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Advances in Soil Health Assessment: Indicators, Techniques, and Future Directions – An Overview

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Introduction

Soil is said to be a complex system (Ladyman *et al*., 2013) at the coincidence of the atmosphere, lithosphere, hydrosphere and biosphere (Brevik *et al*., 2015) that is critical to food production system and way to key sustainability through its support of important societal and ecosystem services (Blum, 2005). Soil health is the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals and humans, and connects agricultural and soil science to policy, stakeholder needs and sustainable supply chain management. Historically, soil assessments focused on crop production, but today soil health also includes the role of soil in water quality, climate change and human health. But for healthy food production, the soil health is to be in good quality. Hence we should abide the science involving the sustainability among the soil and equal food production for present and future generations.

Key Indicators of Soil Health: Physical, Chemical, and Biological

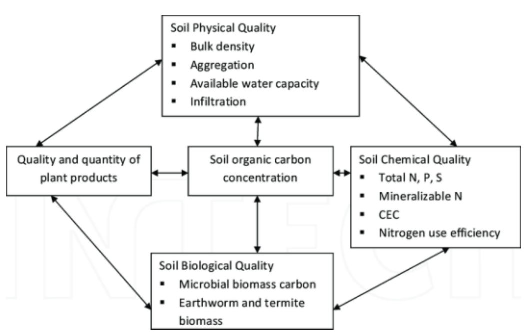

Fig. 1. Key indicators of soil health (Oshunsanya *et al*., 2018)

Soil Physical Properties and Health

Soil texture is an inherent properties. I.e. Sand, slit and clay. Clay forms the extreme colloidal surface as it was less than 0.002 mm in size and it acts as a buffering capacity in the soil. Whereas sand is a fraction which consist of quartz and silica and has no special property on soil system. Loam is contain more or less equal proportion of sand and clay. The unseen part of soil fertility management is Soil physical science. I.e. Soil structure, texture, porosity, infiltration, hydraulic conductivity etc. which will decides other part of soil health management. Soil physical property including soil structure which is a key factor in soil functioning and important factor in evaluating the sustainability in crop production system. Soil structural stability is the ability of aggregates to remain intact when exposed to different stresses (Kay *et al*., 1988) and measures of aggregate stability are useful as a means of assessing soil structural stability. Hence maintaining soil physical properties are essential for sustainable soil system.

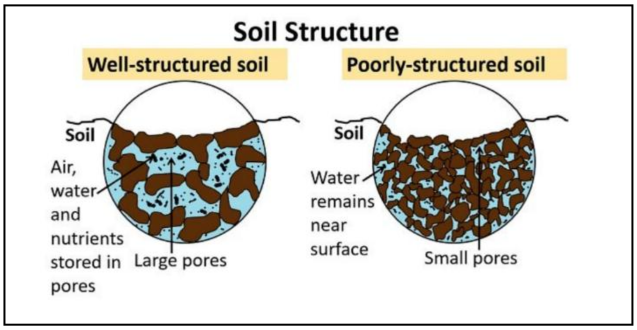

Fig. 2. Elevating the difference among the well-structured and poorly structured soil

Compaction and Its Effects on Root Growth and Water Infiltration

We know that compaction affect the different layers of horizons and it make difficult to penetrate the roots deeper into the soil system. It is mostly due to presence of trafficability and workability in field condition. Generally, the compaction is of

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two types. One is surface compaction and other is sub surface compaction. When it about to meets the compact surface, water infiltration gets reduced. The simple relation between compacted and uncompacted soil and its effect on root system is illustrated below, which was experimented by (Nannen *et al*., 2020)

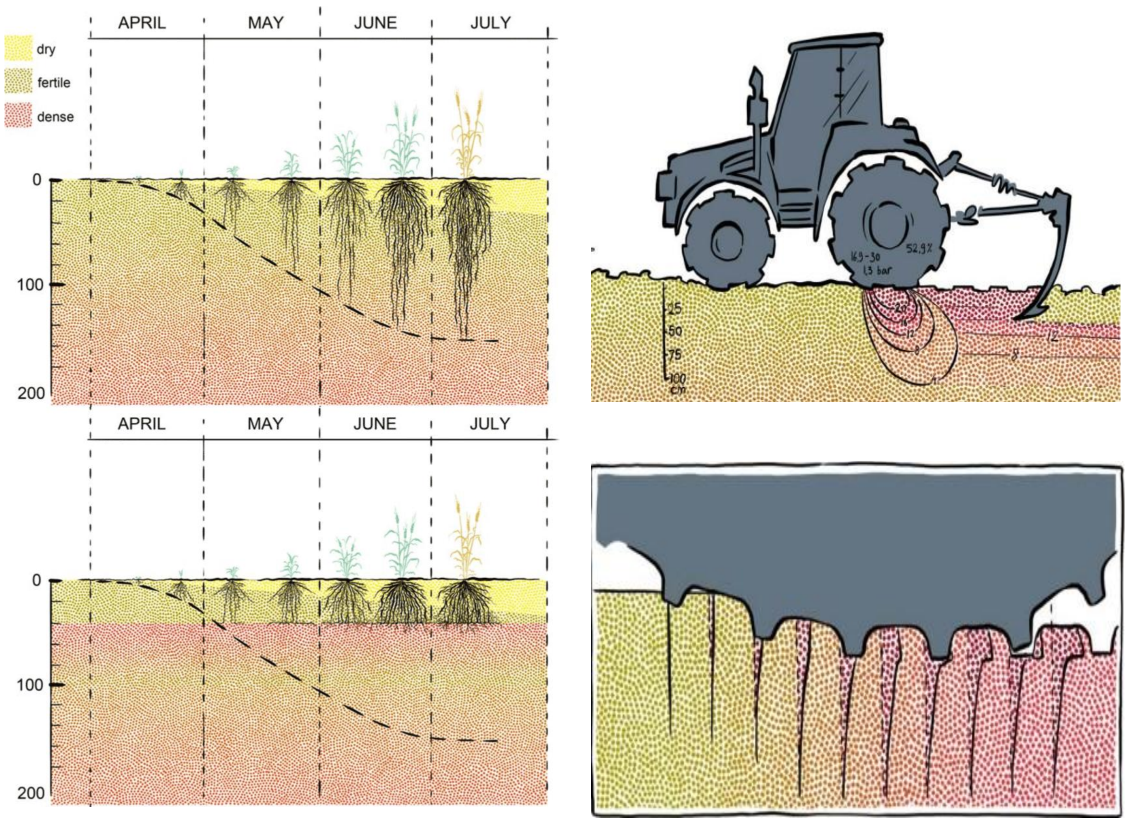

Fig. 3a. The effect of soil compaction on root growth. Top: In healthy soil wheat roots utilize the soil column to a depth of 120 cm. Bottom: In compacted soil root growth is mostly limited to the plowed top soil, which dries out quickly in arid climates; 3b. The main axis of the pressure bulb under a tractor tire extends diagonally into the ground and compacts the soil below the depth of tillage (Söhne and Bolling, 1981).

Soil Chemical Properties and Nutrient Management

Chemical attributes are the key promoters in performing all the chemical reaction in the soil. Soil pH, cation exchange capacity, buffering capacity of the soil, nutrient mobilization were take part in the soil system.

Soil Biology and Microbial Health

Soil microbial activity and diversity play important roles in the sustainability by keeping essential functions in soil health, involving carbon and nutrient cycling (Jeffries *et al*., 2003; Izquierdo *et al*., 2005). Microbial indicators are more susceptible than physical and chemical attributes to changes imposed to the environment like soil use and management (Melo and Marchiori, 1999; Masto *et al*., 2009), and for this reason can early forecast any disturbance in the sustainability of an environment.

Role of Soil Microorganisms in Nutrient Cycling and Plant Health

Soil microorganisms have an important contribution towards the soil productivity and therefore the relationship between soil microbial populations, diversity, functions and soil management practices needs thorough understanding. Also some microorganism were capable of producing a mucilage substances that can bind the soil particles, thus promoting aggregate stability. Three principal components of SOM are as follows:

(1) Plant and animal residues and living microbial biomass;

(2) Active or labile SOM; and

(3) Relatively stable

Microorganisms are key players in the cycling of nitrogen, sulfur and phosphorus, and the decomposition of organic residues. They affect nutrient and carbon cycling on a global scale (Wani *et al*., 2015).

Soil Biodiversity as an Indicator of Soil Health

Soil biota is a broad term which comprises of all the organism that spend a significant portion of their life cycle within a soil profile, or at soil – surface interface. It is also known as soil edaphon or “Soil life”. Soil biota, the biologically active powerhouse of soil, include an incredible diversity of organisms. It includes micro-organisms (bacteria, fungi, and algae) and soil "animals" (protozoa, nematodes, mites, springtails, spiders, insects, and earthworms) in soil. They are more diverse than the community of plants and animals on above ground. Soil biota are concentrated in plant litter, the upper few inches of soil, and along roots. Soil organisms interact with one another, with plant roots, and with their environment, forming the soil food web.

Tab. 1. Relative number and biomass of microbial species at 0 – 6 inches (0-15cm) depth of soil

Microorganisms	Number / g of soil	Biomass (g/m^2)
Bacteria	10^8-10^9	40-500
Actinomycetes	10^7-10^8	40-500
Fungi	10^5-10^6	100-1500
Algae	10^4-10^5	1-50
Protozoa	10^3-10^4	Varies
Nematodes	10^2-10^3	Varies

Importance of Soil biota

Soil microbes break down organic matter

Microorganisms plays an important role in the decomposition of organic matter. Different types of microbes are specialized to different types of organic matter, between them covering just above everything.

Recycling nutrients

Soil microbes plays a crucial role in returning nutrients to their mineral forms, which plants can take up again. This process is known as mineralization. (Eg. Plant can take nitrogen in the form of Ammonical and nitrate).

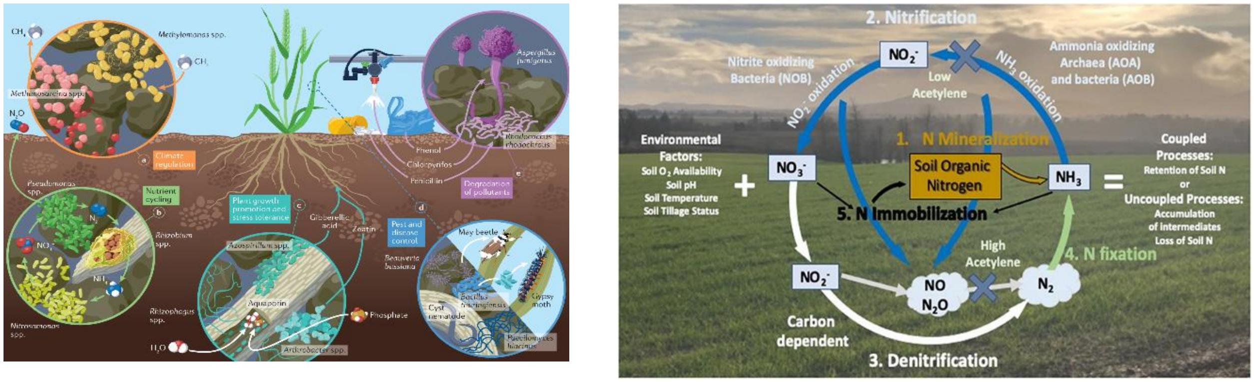

Fig. 4. Recycling of soil nutrients

Techniques to Enhance Soil Microbial Health (e.g., biofertilizers)

Biofertilizer is the microbial inoculants that contain the culture of dormant or live cells of the effective strains of N-fixing, P-solubilizing/ mobilizing, K-solubilizing. Microorganisms at their cellular level which is often applied to seeds, soils, or compost material to accelerate the microbial activities by such organisms through their multiplication and enhance the nutrient's availability, which can be easily accessible by the plants. Very often microorganisms are not as efficient in natural surroundings as one would expect them to be and therefore artificially multiplied cultures of efficient selected microorganisms play a vital role in accelerating the microbial processes in soil. Use of bio fertilizers is one of the important components of integrated nutrient management, as they are cost effective and renewable source of plant nutrients to supplement the chemical fertilizers for sustainable agriculture. Several microorganisms and their association with crop plants are being exploited in the production of biofertilizers. They can be grouped in different ways based on their nature and function.

Tab. 2. Different groups of biofertilizers with example

S. No.	Groups	Examples
N2 fixing Biofertilizers		
1.	Free-living	*Azotobacter*, *Beijerinkia*, *Clostridium*, *Klebsiella*, *Anabaena*, *Nostoc*,
2.	Symbiotic	*Rhizobium*, *Frankia*, *Anabaena azollae*
3.	Associative Symbiotic	*Azospirillum*
P Solubilizing Biofertilizers		
1.	Bacteria	*Bacillus megaterium* var. *phosphaticum, Bacillus subtilis Bacillus circulans, Pseudomonas striata*
2.	Fungi	*Penicillium sp, Aspergillus awamori*
P Mobilizing Biofertilizers		
1.	Arbuscular mycorrhiza	*Glomus sp.,Gigaspora sp.,Acaulospora sp., Scutellospora sp.* & *Sclerocystis sp.*
2.	Ectomycorrhiza	*Laccaria sp.*, *Pisolithus sp.*, *Boletus sp.*, *Amanita sp.*
3.	Ericoid mycorrhizae	*Pezizella ericae*
4.	Orchid mycorrhiza	*Rhizoctonia solani*
Biofertilizers for Micro nutrients		
1.	Silicate and Zinc solubilizers	*Bacillus* sp.
Plant Growth Promoting Rhizobacteria		
1.	Pseudomonas	*Pseudomonas fluorescens*

Conservation Agriculture and Reduced Tillage

Conservation tillage is a widely-used terminology to denote soil management systems that result in at least 30% of the soil surface being covered with crop residues after seeding of the subsequent crop (Jarecki and Lal, 2003). Conservation agriculture removes the emphasis from the tillage component alone and addresses a more enhanced concept of the complete agricultural system. It combines the following basic principles:

1. Reduction in tillage: The objective is to achieve zero tillage, but the system may involve controlled tillage seeding systems that normally do not disturb more than 20-25% of the soil surface;

2. Retention of adequate levels of crop residues and soil surface cover: The objective is the retention of sufficient residue on the soil to protect the soil from water and wind erosion; to reduce water run-off and evaporation; to improve water productivity and to enhance soil physical, chemical and biological properties associated with long term sustainable productivity. The amount of residues necessary to achieve these ends will vary depending on the biophysical conditions and cropping system.

3. Use of crop rotations: The objective is to employ diversified crop rotations to help moderate/mitigate possible weed, disease and pest problems; to utilize the beneficial effects of some crops on soil conditions and on the productivity of subsequent crops; and to provide farmers with economically viable cropping options that minimize risk.

Zero tillage with residue retention improves dry aggregate size distribution compared to conventional tillage (Govaerts *et al*., 2009a). Hence minimizing the tillage operation will enhance the aggregate stability.

Organic formulation Practices for Soil Health

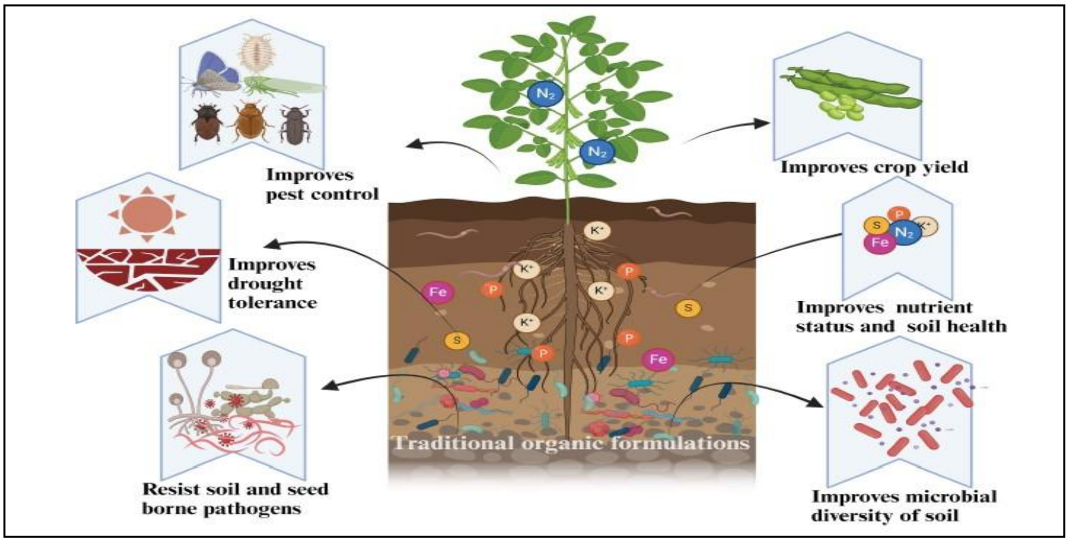

Fig. 5. Beneficial effect of Traditional organic formulation on soil properties

Tab. 3. Benefits of Traditional organic formulation and its effect on plant and soil properties.

Sl. No	Traditional organic formulations	Benefits	References
1.	Amritpani	Induce biotic and abiotic stress tolerance in crops and improve crop growth and yield.	(Kumar and Singh, 2021)
2.	Beejamurtha	Provide macro and micronutrients and control soil and seed-borne pathogens.	(Shyamsunder and Menon, 2021)
3.	Egg amino acid	Promotes plant growth	(Nandhini and Somasundaram, 2023)
4.	Fish amino acid	Provides nutrition to plants	(Nandhini and Somasundaram, 2023)
5.	Five leaves extract	Works against sucking pests	(Nandhini and Somasundaram, 2023)

6.	Jeevamurtha	Improves soil health and nutrition	(Nandhini and Somasundaram, 2023)
7.	Panchagavya	Boosts crops, promotes growth, induces biotic and abiotic stress tolerance in crops	(Kumar and Singh, 2021)
8.	Sanjivak	Promotes growth and induces biotic and abiotic stress tolerance in crops.	(Mathukiya *et al*., 2023)
9.	Biological Extract (Thailand)	Soil health improvement enriches microbial sources in soil and promotes plant growth.	(Chunsathit and Kaenla, 2014)
10.	VESTA (Europe)	Improves soil health, plant growth, and bacterial community composition, diversity, and function	(Deng *et al*., 2019)

Agroforestry and Perennial Crops for Soil Stability

Although every cropping pattern and sequence maintains the soil structural form in same situation. To overcome that, growing of trees and perennial crops can be encourage for soil health stability and build in structural stability in soil ecosystem. The influence of agroforestry on soil quality through changes in ecosystem functions and services caused by direct and indirect effects of trees varies depending on the crop type, climate, and geography. When integrating trees in the farm land, will definitely increases the field capacity and organic matter content (Chatterjee *et al*., 2018), available potassium, available phosphorus, soil carbon stocks (Surki *et al*., 2020), and lower bulk density (BD) (Hailu, 2015), which retain water by increasing the water holding capacity (WHC) and release the water to plants gradually like a sponge

(Schroth *et al*., 2003). Agroforestry also leads to higher soil C-sequestration rates; moisture contents; and levels of available soil K, N, and P, the residues of which are available for subsequent crops, allowing more sustainable farming in the upcoming seasons and reducing the use of chemical fertilizers (Surki *et al*., 2020). And there are many ways or processes by which agro – forestry helps the soil to regain health and quality. They are listed below;

1. Photosynthetic fixation of carbon and its transfer to the soil via litter and root decay,
2. Nitrogen fixation by all leguminous trees and in few non-leguminous species (e.g., Alder and Casuarinas),
3. Improved nutrient retrieval by tree roots, including through mycorrhiza and from lower horizon,
4. Providing favourable conditions for the input of nutrients from rainfall and dust
5. Control of erosion by combination of cover and barrier effect, especially the former,
6. Root uptake of nutrients that would otherwise have been lost by leaching,
7. Soils under trees have favourable structure and water holding capacity, through organic matter maintenance and root action,
8. Provision of a range of qualities of plant litter, woody, and herbaceous,
9. Growth promoting substances,
10. The potential through management of pruning and relative synchronization of timing of release to nutrients from litter with demand for their uptake by crops, and
11. Effects of tree shading on microclimate.

Perennial crops like herbaceous perennial legume crops, such as alfalfa or clover, can suppress weeds via competition and multiple defoliations, and require no N fertilization. Perennial legumes have been a popular option for the transition period. Perennial crops also contribute to all or most of the soil health principles and are considered a promising option for improving soil health and fertility (Pimentel *et al*., 2012).

Crop Rotation and Diversification for Soil Fertility Management

Crop rotation and diversification are the one of the important crucial strategies adopted and followed which will helps the farmers, environment and most important is soil

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fertility management. Since, the way of protruding different types of crops, their root system are also getting different. This make the way for increase in soil aeration porosity. Crop rotation, a beneficial approach, an agricultural practice, which involves growing of different crops in a definite sequence over a period of time in a definite area (Zhao *et al*., 2013). By adopting crop rotation practices, the incidence of pests, diseases and most important weed can be reduced simultaneously (Guinet *et al*., 2023; Garland *et al*., 2023). In addition to crop rotation, the diversification of agricultural landscapes also plays a crucial role in enhancing the sustainability and resilience of farming systems (Tamburini *et al*., 2020). When a farmer only focused on continuous monocropping system, the crop may subject to severe pest and disease and therefore, adopting diversified cropping system or sequence will make soil more fertile and sustainable one. The benefits of Diversified cropping rotation when compared with monocropping is illustrated in Fig. 5.

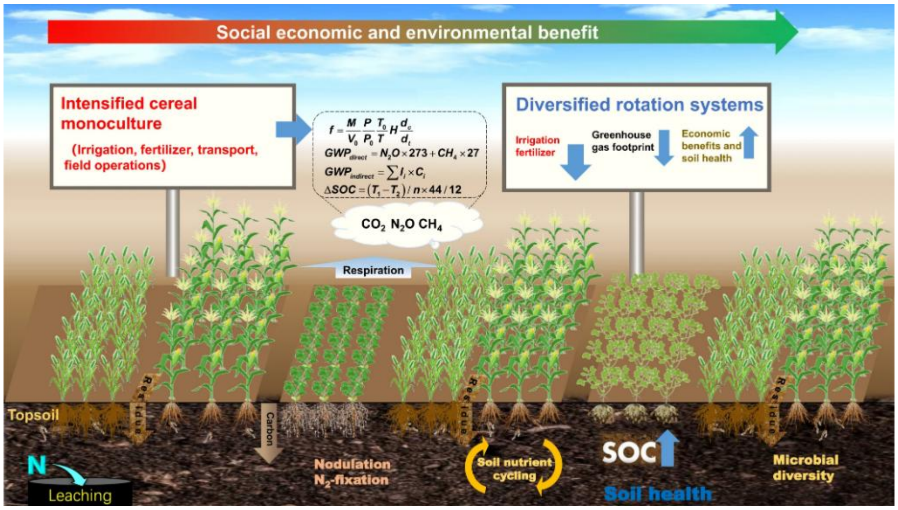

Fig. 6. Social economic and environmental benefit of practicing diversified cropping rotation than monocropping system

Conclusion

Hence, to balance sustainable food production and future food security, the agriculture holds special position towards this approaches. Keeping soil healthier gives back good quality food crops. Hence, agriculture a bowl of sphere, everyone must share equal space and contribute towards it as much as we can for sustainability. Thus, the excessive use of synthetic fertilizers, the systematic deforestation, soil erosion due to high tillage and the action of rains or winds, loss of organic matter and several other factors brought about increasing desertification, the loss of millions of tons of fertile top soil and, indirectly, silted up rivers and lakes, caused soil salinization, climate changes and loss of biodiversity.

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Conflict of Interest

The authors declare that there is no conflict of interest with the present publication.

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