IMPROVING SOIL BIOLOGICAL HEALTH

The role of biological components and monitoring approaches

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IN BRIEF

1. SOIL AS A VITAL LIVING SYSTEM

Soil health is defined as the capacity of soil to function as a vital living system, sustaining plants, animals, and the broader ecosystem. While soil fertility refers to nutrient supply and productivity refers to crop yield, soil health encompasses the biological synergy required for long-term sustainability. The legacy of India's Green Revolution achieved grain sufficiency through a chemical-centric approach, yet this success has come at a cost. The consequences of this systemic over-reliance on chemical inputs include:

- **Fertiliser response ratio collapse:** Diminishing returns where more input yields less output.
- **Hidden hunger:** Growth of nutrient-poor crops leading to micronutrient deficiencies in the population.
- **Nitrate pollution:** Leaching of excess chemicals into groundwater systems.
- **Diminished resilience:** Heightened vulnerability to climate stressors like floods and droughts.
- **Carbon loss:** Reduced sequestration potential and accelerated soil degradation.

2. DECLINING SOIL HEALTH AND ITS PRIMARY DRIVERS

Data from the Soil Health Card (SHC) scheme and long-term experiments of the Indian Council for Agricultural Research (ICAR) confirm a nationwide crisis of multi-nutrients and soil organic carbon (SOC) deficiency, leading to a widespread decline in soil health across India. This is driven by three reasons:

- **Fertiliser imbalance and diminishing returns**: In addition to fertiliser overuse, high subsidy for urea has led to a nitrogen-heavy fertiliser consumption with national N:P:K consumption ratio being 9.8:3.7:1, far from the recommended 4:2:1. The Fertiliser Response Ratio has plummeted showing that high chemical intensification does not mean proportional productivity. This nitrogen dominance instead acidifies the soil, reduces nutrient uptake, brings down SOC levels, and adversely affect soil health.

- **Intensive agronomic practices**: Modern techniques prioritise chemical-intensive monocropping, which restricts microbial diversity and encourages pest buildup. Excessive tillage destabilises soil architecture, while widespread absence of organic inputs prevents the recycling of nutrients back into the soil system.
- **Soil erosion**: India loses 5.3 billion tonnes of soil annually due to erosion, stripping the most nutrient-dense and biologically active topsoil layer.

3. BIOLOGICAL COMPONENTS AND ECOLOGICAL FUNCTIONS

Soil biological health is maintained by a complex hierarchy ranging from microbiota (bacteria/fungi) to megafauna (mammals/reptiles). This living community facilitates three essential functional domains:

- **Nutrient availability and fertiliser use efficiency**: Microbes drive nutrient (e.g., N, P, K) cycles, converting organic matter into plant-available forms through decomposition and mineralisation.
- **Structural integrity and water retention:** Bacteria and fungi produce biological glues to bind soil aggregates. Humus formed after microbial breakdown of organic matter can absorb and retain large amounts of water. Earthworm tunnels and fungal hyphae improve aeration, porosity, and deep-water infiltration.
- **Climate mitigation**: Healthy soils act as carbon sinks and utilise specialised microbes to convert potent greenhouse gases (N_2O) into harmless nitrogen.

4. SOIL BIOLOGICAL HEALTH MONITORING: GAPS AND EMERGING TECHNOLOGIES

The SHC scheme is currently limited by its near-exclusive focus on chemical parameters, thereby not capturing soil biological health.

Critical gaps in monitoring biological parameters include:

- **Logistical fragility:** Biological samples require strict cold chains and testing within 24–72 hours, which is unfeasible at scale under the current SHC framework.
- **Infrastructure and expertise gaps:** Most laboratories lack essential equipment (such as refrigerators and laminar air flow) and qualified soil biologists.
- **Operational constraints:** Biological assays are time-consuming, often requiring several days for cultures to develop. High cost of specialised chemicals and reagents for biological assays makes routine large-scale testing difficult to afford.
- **Lack of benchmarks:** There are currently no established national standards or thresholds to help interpret biological results or guide specific farm interventions.
- **Inadequacy of proxy indicator:** SHC relies on SOC as a proxy indicator,which changes too slowly (over years) to reflect rapid biological shifts and fails to distinguish between active and inert carbon.

Technological advancements are enabling field-level biological assessments through on-farm testing or Point-of-Need (PON) testing. Examples include Soil Respiration Indicator Gel (SRI-Gel), Soil X Probe, Soil Doctor kit, and Soilometer.

5. CONCLUSION AND WAY AHEAD

To restore India's soil health, the report proposes to put adequate focus on biological health of the soil, as outlined below:

Improve soil organic carbon (SOC) content

- **Promote organic and bio-inputs:** Increase the use of farmyard manure, compost, green manuring, and microbial consortia. Support farmers with the necessary materials, infrastructure and knowledge to produce organic/natural inputs.
- **Adopt regenerative practices:** Encourage non-chemical farming, crop diversity, and conservation agriculture practices to improve SOC.

Reform fertiliser and pesticide use

- **Subsidy structure reform:** Address the imbalanced use of nitrogen by improving the fertiliser subsidy structure, including urea in the Nutrient Based Subsidy scheme, giving money in the hands of the farmer, and scaling up integrated nutrient management. Encourage states to utilise PM-PRANAM scheme to reduce chemical fertiliser consumption.
- **Phase-off pesticides:** Promote integrated pest management and the use of bio-pesticides.

Mainstream biological health monitoring

- **Phased inclusion in SHC:** Integrate biological parameters to be tested as part of the SHC scheme, starting with specific districts or agro-ecological zones or a limited set of laboratories or tests.
- **Strengthen laboratory networks:** Invest in infrastructure and station-qualified soil biologists at soil testing centers.
- **Scale up on-farm, Point-of-Need (PON) testing:** Promote affordable field-based PON testing for real-time biological assessment. Encourage village-level entrepreneurship, farmer producer organisations (FPOs), and self-help groups (SHGs) to operate these services, bring testing closer to the farms.

INTRODUCTION

Soil is the natural body on the Earth's surface, consisting of layers composed of weathered mineral materials, organic material, air, and water. Within the ecosystem, soil performs several essential functions—it serves as the natural medium for plant growth, regulates hydrological and nutrient cycles, maintains biological activities, and sequesters vast amounts of atmospheric carbon.

Soil health refers to the overall capacity of soil to function as a vital living system and sustain plant, animal, and the entire ecosystem.[1] It is determined by its physical, chemical, and biological health. Soil fertility is the capacity of soil to supply essential nutrients to crops in plant-available forms, in adequate quantities and correct proportions. Soil productivity refers to the crop yield under a given set of conditions. A fertile soil may not always be productive, as its ability to grow a crop and produce yield can depend on several external factors such as irrigation, temperature, etc.

While the Green Revolution in the 1960s helped address food shortage crisis in India, these gains came at the cost of long-term soil sustainability. It led to India's current grain sufficiency, but it has also contributed to a decline in soil health, among other concerns. These include high cost of production, high dependence on external inputs such as fertilisers, nutrient-poor crops, reduced viability of farming, decreased resilience, hidden hunger, nitrate pollution, and reduced carbon sequestration potential.

The decline continues, driven by factors such as the overuse and imbalanced use of fertilisers, topsoil erosion, and intensive, chemical-dependent agronomic practices. Assessments based on data from the Soil Health Card (SHC) scheme and long-term scientific studies show widespread deficiencies in soil macronutrients and certain micronutrients across the country. At the core of this crisis lies the often-overlooked dimension of soil biological health, which is fundamental to restoring soil's overall function in contrast to the reductionist approach which focuses on the chemical health of the soil.

This report focuses on the potential role of soil biological health in improving soil health in India. It explains what soil biological health is, why it is important for overall soil health, and identifies the challenges and possibilities in including biological parameters into soil health monitoring in India. Finally, it provides policy and implementation suggestions for the way forward.

RESEARCH APPROACH

The report is based on secondary and primary research conducted with about 50 experts and stakeholders through in-person interactions, telephonic, and online discussions. Key expert representatives from the following stakeholder groups include:

- **Scientific community**: Scientists, academicians, and subject matter experts in soil chemistry, soil biology, and soil physics, such as from:
    - Indian Council of Agricultural Research (ICAR) institutions like the Indian Institute of Soil Science, Indian Agricultural Research Institute, Central Arid Zone Research Institute, and Indian Institute of Farming Systems Research.
    - Universities like Bidhan Chandra Krishi Viswavidyalaya, West Bengal; Dr Y S Parmar University of Horticulture and Forestry, Himachal Pradesh; Tamil Nadu Agricultural University, Tamil Nadu; G. B. Pant University of Agriculture and Technology, Uttarakhand; Punjab Agricultural University, Punjab; and Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Madhya Pradesh.
    - Krishi Vigyan Kendras in Tamil Nadu, Madhya Pradesh, Uttar Pradesh, and Punjab.
    - National Academy of Agricultural Sciences (NAAS).

- **Civil society**: Experts involved in sustainable agriculture practices, such as from Ecoscience Research Foundation, Bhaikaka Krishi Kendra, Alliance for Sustainable and Holistic Agriculture, Centre for Sustainable Agriculture, BAIF Development and Research Foundation, and Professional Assistance for Development Action.

- **State agriculture departments:** Andhra Pradesh, Karnataka, Madhya Pradesh, and Rajasthan.

- **Soil testing agri-tech start-ups/laboratory:** Ekosight, Reve Nano-Science LLP, and Biome Technologies Pvt. Ltd.

The report reflects a cumulative understanding developed based on the insights and inputs shared by the diverse set of experts from stakeholder groups mentioned above. It does not reflect the opinion of any institution or any one individual.

SOIL HEALTH IN INDIA

3.1 CURRENT STATUS

The ICAR has categorised Indian soils into eight categories—alluvial soil, black soil, red soil, laterite soil, forest and mountain soil, arid and desert soil, saline and alkaline soil, and peaty and marshy soil. Varying in proportions of sand, silt or clay, these soils are distributed across different Indian geographies based on climate, parent material, and topography. Alluvial soil is the largest group, covering over 40 per cent of land, primarily in the Indo-Gangetic plains.

Over the last decade, India's soil health status has been primarily assessed under the Soil Health Card (SHC) scheme. In addition, ICAR's long-term experiments and independent studies also report on soil health. However, both have largely focused on the chemical parameters of soil. Their results indicate a decline in soil chemical health.

CSE's recent report, analysing samples tested under the SHC scheme during 2023–2025, shows that majority of Indian soils are lacking in nitrogen (N), potassium (P), phosphorus (K), organic carbon, zinc, and boron.[2] Soils were severely nitrogen-deficient (64 per cent of samples tested low [<240 kg/ha]), compared to other macronutrients such as phosphorus (13.7 per cent of samples tested low [<28 kg/ha]) and potassium (13.7 per cent of samples tested low [<140 kg/ha]).

There is an organic carbon crisis, with 48.5 per cent of soil samples testing low (<0.5 per cent), and only 23 per cent testing high (>0.75 per cent). Among micronutrients, 55.4 per cent of samples tested low for boron and 35 per cent tested low for zinc. Analysis showed weak correlation between N fertiliser consumption and soil N availability, as well as weak correlation between NPK fertiliser consumption and soil organic carbon (SOC) levels.

According to Dr Rattan Lal, a globally renowned soil scientist, the optimal SOC concentration should be 1.5 per cent in the root zone.[3] However, ICAR's long-term field studies also show that in reality, SOC levels are quite low. For example, an assessment of over 2.5 lakh soil samples collected from cultivated areas of 620 districts in 29 Indian states during 2019–2024 showed that 33 per cent of this area had SOC below 0.5 per cent.[4] The recent report from Indian Council for Research on International Economic Relations (ICRIER) on 'Healing Soils in India' also captures this widespread SOC deficiency in 12–76 per cent of soil samples tested, along with interstate variability.[5] Another long-term study (2012–2018) by the ICAR-Indian Institute of Soil Science on 0.24 million surface soil samples revealed wide spread multi-nutrient deficiency—about 60 per cent soils deficient in sulphur, and significant deficiencies in boron (44.7 per cent), iron (19.2 per cent), copper (11.4 per cent), and manganese (17.4 per cent).[6]

SOIL FORMATION AND STRUCTURE

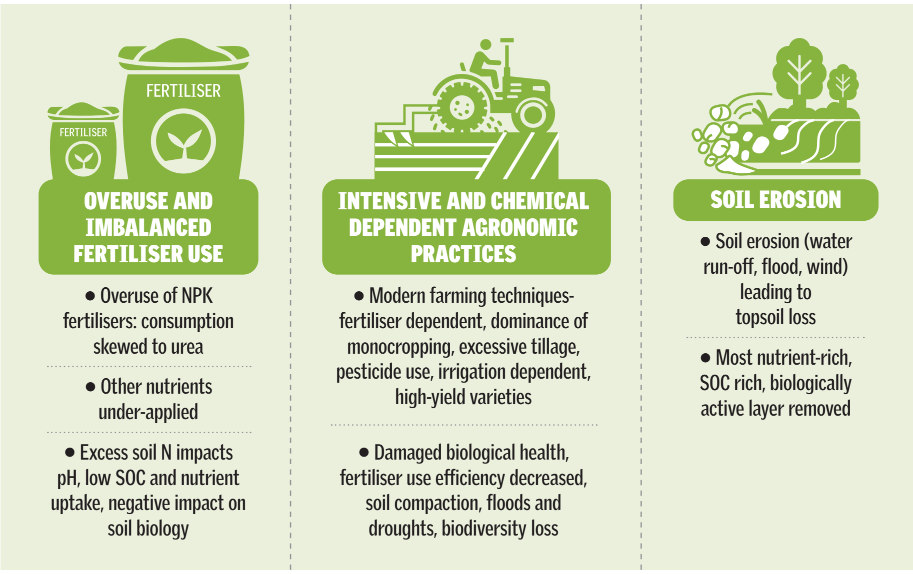
Soil forms and evolves over long periods through a process called 'pedogenesis', which involves the weathering of rocks and the gradual accumulation of organic matter, driven by climate, organisms, geology, topography, and time. As rocks break down, minerals mix with decomposed plant and animal residues to create distinct soil layers. Broadly, soil consists of four layers. The bottom layer is the 'bedrock', a solid mass of rock providing soil's parent material. Above this lies the 'parent rock' layer, formed by weathered rocks. The next layer is the 'subsoil', and the topmost layer is the 'topsoil'. **Topsoil is a combination of organic and mineral components with highest biodiversity and nutrients. Subsoil has a similar composition but contains more minerals leached by rainwater.**[7]

Three main types of soil particles are clay, sand, and silt. Soil's structure is determined by how these particles (along with organic matter) are aggregated, influencing soil porosity, aeration, water retention, root penetration.[8] Variation in size of these particles leads to different properties, and their different combination leads to different soil type.

3.2 REASONS FOR DECLINING SOIL HEALTH

There are several reasons leading to the decline in soil health. These could be broadly grouped into three categories—overuse and imbalanced fertiliser use, intensive and chemical dependent agronomic practices, and soil erosion (see *Figure 1: Reasons for declining soil health*).

Figure 1: Reasons for declining soil health



OVERUSE AND IMBALANCED FERTILISER USE

- Overuse of NPK fertilisers: consumption skewed to urea
- Other nutrients under-applied
- Excess soil N impacts pH, low SOC and nutrient uptake, negative impact on soil biology

INTENSIVE AND CHEMICAL DEPENDENT AGRONOMIC PRACTICES

- Modern farming techniques-fertiliser dependent, dominance of monocropping, excessive tillage, pesticide use, irrigation dependent, high-yield varieties
- Damaged biological health, fertiliser use efficiency decreased, soil compaction, floods and droughts, biodiversity loss

SOIL EROSION

- Soil erosion (water run-off, flood, wind) leading to topsoil loss
- Most nutrient-rich, SOC rich, biologically active layer removed

Source: Developed by authors based on research

Overuse and imbalanced fertiliser use

The use of NPK-based fertiliser has been growing. In the last decade, there was a 19.5 per cent increase in fertiliser consumption between 2013–14 and 2023–24.[9] This fertiliser consumption is largely influenced by subsidy structures and remains heavily tilted towards urea—a major nitrogen source—because of the high government subsidies on urea. In 2023–24, about 68 per cent of total fertiliser consumed was urea.[10] The subsidy on urea is about 85–90 per cent, which is higher than subsidies for P or K-based fertilisers given under the Nutrient-Based Subsidy scheme, introduced in 2010.[11] Urea, which is therefore much cheaper, for example than diammonium phosphate (DAP) becomes the default choice for farmers, who often use it beyond crop requirements, under the assumption that it will lead to more yield. The Department of Fertilisers, under the Ministry of Chemicals and Fertilisers recently noted that the national average for N:P:K ratio in India is 9.8: 3.7: 1, against recommended ratio of 4:2:1, showing nitrogen dominance.[12]

This overuse and imbalanced use of N fertiliser, however, does not correspondingly increase the soil nitrogen level. The low return on fertiliser inputs is evident from the fertiliser response ratio—kilograms (kg) of grain produced per kg of NPK fertiliser applied—which has plummeted from 12:1 in the 1960s to 5:1 in recent decades.[13] This indicates that fertiliser added is not able to improve soil productivity accordingly.

Instead, scientific studies suggest that continuous nitrogen-based fertiliser use can acidify soil (thereby disturbing the soil pH balance), reduce nutrient uptake efficiency, disrupt nutrient ratios, lower SOC levels, and adversely affect soil biological and physical health. Long-term fertiliser experiments conducted by ICAR at Ludhiana has shown how imbalanced chemical fertiliser use decreased soil fertility.[14] Other macro- and micronutrients remain under-applied, which may be the real requirement in soil.

Intensive and chemical-dependent agronomic practices

Sustainable management of soil with diverse farming approaches such as agroecology and organic farming can help produce up to 58 per cent more food.[15] However, with modern farming techniques, farmers are pushed towards farming of high-yielding and chemical-intensive crops to achieve high productivity. Intensive farming depends more on monocropping, intensive tillage, excessive fertiliser, and pesticide use, leaving soil vulnerable to erosion, compaction, and degradation.[16]

For example, monocropping of wheat and rice is dominantly practiced in Punjab and Haryana largely due to minimum support price (MSP) provided by the government. Such intensive monocropping—without crop rotation or diversification—can deplete specific soil nutrients, restrict diversity in soil microbial community by allowing only certain species to thrive, and also encourage pest and disease build-up.[17]

Excessive tillage destabilises soil structure by breaking down soil aggregates, disrupting natural soil porosity, breaking fungal networks, and disturbing earthworms and other soil fauna. There is an overall reduction in SOC levels, soil aggregation, and water retention capacity.[18]

Absence of organic inputs (e.g., farm-yard manure, green manure, and biofertilisers) also reduces carbon in the soil, weakening microbial activity and nutrient cycling. Pesticide overuse can result in their accumulation in the soil and cause toxicity to beneficial soil organisms. Excessive irrigation can also increase soil salinity.

Soil erosion

Widespread erosion, caused by water and wind, strips away the fertile topsoil. As a result, the most nutrient-rich, organic carbon-dense, and biologically active layer of soil is lost, leading to a drastic reduction in soil fertility and productivity.

A review published in 2024 in the journal Soil Security notes that about one millimetre of topsoil is lost annually in India due to soil erosion caused by water, at an average rate of 16.4 tonnes per hectare per year. This is about 5.3 billion tonnes of soil being lost every year due to soil erosion, which results in the loss of around eight million tonnes of plant-available nutrients every year.[19] The National Academy of Agricultural Sciences (NAAS), in its 2025 policy paper on ‘Restoration and Improvement of Soil Health’, makes similar observations, while also noting that loss of topsoil and nutrients would be accompanied by reduced agricultural productivity, increased floods and droughts, and biodiversity loss.[20]

Further, erratic weather patterns, resulting in floods or heat stress, are also accelerating the loss of topsoil and nutrients. During the 2025 floods in Punjab, about two lakh hectares of cultivable farmland across all 23 districts were flooded and waterlogged.[21]

BIOLOGICAL HEALTH OF SOIL

4.1 SOIL ORGANISMS AND THEIR ECOLOGICAL FUNCTIONS

Soil is home to more than 25 per cent of our planet's biodiversity.[22] A biologically healthy soil is one that has the capacity to support and sustain large and diverse microbial communities, suppress pathogens, and support healthy crop development. Soil biological properties and microbial behaviour is said to be key to leveraging the potential of soil microbiome in soil health management.[23]

Soil biological components include both soil flora (the plant and microbial life) and soil fauna (animal life). Apart from the plant life, the soil provides microhabitat to a vast range of soil organisms like bacteria, fungi, nematodes, earthworms as well as mites and reptiles. These life forms thrive and interact within a soil food web to drive essential ecological processes, such as decomposition and nutrient cycling. In just eight centimetres of soil, there are 13 x 10^{15} living organisms, and a single gram of healthy soil has more organisms than there are people on Earth[24] (see *Table 1: Soil organisms and their ecological functions*).

4.2 FUNCTIONS OF BIOLOGICALLY HEALTHY SOIL

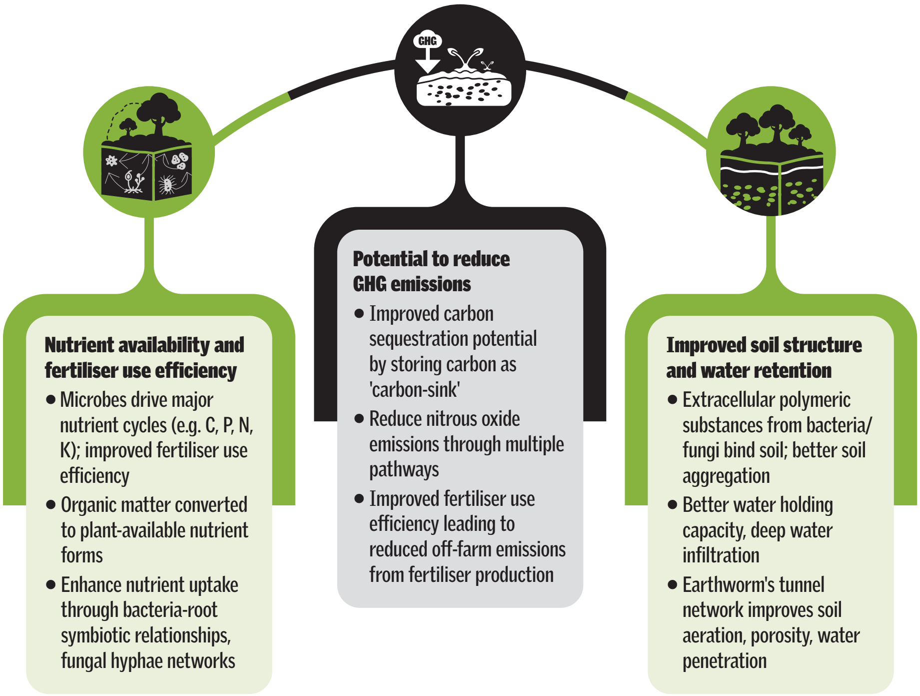
While soil organisms have different ecological functions, their collective action determines biological health of the soil. Biologically healthy soils play a critical role in enhancing overall soil productivity, crop nutrition, and health.[25]

Table 1: Soil organisms and their ecological functions [26, 27]

Soil organisms	Ecological functions
Microbiota (< 0.1 mm)	
Bacteria (e.g., *Bacillus* sp., *Rhizobium* sp., *Pseudomonas* sp.)	Nutrient cycling, fix atmospheric N, produce polysaccharides that improve soil structure and water retention
Actinomycetes	Decompose cellulose and chitin, contribute to humus formation, may fix N in association with some non-leguminous plants
Fungi (e.g., mycorrhizae, saprophytes)	Decompose complex lignin and cellulose, symbiotic bonds with roots to expand nutrient/water uptake, stabilise soil aggregates
Algae and cyanobacteria (e.g., Nostoc, Anabaena)	Primary producers performing photosynthesis, fix N, release oxygen to support aerobic life, form beneficial symbiotic association
Microfauna (< 0.1 mm; the micro-predators)	
Protozoa (e.g., amoebae, ciliates, flagellates)	Regulate bacterial/microbial populations through grazing, influence N mineralisation and availability
Nematodes	N mineralisation, distribution of biomass within plants, some are microbe predators or plant-predators, bio-indicators of soil health
Mesofauna (0.1–2.0 mm; the litter-transformers)	
Mites	Shred plant litter for microbial decomposition, regulate microbe population by predation
Collembola (springtails)	Feed on fungi and litter, accelerate decomposition in surface soils
Pseudoscorpions	Predators feeding on mites and springtails
Macrofauna (2.0–20 mm; the eco-system engineers)	
Earthworms	Mixing soil layers to enable soil formation and maintain soil structure, create vertical channels for aeration/ water drainage, produce nutrient-rich castings, bio-indicators of soil health
Termites	Build mounds to modify soil profiles, facilitate distribution and in-situ decomposition of organic litter
Ants	Build nests incorporating huge amounts of organic matter/nutrients in deeper soil layers
Beetles	Bury animal waste in sub-vertical galleries, enrich soil fertility, larvae influence root health
Other insects (e.g., spiders, snails, centipedes)	Act as predators, shredders, or detritivores that break down surface litter
Megafauna (> 20 mm)	
Small mammals (e.g., moles, rodents)	Primarily dig soil for food or shelter enabling soil mixing, aeration
Herpetofauna (e.g., frogs, snakes, lizards)	Role in high-level soil food web

Note: The classification of soil organisms is based on their body width.

Figure 2: Functions of biologically healthy soil



Nutrient availability and fertiliser use efficiency

- Microbes drive major nutrient cycles (e.g. C, P, N, K); improved fertiliser use efficiency
- Organic matter converted to plant-available nutrient forms
- Enhance nutrient uptake through bacteria-root symbiotic relationships, fungal hyphae networks

Potential to reduce GHG emissions

- Improved carbon sequestration potential by storing carbon as 'carbon-sink'
- Reduce nitrous oxide emissions through multiple pathways
- Improved fertiliser use efficiency leading to reduced off-farm emissions from fertiliser production

Improved soil structure and water retention

- Extracellular polymeric substances from bacteria/ fungi bind soil; better soil aggregation
- Better water holding capacity, deep water infiltration
- Earthworm's tunnel network improves soil aeration, porosity, water penetration

Source: Developed by authors based on research

The large gamut of functions played by biologically healthy soil can be understood under three broad domains—nutrient availability and fertiliser-use efficiency, improved soil structure and water retention, and potential to reduce greenhouse gas (GHG) emissions. A biologically healthy soil is not just linked to physical and chemical aspects of soil health, but also enhances them (see *Figure 2: Functions of biologically healthy soil*).

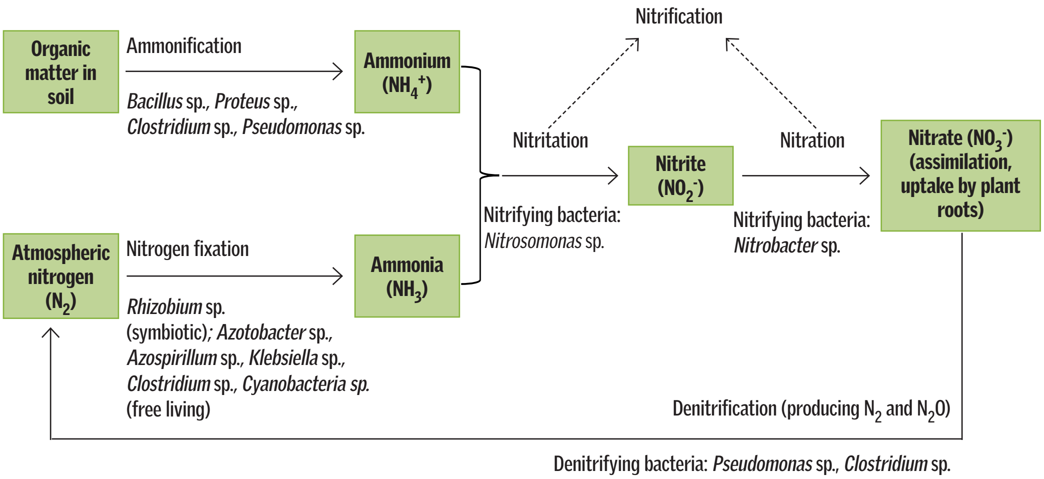
Nutrient availability and fertiliser use efficiency

Soil microbes drive major nutrient cycles by converting organic matter (e.g., dead plants, animal remains in soil) into plant-available forms. This is facilitated through two processes—microbial decomposition, in which bacteria and fungi break down simple carbon sources and plant exudates (while specialised fungi break down tougher substances such as cellulose and lignin), and mineralisation, through which microbes convert organic nutrients into inorganic forms that plants can absorb.

Soil microbes are also involved in making nutrients available to the plant through uptake. Symbiotic relationships, such as *Rhizobium* sp. in root hairs of leguminous plants, enable nutrient availability by fixing atmospheric nitrogen for the plant in exchange for sucrose as a carbon source. Similarly, mycorrhizae enable water and micronutrient uptake through its vast fungal hyphae network in the soil.

For example, in case of the nitrogen cycle, microbes (bacteria) drive the conversion of atmospheric and organic nitrogen into inorganic forms, like ammonium and nitrate for the plant. The cycle involves nitrogen fixation (e.g., *Rhizobium* sp.), ammonification (e.g., *Bacillus* sp.), nitrification to nitrite and nitrate (e.g., *Nitrosomonas* sp. and *Nitrobacter* sp.), and denitrification (e.g., *Pseudomonas* sp.). Complete denitrification returns nitrogen to atmosphere, whereas, if incomplete, it can yield nitrous oxide (N_2O), a greenhouse gas (see *Figure 3: Role of microbes in soil nitrogen cycle*).

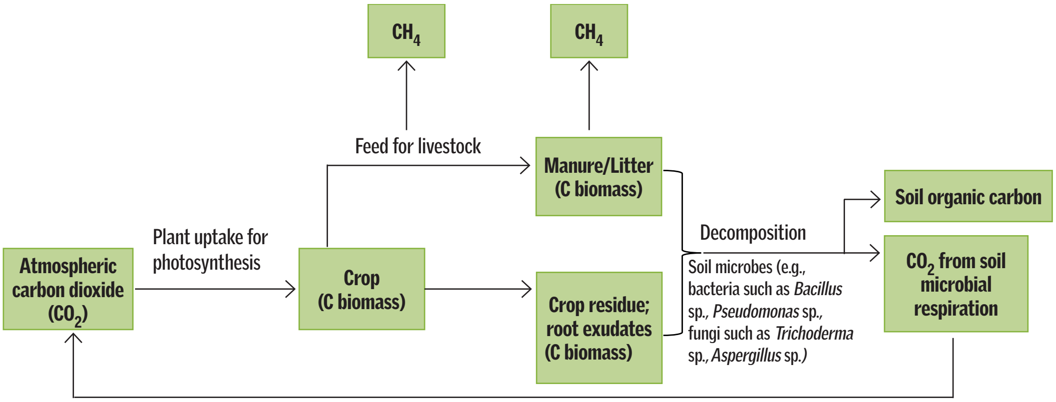
Figure 3: Role of microbes in soil nitrogen cycle



Source: Developed by authors based on research

In the carbon cycle, soil microbes (bacteria, fungi, archae, protists) decompose carbon-rich manure, litter, and crop residues, transforming biomass into soil organic carbon (SOC) while releasing carbon dioxide (CO_2) back into the atmosphere through microbial respiration. This adds to the common pool of CO_2 used by plants to make food by photosynthesis (see *Figure 4: Role of microbes in soil carbon cycle*).

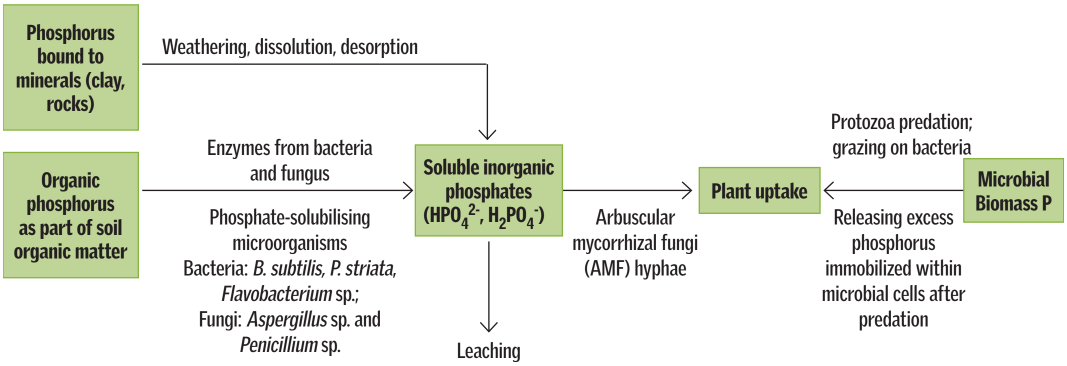
Figure 4: Role of microbes in soil carbon cycle



Source: Developed by authors based on research

Microbes facilitate the transformation of mineralised and organic phosphorus to soluble inorganic phosphates ready to be used by plants. By releasing enzymes, phosphate-solubilising bacteria (e.g., *B. subtilis*) and fungi (e.g., *Penicillium* sp.) solubilise phosphorus, while arbuscular mycorrhizal fungi (AMF) hyphae assist in plant uptake (see *Figure 5: Role of microbes in soil phosphorus cycle*).

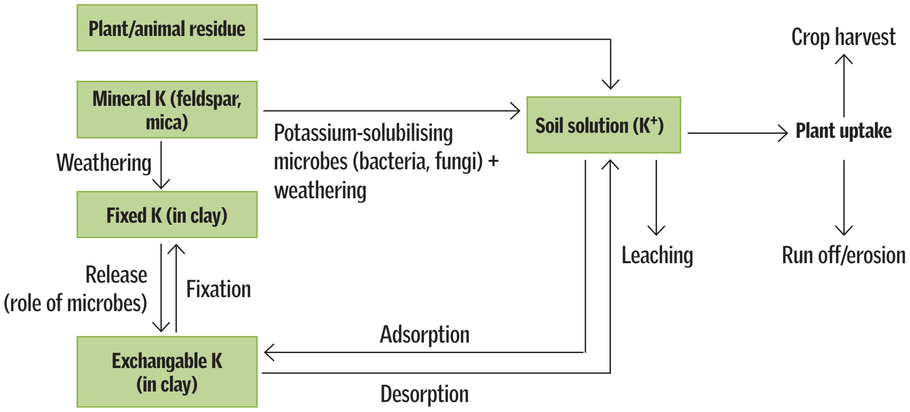
Figure 5: Role of microbes in soil phosphorus cycle



Source: Developed by authors based on research

Potassium moves between minerals, clay, and the soil solution for plant absorption. Potassium-solubilising microbes (bacteria and fungi) play a key role in weathering minerals, like feldspar and mica, and releasing fixed potassium from clay into the soil solution (see *Figure 6: Role of microbes in soil potassium cycle*).

Figure 6: Role of microbes in soil potassium cycle



Source: Developed by authors based on research

Through better nutrient availability, the Fertiliser Use Efficiency (FUE) improves, thereby reducing the need for external fertilisation.

Improved soil structure and water retention

Good biological health of soil can be clearly linked to better soil structure. Bacteria and fungi produce extracellular polymeric substances (EPS) and proteins like glomalin, which bind soil particles and promote better soil aggregation. Microbes break down organic matter into humus, which can absorb and retain large amounts of water—up to about 90 per cent of its own weight. This improves soil's water-holding capacity, reducing irrigation needs and recharging groundwater. Fungal hyphae create large spaces that allow water to infiltrate deep in the soil rather than running off. Network of tunnels created by earthworms and termites improve air passage and create larger pores enhancing soil porosity, deeper root, and water penetration. Overall, many physical aspects of soil such as soil structure, porosity, water holding capacity, aeration improve leading to a stabilised soil architecture.[28]

There is better drainage, reduced erosion, and increased moisture retention in soil.

Potential to reduce GHG emissions

Soil acts as a major engine for carbon sequestration and is the biggest carbon sink after the oceans. In addition to utilising atmospheric carbon dioxide during photosynthesis, microbes convert plant residues into stable humus and necromass (dead biomass of microbial organisms in soil), effectively storing carbon over the long term. Indian soils have the potential to sequester an estimated 6–7 Tg (Teragrams; 1 Tg=10^{12} grams) of carbon annually under improved biological management.[29] A healthy soil biota is also reported to reduce nitrous oxide (N_2O) emissions emissions from the soil by up to 40 per cent in organic farming systems.[30] Specific microbes possessing the *nosZ* gene code for enzyme nitrous oxide reductase that can convert N_2O into harmless atmospheric nitrogen.[31] Improved fertiliser use efficiency can further lead to less chemical fertiliser use, thereby reducing on-farm N_2O and off-farm CO_2 emissions from fertiliser production.

MONITORING THE BIOLOGICAL HEALTH OF SOIL

5.1 INDIA'S SOIL HEALTH CARD (SHC) SCHEME: LIMITED PROVISIONS FOR TESTING BIOLOGICAL PARAMETERS

India's Soil Health Card (SHC) scheme tests for 12 key parameters, primarily focusing on the chemical attributes of soil. These include macronutrients (nitrogen, phosphorus, potassium, and sulphur), micronutrients (zinc, iron, copper, manganese, and boron), pH, electrical conductivity, and organic carbon. The scheme does not test for parameters which are directly indicative of soil's biological health. The exclusion of biological parameters from routine measurements is due to several reasons.

Firstly, there are logistical concerns. Dependent on the highly dynamic living system, biological properties of soil sample can vary based on a number of factors like soil moisture, temperature, management practices, crop type, and the time of sample collection. This impacts the stability of sample and leads to variability in results. For accurate measurement, biological parameters in soil samples are required to be tested immediately or within 24–72 hours after collection, while preserving it in strict cold chain conditions. In the current scenario of SHC implementation, this does not seem feasible most often.

The infrastructure (e.g., refrigerators, continuous electricity supply, and laminar air flow chambers) required for biological samples is not available across the soil testing laboratory network, which limits required sample preservation and testing.

Biological assays are time-consuming, often taking days for microbial cultures to develop. Specific expertise needed for biological testing (e.g., microbiologists or soil biologists) is often missing. Many soil testing laboratories (STLs) reportedly are staffed with experts from backgrounds not related to the testing needs. Chemicals for biological assays incur more expense and add to overall cost, raising concerns about affordability.

Unavailability of established national standards or thresholds to determine the intervention required is another factor that limits the inclusion of soil biological parameters in soil testing programmes.

5.2 SOIL ORGANIC CARBON (SOC): A PROXY—BUT NOT A TRUE INDICATOR—OF BIOLOGICAL HEALTH

Soil organic carbon (SOC) is the carbon component of the soil's total organic material (called soil organic matter or SOM) through microorganisms, plants, and animals. SOC makes up about 50–60 per cent of SOM and exists in two forms: labile carbon pools, which are easily decomposed by microbes, and recalcitrant carbon pools, which are more stable, not easily decomposed, and can persist for centuries.

Microbes degrade soil carbon as their primary nutrition source. A high SOC content in soil means it is able to support a large and diverse microbial population and promote microbial diversity, which in turn helps assume that the soil is biologically active and functioning. It is argued that, measured as part of SHC, SOC is the proxy indicator for soil biological health. Some even consider it as a master indicator, which is not entirely accurate.

Its inclusion in SHC is linked with cost-effectiveness, technical and operational feasibility. But there are concerns that SOC does not completely capture the biological activity of the soil. For example,

- **SOC monitoring only quantifies carbon in the soil and not the carbon activity.** On the other hand, parameters like microbial biomass, enzyme activity, respiration rates, or microbial diversity collectively describe how carbon is being transformed, cycled, and incorporated into biomass. These parameters are suggestive of biological activity in soil (e.g., soil respiration, nutrient cycling, and organic decomposition), which is otherwise not reflected just by measuring SOC levels. SOC also do not capture the diversity of soil communities and whether they are expanding or shrinking.

- **SOC is slow to change and cannot fully capture the dynamic biological health.** Being relatively stable, changes in SOC occur over years in response to management. Therefore, SOC levels are less responsive to the changes in the biological health of the soil. On the other hand, biological parameters are more dynamic and sensitive, can vary with moisture, temperature, farm management, fertiliser application, and similar other factors in much shorter timeframes. For e.g, two soils with similar SOC levels can have different biological health if their moisture levels vary. This is because biological parameters (e.g., microbial diversity) may respond differently to moisture level, while SOC may not.
- **SOC levels do not differentiate between inert and active carbon fractions.** Microbial metabolism is largely supported by labile carbon, while the recalcitrant pool remains biologically inaccessible to them. SOC, therefore, may give an inflated picture of soil biological health, as it represents the overall pool of recalcitrant (inert) and labile (active) carbon.

5.3 SOIL BIOLOGICAL HEALTH BEYOND SOC: INSIGHTS FROM INDIAN SCIENTIFIC COMMUNITY

Several ICAR institutions and universities are conducting testing of soil biological parameters beyond SOC, such as microbial biomass, microbial biomass carbon, soil respiration, microbial diversity, and soil enzymes. These tests have largely been a part of the research efforts to understand how seasonal variations or different farming practices (e.g., organic farming or conservation agriculture) influence the soil microbial community or impact soil biological health. Therefore, conducting such tests are possible and the scientific community sees value in it (see *Table 2: Studies on soil biological parameters (2021–2025)*).

Table 2: Studies on soil biological parameters (2021–2025)

Lead organisation (year)	Location	Key observations	Biological parameters tested
University of Agricultural Sciences, Karnataka (2025)[32]	Kodagu district, Karnataka	Organic coffee soils had higher microbial biomass, respiration, and diversity than conventional plots	Microbial biomass C, soil respiration, microbial diversity
IIT Kharagpur (2025)[33]	West Bengal	Conservation tillage with residue retention improved soil biochemical health	Enzymes (dehydrogenase, phosphatase, urease), soil respiration, microbial biomass C
ICAR-Indian Institute of Soil Science (2025)[34]	Bhopal, Madhya Pradesh	Agricultural practices shifted soil microbiome composition; organic amendments improved diversity; soil microbes resilient to short-term disturbances	Microbial community composition (16S rRNA), diversity indices
ICAR (2025)[35]	Upper Gangetic Plains, India	Integrated organic systems improved biological soil health	Microbial biomass, enzyme activity, organic C
Multi-institutional study (2024)[36]	Middle Gangetic Plains (Bihar)	Seasonal variation strongly affected microbial biomass, respiration, and carbon use efficiency	Microbial biomass C and N, soil respiration, metabolic quotient (qCO_2)
ICAR-Directorate of Rapeseed-Mustard Research (DRMR;2024)[37]	Research farm in DRMR, Rajasthan	Long-term residue recycling, different tillage practices influenced biological indicators, diversified cropping systems, and enhanced microbial activity	Soil microbial biomass, soil enzyme activities, soil chemical changes
Kumaun University & collaborators (2023)[38]	Central Himalaya, Uttarakhand	Microbial biomass components exhibited strong seasonal and altitudinal variation	Soil microbial biomass carbon
ICAR-Indian Agricultural Research Institute (IARI; 2021)[39]	IARI, New Delhi	Conservation agriculture improved microbial indices, enzyme activities, glomalin, and aggregate stability over conventional tillage	Microbial biomass carbon, soil enzyme activity (dehydrogenase, alkaline phosphatase), glomalin
International Rice Research Institute (2021)[40]	Multiple sites	Organic and conservation farming enhanced microbial biomass and activity	Microbial biomass C & N, dehydrogenase activity

Note: Select studies have been represented

In addition, there are ICAR-led projects, which focus on soil microbiome and biodiversity, suggesting a long-term interest and value in understanding soil microbiology and biological health, and the presence of expertise across the country (see box: *National Projects on Soil Microbiome and Biodiversity*).

NATIONAL PROJECTS ON SOIL MICROBIOME AND BIODIVERSITY

- **Indian Soil Microbiome Project:** In 2021, the ICAR-National Bureau of Agriculturally Important Microorganisms (NBAIM) launched this project with an aim to characterise and preserve microorganisms of agricultural relevance from various agroecology.[41] Presently, the project maintains more than 8,000 microbial accessions from the country in its repository, the National Agriculturally Important Microbial Culture Collection.
- **Network Project of Application of Microorganisms in Agriculture and Allied Sectors (AMAAS):** Spanning different states and thematic areas, this ICAR-NBAIM's network project seeks to harness the power of microbes for sustainable agriculture. Launched in 2006, there are 30 projects running in its current phase (2021–2026).[42] The project themes include microbial diversity, microbiome and taxonomy, nutrient and crop stress management using microbial technologies, environment and soil health management, and microbial detection and biotechnology.
- **All India Network Project on Soil Biodiversity and Biofertilisers:** This project aims to exploit the role of soil biodiversity in supplementing crop's chemical fertiliser needs, among others. Apart from soil biodiversity and biofertilisers, it is focused on identifying soil microbes (e.g., bacteria) or soil microbiome-related indices as an indicator for soil biological health.

5.4 EMERGING FOCUS ON BIOLOGICAL PARAMETERS IN ON-FARM OR POINT-OF-NEED (PON) TESTING

Several point-of-need based soil testing devices are being developed to test certain biological parameters. Agri-tech firms, start-ups, and academic institutions are part of this new testing ecosystem. Few examples are given below.

Soil Respiration Indicator Gel (SRI-Gel): It is a probe-based device designed to measure **soil respiration**. Developed jointly by Tamil Nadu Agricultural University (TNAU) and the Indian Institute of Soil Science (IISS), the aim is to enable unskilled farmers to test biological parameters on the spot without expensive laboratory equipment. The device involves a gel pad that traps and measures CO_2 released by actively respiring soil microbes in a time of six to eight hours. This is reflected by a change in colour in the gel pad, across a 6-level gradient scale. Each colour corresponds to a specific soil health grade (poor, moderate, or high) and includes recommendations for soil improvement. The gel pad is reusable for two to three rounds, as the colour returns to its original state once removed from the container. The cost of testing comes to less than Rs 50 per soil sample. TNAU has submitted a patent for the device.

Soil X Probe: This is an artificial intelligence (AI), machine learning, and spectrometry-based soil health probe developed by Reve Nano-Science LLP. It is designed for real-time field-based soil testing. Among others, it monitors five biological parameters—**relative bacterial index, fungal activity index, humus content index, termite influence index**, and **aflatoxin risk index**. The probe, when connected via the Reve App on a smartphone, captures live data and analysis, producing a report in about one minute. Accuracy of the probe is estimated at 80 per cent, and it can be used by unskilled users. It is rechargeable, and can be used continuously for 10–11 hours. The current price is Rs 5 lakh, while recurring cost per sample is quite minimal, with a nominal operational fee of Rs 80–100 to cover cloud services and maintenance.

The Soil Doctor Kit: This is a portable, semi-automatic soil testing system developed by EkoSight, an agritech startup founded in 2021. The kit uses conventional chemistry, such as spectroscopy, and replaces tedious liquid chemical preparation with pre-packed solid or powdered sachets. Out of 18, it tests two biological parameters—**microbial biomass** and **fungal:bacterial ratio**. EkoSight has also developed a decentralised, village-level 'soil doctor clinic' model, and stationed 'soil doctors' at these clinics. Farmers bring soil samples to the clinic and receive results within an hour as a paid service (Rs 500–750 per test). As of January 2026, Ekosight had about 80+ clinics in nine states, with each clinic having a kit and a soil doctor. Non-governmental organisations (NGOs), farmer producer organisations (FPOs), and micro-entrepreneurs can purchase the device for approximately Rs 75,000 (plus Rs 10,000 for setup of clinics and additional GST charge).

Soilometer: This is a rapid, on-the-spot soil testing kit launched by Biome Technologies Pvt. Ltd. in 2024. It uses a colour-based biochemical assay to measure **total viable microbial count (bacteria and fungi)**. A soil sample mixed with activator and reagent produces a color proportional to microbial count. There are two kits: (a) Soilometer (Rs 1,500; five tests; qualitative results in three hours) for microbial health; (b) Soilometer Advanced Kit testing six parameters—N, P, K, organic carbon, pH, and microbial health (Rs 4,400; ten tests; qualitative results of chemical parameters in 30-minutes, microbial health in three hours). Both kits include colour charts and instructions. More than 20,000 kits have been sold so far. Apart from Maharashtra, the pilots are running in Uttar Pradesh, Bihar, Punjab, and Haryana. Under the Krishi Rasayan Saksharta Abhiyan, over 3,000 farmers (Rs 3,000 fee) have been trained by the company in the last three years and provided with soil testing kits, biofertilisers, and biopesticides. Farmers receive post-training support from the company. FPOs and NGOs also buy kits in bulk at discounted rates and engage local youth or women (‘soil warriors’) for scaled-up field-level soil testing.

5.5 POSSIBLE TESTS FOR BIOLOGICAL HEALTH IN SHC SCHEME

Based on inputs from stakeholder experts, a set of tests have been identified in view of affordability and feasibility, which could be included in SHC scheme to assess biological health of the soil (see *Table 3: Tests for biological health in SHC scheme*).

Table 3: Tests for biological health in SHC scheme

Soil test (What it measures)	Method	Cost[#] (per test; broad sense)	Advantages	Concerns
Earthworm population/ castings*^ (Cast count, density of earthworms)	Dig 1x1x1 m^3 pit; count worms/ castings (hand sorting or mustard extraction)	Low	Easy and quick to monitor; not resource intensive	Counting methods can be destructive; high variability due to time, moisture level
Hydrogen peroxide (H_2O_2) test* (Organic matter in soil)	Add few drops of 30 per cent H_2O_2 to soil sample; stronger reaction (bubbles) means higher organic matter content	Low	No equipment needed; easy and not resource intensive; can be repeated over time	Not all soils react with H_2O_2 irrespective of organic matter content
Microbial density/ Microbial population/ Fungi:Bacteria Ratio* (sense of fungal and bacterial population)	Microscopic count; higher fungi population implies good soil health	Low	Technically easy to monitor; need some resources	One-time investment for microscope needed; user should know sample preparation and microscope use
Microbial Biomass Carbon (C in living microbes)	Chloroform fumigation-extraction method followed by extraction of carbon using usually with K_2SO_4	Moderate (~Rs 500 per sample)	Good predictor of nutrient mineralization potential; responsive to organic inputs	Fumigation chemicals could be hazardous; need some establishment (e.g. vacuum pump, water bath) and skilled labour
Permanganate Oxidisable Carbon (Labile/active carbon pool)	Chemical oxidation with $KMnO_4$ and colorimetric assay	Moderate (upto Rs 500 per sample)	Quick, affordable; chemicals and equipment present in standard lab	Standardisation required; sensitive to soil texture and mineralogy
Soil respiration (CO_2 evolved by microbial activity)	Closed jar/alkali trap method or use of infra-red gas analysers	Moderate (upto Rs 500 per sample)	Quantitative and reproducible	Time consuming; needs incubation; moisture control critical
Microbial enzyme activity (Dehydrogenase; Soil oxidative enzyme activity)	Colourless Triphenyl Tetrazolium Chloride (TTC) reduced to red Triphenyl Formazan (TPF); TPF measured in spectrophotometer	Moderate (~Rs 500 per sample)	Gives direct sense of metabolic activity of microbial community	Enzyme assays sensitive to storage; interpretation requires expertise; requires soil incubation; need some establishment (e.g., BOD incubator)

^ Earthworm count is more accurate but cast count can also be an indicator; *Can be done in field or with minimal laboratory needs; [#]Cost assessment is based on primary inputs.

Note: Some other tests which can be done are estimating mineral nitrogen, carbon-nitrogen ratio and microbial community composition (with 16S rRNA)

Source: Developed by authors based on primary research inputs

These can be understood broadly as sensory tests, tests with minimal laboratory needs, tests that need proper laboratory infrastructure. Examining soil colour, odour, and texture are not specific tests of soil biological health, but they can provide a quick qualitative understanding about soil health. Counting earthworm castings or detecting presence of mites, insects, or ants are field-based assessments needing minimal cost and resource.

Tests like H_2O_2 test or fungi:bacterial ratio can be done with minimal laboratory needs; while some tests, such as testing for microbial biomass carbon and microbial enzyme activity, need a proper laboratory set up. There are also high-end tests, such as to determine microbial community composition using 16S rRNA sequencing, which have not been included here.

The Food and Agriculture Organization (FAO) of the United Nations also recommends monitoring soil biological health (see box: *FAO Recommendations on Monitoring Soil Biological Health*).

FAO RECOMMENDATIONS ON MONITORING SOIL BIOLOGICAL HEALTH

The FAO recommends testing of biological parameters in the soil. For example, FAO's Global Soil Laboratory Network (GLOSOLAN) provides Standard Operating Procedures (SOP) for soil biological analysis.[43] It recommends several parameters for testing—microbial biomass, soil respiration, enzyme activity (β-glucosidases, arylsulfatase, N-acetyl-β-glucosaminidase, dehydrogenase, phosphomonoesterases), soil mesofauna and nematodes.

In addition, FAO's Global Soil Doctors Programme provides methods for testing of four soil biological properties—earthworm density, litter decomposition, active/labile carbon, and soil respiration.[44]

FAO's Protocol for the Assessment of Sustainable Soil Management mentions measuring soil respiration rate for soil biological activity.[45] To better interpret results, it also provides additional indicators for soil biological activity (soil microbial biomass and specific enzymatic activity method) and soil biodiversity (counting and identification of macro, meso organisms, and genomic analysis).

CONCLUSION AND WAY AHEAD

It is clear that enhancing soil biological health is essential for improving the ongoing decline in soil health in India, given the critical benefits delivered by the biological components of the soil. These include nutrient availability and fertiliser use efficiency, improved soil structure and water retention, and the potential to reduce GHG emissions.

Advantages rendered by the biological aspects of the soil can go beyond these functions and include increased food productivity, nutritive crops, better farmer incomes, water conservation, prevention of desertification, reduced environmental pollution, and, most importantly, building resilience in the Indian agriculture sector.

However, the narrative of improving soil health is still largely focused on chemical-centric approaches due to a combination of reasons, including after-effects of Green Revolution, food security needs, research and commercial focus on agriculture chemicals, and subsidy structure related to agriculture and fertilisers. This chemical-centric focus to improve soil health—a reductionist approach, as often believed—has also led to the absence of national-level monitoring of soil biological parameters, as evident from the Soil Health Card (SHC) scheme. The only exception is the testing for soil organic carbon as a proxy indicator (but not true) of soil biological health.

The recognition to invest in understanding soil biological health has evolved, as is evident from the increasing scientific studies and projects that involve testing of a wide variety of biological parameters in soil. Agri-tech start-ups have also started focusing on biological health by taking testing from lab to land, and closer to farmers, who are also seeing value in it now. This is over and above the conviction—in maintaining soil biological health—shown by civil society and farmer collectives promoting non-chemical agriculture.

While including biological parameters in national-level monitoring such as SHC scheme has challenges, it is considered as the need of the hour, in view of its potential benefits. These possibilities have to be explored through a phased approach.

In view of the above findings, the following recommendations are proposed:

1. IMPROVE ORGANIC CARBON CONTENT IN THE SOIL

This can be done through:

- **Promoting use of organic and bio-inputs** (on-farm and off-farm), such as farmyard manure, compost, green manuring, biofertilisers, microbial consortia, and farm use of agriculture crop-residue. Necessary awareness, infrastructure, and incentives to produce and use such inputs needs to be enhanced. Systemic long-term support to local-level bio-input resource centres (BRCs) can be one effective measure among others.
- **Promoting agronomic practices**, such as related to non-chemical farming, regenerative/agro-ecological/conservation agriculture, water use efficiency and crop diversity.

  Improving soil organic carbon can create incentives—through carbon credits in agriculture—which can further be used to invest in soil-health.

2. REDUCE CHEMICAL FERTILISER USE AND PHASE-OFF CHEMICAL PESTICIDE USE

- **Reduce chemical fertiliser use** by improving the fertiliser subsidy structure, which has also led to the imbalanced and high use of N-based urea. Including urea in the Nutrient-

Based Subsidy (NBS) scheme, currently applicable to other fertilisers, can be an option. Other could be reducing the gap between the price of urea and other fertilisers such as DAP. Another would be to provide direct financial support to the farmers, enabling them to opt for non-chemical fertilisers, in addition to aggressive measures to scale-up integrated nutrient management. Encouraging states to leverage the PM Programme for Restoration, Awareness Generation, Nourishment, and Amelioration of Mother-Earth (PM-PRANAM) scheme to reduce fertiliser use can go a long way.

- **Phase-off chemical pesticide use** by promoting integrated pest management and use of organic and bio-pesticides.

3. MAINSTREAM MONITORING OF SOIL BIOLOGICAL HEALTH

- **Include biological parameters in the SHC scheme**. This should be considered through a phased approach, such as beginning with a limited set of districts, agro-ecological zones, laboratories, or tests. The selection of tests should be carefully considered based on cost, capacity, and thresholds or benchmarks, which should be developed in parallel. For example, testing for **microbial biomass carbon** and **microbial enzyme activity (dehydrogenase)** are two key tests which can be considered recognising that these tests are to be conducted in fresh samples and would need short-term storage infrastructure for temperature control.
- **Strengthen soil testing laboratory (STL) infrastructure and scale up required capacity.** This should involve developing a good understanding of which biological parameters can be tested and what are the laboratory requirements for each of those tests. Based on this mapping and gaps assessment, laboratory infrastructure should be strengthened and capacity-building investments should be made. For e.g., qualified experts, such as soil biologists, should be stationed in STLs and trained in biological sample collection, data analysis, and interpretation.
- **Promote inclusion of affordable on-farm or point-of-need (PON) testing of soil biological parameters.** This can be done through

incentivising and promoting PON or on-farm technologies which can effectively and affordably test biological parameters useful for farmers. This should however be complemented by initiatives to ensure quality and validation of results. The lab-to-land pathway can be a successful middle approach between the high-end laboratory testing and basic sensory-based testing, which can be done by farmers. Village-level entrepreneurship among local youth, FPOs, or self-help groups (SHG) could be encouraged for testing at local levels.

- **Create awareness among farmers and local ecosystem**. Efforts should focus on spreading awareness regarding the importance of understanding biological health and the interventions that can help improve it.

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India's soil health continues to decline, driven by factors such as the overuse and imbalanced use of fertilisers, topsoil erosion, and intensive, chemical-dependent agronomic practices. At the core of this crisis lies the often-overlooked dimension of soil biological health, which is fundamental to restoring soil's overall function.

This report focuses on the potential role of soil biological health in improving soil health in India. It explains what soil biological health is, why it is important for overall soil health, and identifies the challenges and possibilities of including biological parameters in soil health monitoring in India. The report also provides policy and implementation suggestions for the way forward.

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