EU CAP Network Focus Group

'Regenerative agriculture for soil health'

Mini Paper 3

Outcomes and indicators for regenerative agriculture across Europe

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Introduction – Motivation

1.1. Context

According to the European Union Thematic Soil Strategy, soils worldwide are subject to several anthropogenic threats, such as erosion, sealing, pollution, loss of organic matter and biodiversity, compaction and degradation (EC, 2021; EC, 2021b). All these threats and associated negative on-site and off-site environmental impacts are largely attributed to land-use intensification and inadequate land management (Montanarella and Panagos, 2021). As a result, many important soil functions such as primary productivity provisioning, biodiversity maintenance, atmospheric CO_2 uptake, and nutrient and water cycling regulation are compromised, ultimately leading to a degenerative process with regional and global negative repercussions (FAO and ITPS, 2021; EC, 2006). These land degradation processes are further exacerbated by global change, notably extreme droughts and extreme precipitation events. Thus, there is an urgent need for land management practices and systems that have the capacity to stop and even revert this negative spiral.

1.2. Problem statement

Regenerative Agriculture (RA) is an outcomes- and principles-based approach to agriculture that has the potential to address these challenges by focusing on restoring and enhancing soil health and functioning. It promotes the implementation of a system of practices adapted to the local context. By restoring soil health, regenerative agriculture also aims to:

(1) reverse biodiversity loss;
(2) restore well-functioning water cycles;
(3) adapt to and mitigate climate change;
(4) increase economic profitability.

Currently, although there are many definitions in use for regenerative agriculture, a broad consensus of its practices, outcomes and criteria for measurement is lacking. This lack of consensus can be seen as problematic, given that it may prevent policymakers, practitioners and other relevant actors to unite behind the idea of regenerative agriculture and promote it, as well as leaving room for greenwashing. However, providing a definition that includes all practices and measures of RA may not be practical, as RA entails sets of very diverse practices that can be implemented to varying degrees, and trying to define precisely RA may lead to exclusion of specific sets of practices that do not fall under that definition. The fact that regenerative agriculture is by definition and necessity place and context specific further confounds this problem.

1.3. Content

In this Mini Paper the EIP-AGRI Focus Group on Regenerative Agriculture for soil health proposes generic outcomes that can and should be linked to RA and how to measure these stated outcomes.

Firstly, we will detail the contextual challenges and requirements for such a system, following which we will introduce the main desired outcomes for RA and suggest appropriate indicators that can be readily measured and interpreted in practice (lab and in-situ techniques). Furthermore, we will reflect on how to set this up in a flexible framework that allows for place and context specificity.

Dissertation

2.1 Challenges and requirements

We identify three main challenges that need to be addressed when designing an outcome-based indicator framework for RA: (1) Lack of widely accepted and benchmarked indicators for Soil Health; (2) Trade-offs between a generic and cost-efficient framework and the need for place and context specificity; (3) Operationalisation of already existing knowledge on RA.

1. Most scientific literature cites soil fertility, structure, biodiversity, resilience, and water dynamics as major aspects of soil health (Maurya et al., 2020, Bhaduri et al., 2022). Due to the complexity of soil systems, the scientific community has great difficulties establishing benchmarks on soil health. Chemical and physical soil indicators are well defined and benchmarked with large amounts of data, unlike for soil biological data, which are crucial for regenerative agriculture and its outcomes. Emerging technologies such as remote sensing, molecular biology, and precision agriculture offer new tools for soil assessment, monitoring, and verification, especially on soil biodiversity and organic carbon assessments.

2. A pan-European outcome/indicator framework for RA should be generic and cost efficient yet allow for place and context specificity to be effective. Current international systems for measuring soil health such as LUCAS SOIL are top down and rely on a minimum indicator set which is evaluated in a standardised manner regardless of place and context specific factors such as climate, soil type, and farming system (Orgiazzi et al., 2018). Moving towards a system that allows for customisation based on place and context however could lead to a prohibitively expensive and cumbersome system, as indicator measurements in such a diverse, complex environment would need to be done at field level throughout Europe (Wade et al., 2022). Establishment of easy to measure (proxy) indicators for the regenerative outcomes and setting place and context specific benchmarks along which the results could be evaluated could provide a solution to this, again with the drawback that it requires a large database of comparable samples that include the relevant information to be able to assess specific place and context parameters. Another approach is to monitor the applied regenerative practices rather than the outcomes themselves (Jeffery & Verheijen, 2020), as is currently done for Organic Agriculture and other certifications. The challenge here is that the same practice can lead to different outcomes, depending on where it is applied. Furthermore, while result based payments require more resources than practice-based payments, result based payments also produce higher awareness and interest for change among managers, side by side to the environmental or in this case soil health outcomes (Guimarães et al 2023; Pinto-Correia et al 2022).

3. Another paper on outcomes and indicators is of no added value if no attention is paid to the operationalisation of this knowledge. How can this paper help stakeholders including land managers adopt regenerative agriculture as well as measure its outcomes?
For the wide practice linkage and practice effects of the knowledge on regenerative agriculture, efforts of a different kind than what has been experimented so far are needed. The first overarching goal is to increase the number of land managers which are impacted by the ongoing R&I projects and knowledge produced: they acquire new knowledge in relation to the soils they are dealing with, the possible practices and the expected outcomes and they may also, accordingly, change current management practices towards more regenerative practices to increase soil health.

Understanding and describing RA outputs as accurately as possible is absolutely essential for enabling social learning by involving farmers and researchers in a joint pathway for participatory monitoring and evaluation of regenerative agriculture (Lujan-Soto et al 2021).

2.2 State-of-the-Art

From the previous section it becomes clear that for RA to become a mainstream success there is a need for a pan-European, outcome based, place and context specific indicator framework for Soil Health that not only focuses on scientific measurements but is co-developed with, and relevant for land managers.

Research

Ongoing research that is relevant towards this has been identified:

- The EU Soil Strategy aims to achieve healthy soils by 2050. The EU Mission 'A Soil Deal for Europe' (Mission Soil) aims to lead the transition towards healthy soils by 2030 and supports R&I on soil health, including soil health monitoring. The Mission project BENCHMARKS, one of the ongoing research projects monitoring this, "collaborates with stakeholders in 24 European case studies to co-develop and evaluate a multi-scale and multi-user focused monitoring framework that is transparent, harmonised and cost-effective" (BENCHMARKS, 2022). It can be assumed that the output of this project will include an indicator framework that is very pertinent and applicable for the measurement of regenerative outcomes.
- ReGeNL is an EU 129 million Dutch RA program starting in 2024. Its goal is to kickstart the Dutch foods system transition towards RA. A core focus will be to develop context specific clusters of RA practices, scientifically linking these to outcomes (through measurements and modelling), as well as to payment schemes.
- There are many new innovations and technologies currently being developed to measure specifically as well as cost effectively. Promising examples range from remote sensing for monitoring soil plant cover to DNA sequencing for soil life. Also, the search is on for reliable, easy to measure and time sensitive (proxy) indicators that can be measured across contexts and systems. A good example of this is separating Soil Organic Matter (SOM) into fractions of Particulate Organic Matter (POM) and Mineral Associated Organic Matter (MAOM, (a very stable form of organic carbon in the soil) in order to assess and even predict soil carbon sequestration (Lavallee et al., 2020). If in the near future, this could be done accurately with NIR sensing methods, this could prove very valuable.

Fig. 3. Simple aggregate stability test of soil in water using a coarse metal mesh, Source: Hatfield, J.L., Wacha, K. and Dold, C. (2018), Why is SOIL ORGANIC MATTER so important?. Crops & Soils, 51: 4-55. https://doi.org/10.2134/cs2018.51.0205

Best Practices

Various programs are already in place to help land managers monitor their regenerative systems. A well-known example is the Savory Method, also known as Holistic Land Management, which not only helps farmers make management decisions, but also provides a set of easy-to-use indicator measurements to guide them over time. There are also certifying bodies such as the Rodale institute that have launched the Regenerative Organic certification. As with 'regular' organic, this is based on a set of practices rather than on the verifiable outcomes. From the industry side there is the SAI platform with their Regenerating Together program. This program includes an outcome assessment and progress reporting tool.

Recently, public and private laboratories have started going beyond common lab tests for nutrient levels in soil, by offering soil assessment services that include physical and especially biological soil parameters. One such example, is the Cornell University's Comprehensive Assessment of Soil Health test (CASH). Their lab offers commercial soil health tests that provide standardized information on soil biological and physical parameters. These services offer a scoring system for the measured indicators, which represent critical soil processes, helping farmers identify soil health problems and guide them to adopt improved and more sustainable soil and crop management practices.

For on-farm monitoring of soil quality, a soil kit has been developed by the USDA. The kit contains all tools and supplies needed to measure a set of selected physical, chemical, and biological properties of the soil, and can be used as a screening tool to allow the comparison of agricultural management practices, monitoring changes in soil quality over time, and for diagnosing possible soil health problems. The tests included in the kit can be easily conducted on the farm by either farm advisors or the farmers themselves to assess the quality of their soil (Seybold et al, 2001).

The Global Soil Partnership of the FAO has developed a soil educational field kit to train farmers, which is accompanied by a series of Training modules, where with the use of simple tools, farmers can learn to perform in-field assessment of physical, chemical, and biological conditions of their farm's soil (FAO, n.d.). Finally, the Visual Soil Assessment (VSA) Field Guides of the FAO provide easy to follow guidelines to assess soil quality with minimal tools (FAO, 2008).

2.3 Proposed Outcomes and Indicators

Desired outcomes of RA range from soil health and environmental to the social and economic domains. However, as soil health is the basis, and this MP cannot cover all outcomes, the focus of this section, as of the rest of the MP, is on the outcomes related to soil health.
Here we distinguish six main desired soil health outcomes, based on the main soil functions (Schulte et al., 2014) and widely established concepts of RA (Schreefel et al., 2020):

- **Increased infiltration and water holding capacity**

"To receive, store and conduct water for subsequent use and as such to prevent droughts, flooding and erosion" (Wall et al., 2020). In many parts of Europe a direct effect of climate change is that rain falls in shorter, more intense periods interspersed with longer periods of drought. Important European rivers such as the Rhine, are increasingly dependent on rainfall rather than melting snow and ice, further compounding the challenge of water management and availability. Using RA methods to increase the infiltration and water holding capacity of agricultural soils can play a crucial role in building a system that is adapted to climate change.


Fig. 4. Infiltrometer, Source : FAO

- **Reduced erosion**

The main goal of RA is to protect the soil from erosion by increasing soil cover with cover crops, pruning residues and crop residues retention. It is important to bear in mind that soil erosion rates around Europe are higher than tolerable rates. In particular, in Mediterranean countries erosion rates in agricultural land range from 4-8 tonnes per hectare per year, or 1-2cm of soil loss per year, if the soil is not protected with vegetation (Zhang et al., 2021). These erosion rates are unsustainable given that a century is needed for 3 mm of soil to be formed (Evans et al., 2019).

- **Increased biodiversity**

Increase in soil biodiversity and abundance of organisms: although it is often very difficult to establish straightforward links between biodiversity and soil functions, in general increased biodiversity (and increasing abundance of soil life) are related to many other improved soil functions (aggregation, nutrient cycling, nutrient retention, disease suppressiveness).

- **Increased carbon sequestration**

SOC is probably the key manageable variable, including in RA systems, given its enormous impact on nearly all biological, physical and chemical properties and processes. Increases in SOC will therefore increase production potential, resilience against soil degradation, resilience against climate change (droughts, flooding). Soil organic C (SOC) is found in two major pools: as particulate organic matter (POM; particulate organic residues mostly of plant origin) and mineral-associated organic matter (MAOM; a very stable form of organic carbon in the soil). RA practices such as no-till, cover crops and legumes contribute significantly to the formation of MAOM (Kauer et al., 2021).

- **Increased nutrient cycling**

Nitrogen, a crucial nutrient for plant growth, exists mainly in crop residues, soil organic matter, and in manures and composts, in the form of complex organic compounds. These complex organic forms of nitrogen are inaccessible to plants as they cannot be directly absorbed by their roots, so plants rely on the process of nutrient cycling to convert this organic nitrogen into forms like aminoacids, ammonium and nitrate, which are readily uptaken by plant roots. The Soil N supplying potential is related to both the abundance and the metabolic activity of its microbial biomass. Soil biodiversity serves as a critical indicator of the potential for diverse nutrient cycles within the soil ecosystem.

- **Pest and Disease suppressiveness**

Described by Creamer et al. (2022) as "the capacity of soils to prevent the establishment and development of soil-borne plant pathogens (microorganisms and microfauna) and pests (meso- and macrofauna) despite their presence in the field, the availability of a susceptible host, and a suitable environment" this is a crucial outcome of RA in order for a resilient food system that produces healthy food and no longer relies heavily on artificial inputs for its productive capacity.

What indicator measurements can be linked to these outcomes? In the following table we distinguish between the indicators and the indicator measurements. We identify a selection of the 'best' indicators for each outcome, following which we attach two types of indicator measurements to these: (1) the scientific indicator measurement and (2) the farmer indicator measurement (Table 1). This aims to address the points made under sections 2.1 and 2.2 and bridge the gap between science and practice as well as place and context specificity.

Table 1. List of indicators for the assessment of Regenerative Agriculture Outcomes. Indicator measurements have hyperlinks to protocols or guide, while a list of all referenced guides can be found in the References section. Source : European Commission

RA Soil Health Outcome	**Indicators**	**Indicator Measurements**	
		Scientific	*Farmer*
Increased water holding and infiltration capacity	Water infiltration rate	Hydraulic conductivity, infiltration rate (soil infiltrometer, Fig 1),	Infiltration rate test Presence /absence of puddles and surface runoff several days after last rain
	Soil compaction	Penetrometer measurements, bulk density	Inspect compacted layers in a small profile pit and visual assessment of mottles, penetrometer measurements.
	Soil water content	Gravimetric/volumetric measurement	Soil water content: gravimetric method
	Water holding capacity	Pressure plate method (PF curve), funnel method	Funnel method
Reduced erosion	Soil cover	Quadrat method (% of plant cover)	Visual inspection: Bare soils or sparse green cover vs high density plant cover (or high residue cover) Canopeo app, measures % soil cover using the camera of a smartphone
	Soil structural stability (Aggregate stability)	Aggregate stability indices (Soil Survey Investigations Report No. 42, Version 6.0, Fig. 2), Glomalin content	Simple soil slake test in beaker with water using mesh (Fig. 3)
	Erosion rate	Erosion plots Estimation of the volume of soil lost after an erosive event by measuring the length, width and height of the gullies and rills observed in the field.	Visual inspection: Presence/absence of rills, gullies and visible erosion signs after a rainfall eventPorgand347
	Root proliferation (provide good structure and protect soils against erosion)	Analysis of soil cores	Visual inspection in a small profile pit

Increased biodiversity	Aboveground Functional biodiversity	Quadrat method/Shanon index	Indicator plants (e.g., leguminous), beneficial insects, pollinators
	Soil fauna	Earthworm numbers/diversity; nematodes	Earthworm numbers, earthworm burrowings, macro-arthropod numbers possibly through pitfall traps
	Microbial diversity and activity	Enzyme activities, C mineralization /respiration, Litterbag decomposition test, PLFA (Phospholipid Fatty Acids – quantification of main functional groups of soil microorganisms)	Soil decomposition rate - underpants (Fig. 4); teabags
Increased carbon sequestration	Soil Organic Carbon and Soil Organic Matter	Soil Total Carbon, SOC stocks, Particulate organic matter (POM) and Minerals Associated Organic Matter (MAOM)	Soil organic matter: reaction with hydrogen peroxide Soil organic matter: color observation
	Readily available C pool (microbial carbon food source)	Permanganate oxidizable C (POXC)	
Increased nutrient cycling	pH	pH-KCl or pH-H2O	Soil pH: Indicator Strips
	Available organic N pool	Autoclaved citrate extractable (ACE) protein content	
	Soil microbial activity	Activities of enzymes involved in the C-, N-, P-, and S-cycles; basal respiration using a respirometer	Basal respiration field test (Solvita Soil Health Test) Soil decomposition rate - underpants (Fig. 4); teabags
Pest & Disease suppressiveness	Pathogen pressure or disease suppressiveness	Root Health Bio-assay (Cornell CASH), cellulolytic enzyme activity– e.g. β-glucosidase or cellobiohydrolase	

Fig. 2. Soil aggregate stability test, Source: Ristow et al. 2016

- *How can this address the challenge of place and context specificity?*

Now that we have established indicators for each of the RA outcomes and proposed practical as well as scientific measurements for these indicators, the challenge for this framework remains the place and context specificity of RA. For the practical measurements the solution is relatively simple, as the goal here will nearly always be for the land-manager to observe change in soil health status over time and linked to changes in management practices. By measuring and observing periodically within the field/farm's own context, benchmarking can occur through a baseline measurement and the monitoring of change over time (and possibly space) from this baseline. Secondly, farmers in Europe widely indicate that they prefer peer-to-peer workshops and topical groups for knowledge exchange. Throughout Europe the Mission Soil is setting up regional Living Labs for the improvement of soil health. These could be the perfect organizing body for peer-to-peer groups of land managers that operate in similar systems and contexts, allowing them to share their experiences on RA practices and their links to the proposed soil health indicators.

At a scientific level the situation is slightly more complicated, where various solutions present themselves. In their paper Scheefel et al. present a flexible yet coherent framework, that allows for goalsetting based on place, context as well as scale and actor type and then proposes a set of indicators over time and scale (practice, result and outcome based) and the ways these can be measured (survey, stats, sample, space) (Scheefel et al., preprint). This framework offers the handholds for establishing a place and context specific system that is effective (measuring the relevant indicators for the relevant actors) and cost efficient (carefully assessing the scale and methods for measurements as well as using what is already there) for outcome-based measurements. The table presented in the previous paragraph can be fitted to this framework, whereby often the farmer indicator measurements are practice or result based and the scientific measurement lean towards result and outcome based. Farmer measurements rely on observation and sampling, whereas the scientific measurements can and should select from all available methods and only resort to sampling (due to costs) when no other reliable data at the required scale (field/farm/region/national/Europe) is available.
The final challenge here is the harmonisation of existing data and ongoing soil sampling efforts throughout Europe. For this there are already various large-scale projects within Europe and the Mission Soil. The most important of these is the BENCHMARKS project, that has as its stated purpose (amongst others) to derive local benchmarks through stratified normalization of monitoring data (BENCHMARKS, 2022). If this is a success this would allow for benchmarking indicators specifically within pedo-climatic regions and farming systems.

2.4 Conclusions

Six key RA outcomes for soil health have been described and indicators have been proposed for each. Indicator measurements are described for scientific as well as practical purposes. Allowing scientific, policy and value chain tracking of outcomes on the one side and enabling land managers to receive direct feedback from their soils regarding their management on the other side.

Peer-to-peer learning within already established Living Labs is suggested for farmer uptake of practices and monitoring, whereas a EU wide flexible yet coherent monitoring framework is proposed for effective and cost-efficient monitoring from a scientific perspective. The proposed table fits well within this framework.

Research needs for practice

Place and context specificity of practices and their soil health outcomes.

Research needs for soil health indicators in Regenerative Agriculture emphasize understanding the specificities of agricultural practices and their outcomes in diverse contexts. This should be investigated across various climatic zones and soil types to determine optimal strategies for improving soil health, with a specific focus on collecting sufficient data for benchmarking of soil biological indicators. Additionally, assessing the relative relevance of regenerative practices for different agricultural systems, such perennial, annual and horticultural crops, is crucial.

Further development and validation is required for innovative tools such as soil test kits and visual assessment guides, for in-field monitoring of soil health, which can be performed by farmers or advisors to monitor improvement in soil health. Additionally, there is also a great need for research to identify indicators for assessing soil microbial diversity and activity and their efficiency in supporting nutrient cycling and carbon sequestration. These resources can empower farmers to conduct regular assessments of soil quality, enabling them to track progress over time and make informed decisions regarding land management practices. By incorporating these farmer-accessible and user-friendly soil quality monitoring techniques, we can enhance the efficiency and effectiveness of regenerative agriculture practices.

Development of complex indicators that reflect the contribution of soil to key ecosystem services or best describe soil health as a holistic parameter

Many soil health indicators exist, but they are often not directed towards practical use, or it is not well known how they really reflect soil management (in this case specifically sets of RA practices). They also need to be finetuned for specific combinations of climate-soil-crop rotation.

The main challenge is the ability to identify key parameters or a set of parameters, combined into a single aggregate indicator, that describe the contribution of soil to essential ecosystem services or best express the concept of soil health. For example, to describe the contribution of soil to water regulation ecosystem service, the integrated parameter describing all the processes within hydrological cycle such as infiltration, soil hydraulic conductivity, field water holding capacity, permanent wilting point, porosity etc. The aim should be to simply rate soils in terms of improving ecosystem service function or increasing soil health.

Development of simple and reliable indicators of soil biodiversity describing the proportion and quantity of microorganisms or soil biota key to soil health

Soil microorganisms contribute to a number of ecosystem functions in the soil, either through nutrient cycling, transformation of organic matter and storage of stable forms of carbon in the soil, or the formation of stable soil aggregates and thus a positive effect on soil physical properties. However, the main challenge is to understand what defines an optimal state in terms of the quantitative and qualitative representation of soil microorganisms and soil biota and which simple but reliable indicators can be used to assess the state of soil biodiversity in terms of optimal impact on soil health and soil ecosystem functions. Perspective indicators could be, for example, the quantification of the ratios of the main functional groups of soil microorganisms through the analysis of phospholipid-derived fatty acids (PLFA) or metabarcoding.

Methods for monitoring large-scale changes in soil health using remote sensing and fixed sampling points

Assessing positive or negative changes in soil health is very difficult at large spatial scales due to the high heterogeneity of soils. However, the ability to monitor changes in soil health over large areas is a potentially important tool for assessing the success of regenerative agriculture practices or, conversely, an early indicator of the need to adapt these practices to specific local conditions. The potential for large-scale monitoring of soil health is provided, for example, by remote sensing methods, but due to the possible influence of several factors and therefore the lower reliability of remote sensing approaches, it is necessary to ensure their calibration, for example by analyses at fixed sampling points.

Fig. 5. Underpants before and after burrial in a healthy soil. The cellulolytic activity of the soil microbes has largely decomposed the cotton, Source : https://www.swissinfo.ch/eng/sci-tech/buried-underwear-proves-good-soil-in-private-gardens/47938014

Synchronisation of existing soil health and regenerative programmes

The Mission Soil under Horizon Europe, marks a significant increase in funding for soil health and regeneration research. This initiative, alongside other projects from other EU programmes (as PRIMA, LIFE or ERC), and national or private funding, underscores the need for complementary efforts to avoid duplication, maximize impact, and accelerate progress towards soil regeneration goals. Effective coordination among projects is imperative to build upon existing knowledge, prevent gaps, and ensure diverse geographical and socio-economic coverage across the EU. Stakeholder involvement is crucial for practical implementation of soil regenerative practices, requiring enhanced coordination efforts within each Member State to prevent stakeholder fatigue and ensure broader engagement. Research needs focusing on co-constructing guidelines with project coordinators and national representatives to enhance synergies and avoid duplications at both project and field implementation levels.

Ideas for innovations

Ideas for innovative projects /solutions

1. **Design a platform to help match clusters of RA practices to outcomes**
   In order to effectively evaluate the outcomes of regenerative agriculture, it is necessary to look for indicators or combinations of indicators that describe key ecosystem services, either individually or in combination, as quantifying ecosystem services can help develop a comprehensive assessment of regenerative management.

Following the large scale, long-term soil sampling campaign (BENCHMARKS), develop a database and software that can predict, based on the previously mentioned contextual factors, which cluster of RA practices lead to which outcomes.

2. **Result-based models (RBMs), particularly in agri-environmental schemes**
   For the required paradigm shift towards regenerative agriculture, a combination of conventional and result-based payments may be a way forward and is worthwhile experimenting. Result-based models (RBMs), particularly in agri-environmental schemes, offer a participatory and efficient monitoring mechanism. RBMs encourage farmers to engage in designing tools and making management decisions aligned with defined outcomes. While RBMs have been tested in specific contexts, more modalities tailored to EU regions are needed. This approach requires clear environmental objectives, agreed upon by all stakeholders, and easily applicable indicators, developed through a co-construction process. Continued local support mechanisms, such as technical advisory offices and field visits, are essential for successful implementation. Despite significant resource requirements, RBMs facilitate farmer awareness and training, exemplified by pilot projects in Ireland, Spain, and Portugal.

Potential EIP-AGRI Operational Groups

1. **Soil (biological) quality indicators at farm level to evaluate effects of specific RA practice**. Farmers need to be able to use easy, practical and cheap tools to evaluate the effects of specific RA practices on soil health. Essential is that farmer see the evolution of soil quality as influenced by specific RA practices. From this, also more general beneficial effects of specific RA practices can be derived and extrapolated to other regions. OG can create Inventories of existing easy to use tools and apply them with specific RA practices; monitor the evolution over time. They can also use or develop Apps to assess and interpret the soil quality.
2. **Develop Functional microbiome assessment methods** as a tool to advise farmers how to evaluate and modulate soil microbiota before applying biofertilizers or biostimulants. These measurements can be done for major parameters such as soil heath (biodiversity, functionality), disease incidence (pathogens target for crop species), stress adaptation (biotic and abiotic stress) and nutrition metabolization (macro and micronutrients) (Biome makers ®). By targeting what is missing in soil, farmer can adjust and be more precise on their appliance in field operations.

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Links to protocols and guides for Indicator measurements

FAO-Soil compaction - infiltration test
https://www.fao.org/fileadmin/user_upload/GSP/GSDP/Field_exercises/New_format_EN/P04-Infiltration-EN.pdf

FAO- Standard operating procedure for soil bulk density
https://openknowledge.fao.org/server/api/core/bitstreams/deed7688-a43e-4532-962f-d48768bd61c4/content

FAO-Standard operating procedure for soil pH determination.
https://openknowledge.fao.org/server/api/core/bitstreams/6ad6862a-eadc-437c-b359-ef14cb687222/content

Decomposition study using tea bags https://www.fibl.org/fileadmin/documents/shop/1098-teabag.pdf

FAO-SOIL COMPACTION AND AERATION: MOTTLES
https://www.fao.org/fileadmin/user_upload/GSP/GSDP/Field_exercises/New_format_EN/P05-Mottles-EN.pdf

FAO-Standard operating procedure for soil moisture content by gravimetric method
https://openknowledge.fao.org/server/api/core/bitstreams/e8811ce2-af62-470f-90fb-71b1da2d00c0/content

FAO-Soil water content: gravimetric method
https://www.fao.org/fileadmin/user_upload/GSP/GSDP/Field_exercises/NEW_Field_exercises/P06b-gravimetric-soil-water-EN-1-2.pdf

FAO-Soil cover estimation https://www.fao.org/fileadmin/user_upload/GSP/GSDP/Field_exercises/NEW_Field_exercises/P07-soil-cover-EN.pdf

FAO-Soil structure - aggregate stability: slake test. https://www.fao.org/fileadmin/user_upload/GSP/GSDP/Field_exercises/New_format_EN/P03-Aggregate-stability-EN.pdf

FAO Earthworms counts. https://www.fao.org/fileadmin/user_upload/GSP/GSDP/Field_exercises/NEW_Field_exercises/B02-earthworms-EN.pdf

FAO-Organic matter: reaction with hydrogen peroxide. https://www.fao.org/fileadmin/user_upload/GSP/GSDP/Field_exercises/New_format_EN/C02b-SOM-peroxide_EN.pdf

FAO-Organic matter: colour observation. https://www.fao.org/fileadmin/user_upload/GSP/GSDP/Field_exercises/New_format_EN/C02a-SOM_colour_EN.pdf

FAO-Soil pH using indicator strips. https://www.fao.org/fileadmin/user_upload/GSP/GSDP/Field_exercises/New_format_EN/C01b-pH_strips_EN.pdf

A Simple, Affordable, Do-It-Yourself Method for Measuring Soil Maximum Water Holding Capacity https://www.tandfonline.com/doi/full/10.1080/00103624.2023.2296988

Decomposition rate using underpants. https://www.beweisstueck-unterhose.ch/

Canopea app. https://canopeoapp.com/#/login

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