2) : the proportion of the total variance in a dependent variable that can be attributed to a particular independent variable*

Mocali et al. 2025, in preparation