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# Role of soil physical, chemical and biological properties for soil health improvement and sustainable agriculture

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## Abstract

Soil health refers to the ecological equilibrium and the functionality of a soil and its capacity to maintain a well balanced ecosystem with high biodiversity and productivity. Soil health as a tool for sustainability, physical, chemical, and biological properties. Among the physical indicators, soil texture, aggregation, moisture, porosity, and bulk density have been extensively used, while among chemical indicators soil pH, total C and N, mineral nutrients, organic matter, cation exchange capacity and biological ones such as microbial biomass C and N, biodiversity, soil enzymes, soil respiration, etc., in addition to macro and meso-fauna play a major role in maintenance of soil health. Many human activities have caused desertification, loss of biodiversity, disruption of aggregates, loss of organic matter and nutrients. It is imperious to maintain soil health and productivity with increasing emphasis on reforestation and recovery of degraded areas through the use of organic amendments, reintroduction of plants, soil fauna and microorganisms.

**Keywords:** Soil health, productivity, physical, chemical, biological, sustainable, agriculture

## Introduction

Soil is a dynamic interface between the lithosphere (rock), atmosphere (air), hydrosphere (water), and biosphere (living things). It is the zone in which rocks and organisms, and the air and water that move in and through and around them, interact. Soil is not just the physical parts that make it up, but also the active interactions between its various physical, biological, and chemical parts. A soil's characteristics determine how the soil functions as a foundation of the ecosystem. Soil health is the condition of the soil in a defined space and at a defined scale relative to a set of benchmarks that encompass healthy functioning. Soil health invokes the idea that soil is an ecosystem full of life that needs to be carefully managed to regain and maintain our soil's ability to function optimally. Soil Health refers to the ecological equilibrium and the functionality of a soil and its capacity to maintain a well balanced ecosystem with high biodiversity above and below surface, and productivity.

A healthy soil has been defined as "The continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal and human health" (Doran and Safley, 1997) [18]. The terms 'soil health' and 'soil quality' are becoming increasingly familiar worldwide. Doran and Parkin, in 1994 [17], defined soil quality as "the capacity of a soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health." The term 'soil health' has been generally preferred by farmers, while scientists have generally preferred 'soil quality'.

Managing for soil health (improved soil function) is maintaining suitable habitat for the countless number of creatures that comprise the soil food web. This can be accomplished by disturbing the soil as little as possible, growing as many different species of plants as practical, keeping living plants in the soil as often as possible, and keeping the soil covered all the time.

A soil physical condition is the degree of compaction, capacity for water storage and ease of drainage is also critical to soil and plant health. Good soil tilth promotes rainfall infiltration, thereby reducing runoff and allowing moisture to be stored for later plant use. It also encourages proper root development. When aeration and water availability are ideal, plant health and growth benefit. For example, crops growing in friable soils with adequate aeration are less adversely affected by both wet and dry conditions than those growing in compacted soils. Soils with good physical structure remain sufficiently aerated during wet periods, and in contrast to compacted soils they are less likely to become physical barriers to root growth as conditions become very dry.

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Organic matter improves aeration by promoting the aggregation of soil particles. Secretions of mycorrhizal fungi, which flourish in organic matter also improve a soil's physical properties.

Among the important chemical determinants of a soil's health are pH, salt content and levels of available nutrients. Low quantities of nutrients, high levels of such toxic elements as aluminum and high concentrations of salts can adversely affect the growth of your crops. Healthy soils have adequate but not excessive nutrients. Excessive available nitrogen can make plants more attractive or susceptible to insects, and over abundant nitrogen and phosphorus can pollute surface and groundwater. Well-decomposed organic matter helps healthy soils hold onto calcium, magnesium and potassium, keeping these nutrients in the plants' root zone.

Soil microorganisms can be classified as bacteria, actinomycetes, fungi, algae, protozoa and viruses. Each of these groups has different characteristics that define the organisms and different functions in the soil it lives in. Importantly, these organisms do not exist in isolation, they interact and these interactions influence soil fertility as much or more than the organism's individual activities.

In recent years the potential application of cultivating soil fungal biodiversity to improve soil quality and increase productivity of agricultural ecosystems has been highlighted as a new and very promising development in plant productivity (Bagyaraj and Ashwin, 2017) [3], which may come be called 'the 2nd Green Revolution.' The implementation of such solutions may offer an alternative to the current overuse of fertilizers toward more sophisticated manipulations of plant productivity. Beneficial micro organisms participate in decomposition of organic matter and deliver nutrients for plant growth. Their role is very important in plant protection against pathogenic microorganisms as biological agents, which influences soil health (Frac *et al*., 2015) [19]. The assessment of micro organisms or biodiversity as quality indicators cannot be limited only to the determination of biodiversity indexes, but also should include a structure analysis of micro organism's population in order to determine the functions they play in affecting soil quality and plant health. The use of different kinds of organic manure has a strong influence on soil health, through indirect effects (i.e., via changes in physicochemical characteristics) and a direct effect on soil microbes communities.

### Important soil functions related to crop production and environmental quality

- Retaining and cycling nutrients
- Supporting plant growth
- Sequestering carbon
- Allow infiltration, and facilitate storage and filtration of water
- Suppressing pests, diseases and weeds
- Detoxifying harmful chemicals
- Supporting the production of food, feed, fiber, and fuel

### Characteristics of a healthy soil

**Good soil tilth:** Soil tilth refers to the overall physical character of the soil in the context of its suitability for crop production. Soil with good tilth is crumbly, well structured, dark with organic matter, and has no large and hard clods.

**Sufficient depth:** Sufficient depth refers to the extent of the soil profile through which roots are able to grow to find water and nutrients. A soil with a shallow depth as a result of a compaction layer or past erosion is more susceptible to damage in extreme weather fluctuations, thus predisposing the crop to flooding, pathogen, or drought stress.

**Good water storage and good drainage**: During a heavy rain, a healthy soil has large, stable pores to take in water. These large pores conduct water to the medium and small pores where it will be stored for later use. This range of pore sizes in a healthy soil allows for increased water storage for plants during dry spells. During extended rainy periods, the large pores will still empty by gravity and allow fresh air to enter for plants and soil organism to thrive.

**Sufficient supply of nutrients:** An adequate and accessible supply of nutrients is necessary for optimal plant growth and for maintaining balanced cycling of nutrients within the system. An excess of nutrients can lead to leaching and potential ground water pollution, high nutrient runoff and greenhouse gas losses, as well as toxicity to plants and microbial communities.

**Small population of plant pathogens and insect pests:** In agricultural production systems, plant pathogens and pests can cause diseases and damage to the crop. In a healthy soil, the population of these organisms is low or is less active. This could result from direct competition from other soil organisms for nutrients or habitat, hyper parasitism, etc. In addition, healthy plants are better able to defend themselves against a variety of pests.

**Large population of beneficial organisms:** Soil organisms are important to the functioning of the soil. They help with cycling nutrients, decomposing organic matter, maintaining soil structure, biologically suppressing plant pests, etc. A healthy soil will have a large and diverse population of beneficial organisms to carry out these functions and thus help maintain a healthy soil status.

**Low weed pressure:** Weed pressure is a major constraint in crop production. Weeds compete with crops for water and nutrients that are essential for plant growth. Weeds can block sunlight, interfere with stand establishment and harvest and cultivation operations, and harbor disease causing pathogens and pests.

**Free of chemicals and toxins that may harm the crop:** Healthy soils are either devoid of excess amounts of harmful chemicals and toxins, or can detoxify or bind such chemicals. These processes make these harmful compounds unavailable for plant uptake, due to the soil's richness in stable organic matter and diverse microbial communities.

**Resistant to degradation:** A healthy, well aggregated soil full of a diverse community of living organisms is more resistant to adverse events including erosion by wind and rain, excess rainfall, extreme drought, vehicle compaction, disease outbreak, and other potentially degrading influences.

**Resilience when unfavorable conditions occur:** A healthy soil will rebound more quickly after a negative event, such as harvesting under wet soil conditions, or if land constraints restrict or modify planned rotations.

### Soil physical and chemical indicators of soil health

#### Physical indicators

Physical indicators of soil health generally include simple, fast and low-cost methodologies. Moreover, such indicators like texture, bulk density, porosity, and aggregate stability are also correlated with hydrological processes like erosion, aeration, runoff, infiltration rate, and water holding capacity (Schoenholtz *et al*., 2000) [39]. In general, a soil is considered physically poor when it shows low rates of water infiltration, enhanced surface runoff, poor cohesion, low aeration and root density, and difficulty for mechanization (Dexter, 2004) [16].

Soil texture is an important factor affecting the balance between water and gases, but it is very stable along time, independently on the soil management. Therefore, bulk density and total porosity can better represent the effects of soil use and management on the water/air relationships (Beutler *et al*., 2002) [8].

Lower bulk densities have been generally observed in soils under less anthropogenic interferences like native forests (Bini *et al*., 2013) [9], where the greater levels of soil organic matter permit a better aggregation of soil particles, improving the soil structure. As a result, an increase in soil macroporosity improves the soil permeability not only for water, but also for air and roots (Tejada *et al*., 2006) [50].

The total soil porosity can be classified as textural, depending on the proportion of soil particles, and structural, depending on biopores and as macro-structure. The second one is easily affected by soil use and management (Dexter, 2004) [16], which may change the characteristic soil water retention curve based on structural pores.

The structure corresponds to the arrangement of the primary soil particles (sand, silt and clay) and is affected by the cropping methods and compaction (Dexter, 2004) [16]. The granular structure is considered the most suitable for plant growth, allowing for a better balance between macro and micropores, and consequently, between the air/water proportion. Structure is the major soil physical attribute affected by organic matter, and as a consequence other physical characteristics such as porosity, bulk density, aeration, water infiltration and retention, are also affected.

Soil aggregates are formed by particles smaller than 0.2 μm that group to form microaggregates (20-250 μm), and microaggregates are grouped to form macroaggregates. Microaggregates are more stable and less affected by soil use and management. In addition, they are responsible for long-term stabilization of soil organic carbon (Six *et al*., 2004) [43]. Macroaggregates are more susceptible to the soil use and management, and are especially related to the dynamics of the soil organic matter (Six *et al*., 2004) [43]. The dispersion of soil aggregates under intensive management is usually less severe than in soils with more inputs of organic matter, which results in greater microbial activity (Qin *et al*., 2010) [36]. The decrease of soil organic matter followed by dispersion of aggregates reduces the macroporosity and the soil oxygenation, and impairs the performance of decomposing microbiota and their access to the organic material (Degens *et al*., 2000; Tejada *et al*., 2006; Chodak and Niklinska, 2010) [14, 50, 13].

Soil aggregates affect aeration, permeability, nutrient cycling, and serve as refuge for microorganisms and soil fauna in microsites. By turn, the soil biota (microorganisms, fauna, and plants) affects the soil aggregates. Many organic substances as secretions, mucilages, mucigels, and cell lysates act as cementing substances produced by several organisms as earthworms, as representatives of soil fauna, arbuscular mycorrhizal fungi, bacteria and also the plants, in addition to their stimulation of microbial activity and action on soil aggregation (Preston *et al*., 2001) [35].

Organic matter and biological attributes shape the soil physical structure and consequently the hydrological processes (erosion, drainage, runoff, and infiltration rate). In addition, they are fundamental for water and nutrients supply in soil. Humic substances increase the soil capacity for water retention due to charges in their carboxylic and phenolic groups which attract the water molecule and thus reduce its percolation through the soil profile.

As the content of available water is a determining factor of the microbial activity in soil, the soil physical attributes affecting water availability and aeration will also affect the soil microbial activity, since the inverse correlation between water availability and microbial activity has been described before (Geisseler *et al*., 2011) [21].

## Chemical indicators

Chemical attributes of soil health are correlated with the capacity to provide nutrients for plants and/or retaining chemical elements or compounds harmful to the environment and plant growth. Soil pH, cation exchange capacity (CEC), organic matter and nutrient levels are the main chemical attributes used in soil health assessment, especially when considering the soil capacity for supporting high yield crops (Kelly *et al*., 2009) [28]. These soil chemical indicators can also be useful in considering the soil's capacity for sustaining forest production and sustainability, maintaining nutrient cycling, plant biomass and organic matter (Schoenholtz *et al*., 2000) [39].

The most important chemical parameters to be assessed were pH, available P, K, Cu, Fe, Mn and Zn. Soil pH is a key indicator because it correlates directly with nutrient availability/solubility and also affects microbial activity. Thus, assessment of pH allows to predict the potential for nutrient availability in a given production system (Sousa *et al*., 2007) [45].

Soil organic carbon is also a key attribute in assessing soil health, generally correlating positively with crop yield (Bennett *et al*., 2010) [6]. The soil organic carbon affects important functional processes in soil like the storage of nutrients, mainly N, water holding capacity, and stability of aggregates (Silva and Sa-Mendonça, 2007) [40]. In addition, the soil organic carbon also affects microbial activity. Hence, this is a key component of soil fertility. High organic matter contents reduce pesticide efficiency, increasing the frequency of needed applications. Complexation with soluble organic matter facilitates pesticide sorption on organic fractions and transport through soil or groundwater (Sojka and Upchurch, 1999) [44].

Nitrogen is the most required plant nutrient, which is found in several chemical forms in soil (Cantarella, 2007) [11]. Soil nitrogen has been assessed mainly as mineral N, especially nitrate, organic N or potentially mineralizable N, as stored in the soil organic matter (Cantarella, 2007) [11].

Phosphorus (P) is also a key nutrient for agricultural yields and is essential in assessments of soil quality. Along with nitrogen, P is the main nutrient that limits the agricultural yields in tropical soils, especially in highly weathered, oxidic soils, where the major part of the total soil P is fixed in clay minerals and oxides. The available P in the soil solution is present as orthophosphates, but the microbial P and organic-P are also stocks that can rapidly become available (Pankhurst *et al*., 2003; Zhang *et al*., 2006) [34, 54].

Biological Indicators

| Indicator | Cycle | Function | Measurement |
|---|---|---|---|
| Microbial Biomass | Mainly C, but also N and P | Source and/or drain of C and nutrients | C and nutrient stocks in cells |
| Soil Respiration | C | Microbial mineralization of organic carbon | $CO_2$-C evolution |
| $qCO_2$ index | C | Metabolic condition of the microbial community | Amount of C-$CO_2$ released per unit of microbial biomass in time |
| Microbial functional groups | C, N, P, etc. | Proteolytics, cellulolytics, amilolytics, proteolytics, phosphate solubilizers and diazotrophic, nitrifying, denitrifying and ammonifying bacteria | Colony forming units (CFU) or most probable number (MPN) on specific or selective media |
| PCR-DGGE | All | Genetic diversity | DNA extraction, amplification and separation |
| PLFA-profiling | All | Diversity and biomass | Fatty acids extraction and quantification |
| Biolog | All | Metabolic diversity | Metabolization of different C sources |

## Soil constraints

It is important to recognize soil constraints that limit crop productivity, farm sustainability, and environmental quality.

## Soil structural constraints

Development and stabilization of soil structure help in understanding the other soil physical properties, i.e. soil water, aeration, soil pores, temperature, mechanical properties, susceptibility to crust development, erosion, etc. Therefore, soil structure is important for all aspects of soil use and management. Soil structure problems are associated with texture, topography and rainfall. The predominant soil structural associated problems include crusting and hardening, slow pearmeability and high pearmeability. Rainfall and temperature are two important factors influencing soil aggregation. Evaporation causes the formation of intra-granular braces by the organic materials accumulated between particles. When the moisture content is gradually reduced, it forms uniform coating over the particles as the soil dries up (Ghildyal and Gupta, 1991) [22]. The common causes for soil structure degradation in rainfed regions include poor tillage operations, rapid decomposition of organic matter, compaction by machinery tyres and exposure of bare soil surface to falling raindrop energy. Crop cultivation too frequently results in degradation of soil structure to some degree.

The aggregate stability depends upon the resistance of soil particles to the disintegrating influence of water and mechanical manipulation. The cultivation process loosens the surface soil, thereby disintegrates the water stable aggregates (WSP) and also dispersion by exposing the soil to the action of raindrops and by decreasing organic matter through rapid oxidation. The mechanical manipulation of soil at improper soil moisture status also leads to crushing of soil aggregation.

Poor aggregation due to intensive tillage, limited use of soil building crops and soil cover, low active rooting density, limited duration of root presence during the year, limited organic additions, low biological activity to stabilize aggregates. This leads to crusting and cracking; poor seedling emergence and stand establishment; poor water infiltration and storage; increased occurrence of erosion and runoff; reduced root growth; less active microbial communities; reduced aeration; reduced drought resistance due to decreased water intake during rainfall events.

## Crusting and hardening

Surface crusting and hardening are the most frequently reported physical problem. Crust on the soil surface which interferes with germination and growth of the crops. The optimum proportion of coarse and fine fractions in the surface layer along with less than 1% organic matter provides conditions conducive for hardening of the soils. Crusting and hardening are directly related to the soil aggregate stability, rainfall characteristics and its mineral and chemical composition. The maximum root growth of most of the crops is confined to the surface layers, unless this layer remains moist, the crop growth suffers (Agrawal and Batra, 1977) [1]. The crust formed on the surface offers mechanical impedance during the early stages of crop growth to the emerging plumes of the seedlings and consequently some seedlings get injured at their tips and fail to emerge (Ranganatha and Satyanarayana, 1979; Singh and Chowdhary, 1985; Sinha and Ghildyal, 1979) [37, 41, 42]. Due to sealing of surface soil by finer particles, water that would normally infiltrate into the soil will be lost to run-off during rainstorm because the direct impact of raindrops can break down aggregates which block the pores that would normally conduct water. The overall effect of sealing is reduction in porosity and permeability of the soil surface.

## Subsurface hard pan and compactness

This problem is more severe in areas where dryness is most pronounced and in soils that contain a large amount of very fine sand and coarse silt (Alfisols, Aridisols, Entisols) in surface horizons. The subsoil hard pan is due to the illuviation of clay to the subsoil horizons coupled with cementing action of oxide of iron, aluminium and calcium carbonate, which increase the soil bulk density to more than 1.8 Mg $m^{-3}$. Further, the hard pan can also develop due to continuous cultivation of crops using heavy implements up to certain depths. The higher bulk density, does not permit proper root development. The increase in bulk density decreases the hydraulic conductivity and water diffusivity and infiltration rate. The reasons for higher bulk density are excessive tillage and improper tillage time (at excessive or deficit soil moisture condition). To some extent, heavy tillage implements are also responsible for increasing the bulk density (Ghildyal and Gupta, 1991) [22]. Higher bulk density also restricts the proper soil aeration that restricts root respiration as well as aerobic microbes that help in the transformation of different nutrients.

Soil compaction occurs when traffic or tillage when soil is wet (‘plastic’), heavy equipment and loads and uncontrolled traffic patterns. This results in reduced root growth in surface and subsurface soils; limited water infiltration, resulting in runoff, erosion, ponding and poor aeration; drought sensitivity due to reduced water storage and reduced rooting; reduced nutrient access due to poor root growth and restricted water flow; increased pathogen pressure due to poor drainage and to plant stress; increased cost of tillage and lower yields.

### High permeability

High permeability and poor nutrient retention capacity are associated with sand and loamy sand texture (Entisols, Aridisols and Inceptisols). Due to high permeability, most of the rainwater is lost in deeper soil layers and the availability of water in the upper soil profile is only for a short period. The high permeability and poor nutrient retention capacity of soils reduce the water and fertilizer use efficiency and cause water logging.

### Slow permeability

Due to slow permeability, water stagnates in the field during heavy rainfall. Further, the prevailing anaerobic condition causes the accumulation of carbon dioxide and other toxic byproducts in the zone, which restricts root growth (Krantz *et al*., 1979) [29].

### Soil water retention

Generally, soil water retention at 0.33 and 15 bar of various soil types. In Vertisols and associated soils with high clay content, higher water retention at both the tension levels (at 0.33 bar and 15 bar). Sand content showed a negative correlation with water retention in most of the soil types.

### Available water content

The available water content was higher in fine textured soils Rao *et al.* 2009 [38]. The available water storage capacity of coarse textured soils was poor, resulting in quick drying of the soils. The available water (available water content and plant available water content) required for better yield depends on rainwater stored in the profile and the capacity of the soil to release the same during crop growth period.

### Water transmission

A good distribution of pores throughout a soil profile is vitally important for crop growth, which is necessary for water, air and nutrients to circulate in the soil. The soils particularly Entisols and Aridisols, contain good hydraulic conductivity. In case of Alfisols, lack of fine clay particles and low amount of organic matter within the soil matrix limit the water transmission characteristics. Alfisols are mostly structureless or massive, and hence have low hydraulic conductivity. Exchangeable Sodium Percentage (ESP) is an important factor which positively contributes to water retention, but negatively to water movement (saturated hydraulic conductivity) and yield of crops (Deshmukh *et al*., 2014) [15]. The ESP value more than 5 impairs the hydraulic properties of soils due to deterioration in the soil physical properties (Kadu *et al*., 1993; Balpande *et al*., 1996) [27, 4].

### Infiltration

Infiltration through the soil surface depends on soil surface features and hydraulic conductivity. If the soil has high infiltration rate, water applied through irrigation and received through rainfall enters into the soil as early as possible, which in turn reduces the evaporation and run-off losses. Infiltration is a consequence of porosity and it also influences porosity by detaching, transporting and relocating soil particles through its mechanical action. Change in porosity leads to change in water movement through the soil profile. The water supply of soils is also reduced by impaired infiltration due to lower conductivity of the pores wherever vegetative cover is not available to dissipate the energy of falling raindrops. Cultivation increases infiltration initially but in the long run, porosity and infiltration rates are usually lower than in untilled soil under mulch cover.

Low water-holding capacity due to the little water is transmitted to deeper layers of the profile due to poor porosity as a result of seal formation. Organic carbon content of Vertisols is low to moderate due to higher rate of decomposition (Velayutham *et al*., 2000) [52]. These soils have low infiltration and percolation rates, less movement of nutrients and free air transport within the soil profile. In sandy soils, the decrease in porosity is less, it is higher in soils having higher clay content. This invariably leads to decrease in water movement through soil profile and deep percolation (Painuli and Pagliai, 1996) [33]. Thus, infiltration of water into the soil is a basic and important process directly controlling surface run-off, soil erosion, soil water storage and deep percolation.

### Low water and nutrient retention

Due to low organic matter and resulting poor structure; low water holding capacity, low exchange capacity; poor retention and biological recycling of nutrients in biomass and soil organic matter; excessive tillage; insufficient use of soil building crops. This leads to ground and surface water pollution, reduced microbial community, nutrient deficiencies and poor plant growth, drought stress.

### Salinity and Sodicity

Due to frequently found in semi-arid and arid climates, especially under irrigated systems. Results in loss of crop yield and quality; loss of aggregation and thus infiltration and drainage functions if sodicity is the problem.

### Heavy Metal Contamination

Due to common in urban areas and other sites with past use of contaminant sources such as lead paint, fertilizers, pesticides (e.g., lead arsenate use on orchard land), past activities such as high traffic, industrial or commercial activity, treated lumber, petroleum spills, automobile or machine repair, junk vehicles, furniture refinishing, fires, landfills, or garbage dumps.

Results in higher risks of human exposure when children or adults swallow or breathe in soil particles or eat food raised in or on contaminated soil; inhibition of soil biological activity; plant toxicity, and reduced yield and or crop quality.

## Soil health management strategies

### Tillage

Extensive tillage reduces soil aggregation, resulting in crusting and soil compaction, in addition to decreased beneficial microbial activity. It is now well understood that reducing tillage intensity and mechanical soil disturbance can improve soil health and maintain or even increase yields, while reducing production costs due to saved labor, equipment and fuel.

There are many different strategies for reducing tillage intensity

**No Tillage**: A no-till planter or transplanter does minimal soil disturbance to plant the crop. This is true, “single-pass” planting.

**Ridge Tillage:** Crops are planted into minimally disturbed ridges that generally remain in the same place. Only surface soils are disturbed when ridges are rebuilt annually around the planted crop.

**Strip Tillage:** A shank set just below the depth of the compacted layer rips a compacted layer while a series of coulters forms a narrow, shallow ridge in preparation for planting. Plants are later sown into tilled strips with a pass of the planter.

**Zone Tillage:** Similar to strip tillage, but without the rip shank, which is not necessary when you lack subsoil compaction. Instead of preparing the entire field as a seedbed, only a narrow band is loosened by zone and strip tillage, enabling crop or cover crop residue to remain on the soil surface as a mulch.

**Permanent drive rows:** Drive rows are particularly possible with new Global Positioning System (GPS) enabled technologies and often better facilitates reduced tillage systems.

**Roller crimpers, rotovators:** These are being developed to be set to disturb only the surface inch of the soil, and other minimal disturbance methods for managing spring cover crops.

**Cover crop inter-seeders and no-till drills:** These may be used to avoid additional tillage passes for establishing cover crops.

**Frost Tillage:** Frost Tillage means alleviating soil compaction or injecting manure in the winter. It is done when the soil is frozen between 1 and 3 inches deep. Such conditions generally only occur on a few days per winter, depending on location.

### Crop Rotation

Crop rotation was practiced to avoid depleting the soil of various nutrients and to manage pathogens and pests. Crop rotation is an important component of soil health management in many agricultural production systems. Crop rotations can be as simple as rotating between two crops and planting sequences in alternate years or they can be more complex and involve numerous crops over several years or even at the same time for improved soil health. Proper crop rotations generally increase species diversity, and reduce insect pressure, disease causing pathogens, and weed pressure by breaking life cycles through removal of a suitable host or habitat.

Additionally, crop rotation can improve nutrient management and improve soil resiliency (to drought, extreme rainfall and disease). Generally yield increases when crops in different families are grown in rotation versus in monoculture referred to as the “rotation effect”. A cropping sequence for soil health management should include the use of cover crops and or season-long soil building crops.

### Organic Amendment (Organic matter)

Organic matter is critical for maintaining balanced soil biological communities, as these are largely responsible for maintaining soil structure, increasing water infiltration and building the soil’s ability to store and release water and nutrients for crop use. Organic matter can be maintained better by reducing tillage and other soil disturbances, and increased by improving rotations and growing cover crops as previously discussed. Organic materials can also be added by amending the soil with composts, animal manures, and crop or cover crop residues.

The addition of organic amendments is particularly important in vegetable production where minimal crop residue is returned to the soil, more intensive tillage is generally used, and land is more often a limiting factor making the use of cover crops more challenging. Various organic amendments can affect soil physical, chemical and biological properties quite differently, so decisions should be based on identified constraints and soil health management goals. Organic amendments derived from organic wastes should not only be tested for nutrients, but also for contaminants such as heavy metals.

### Animal manure

Applying manure can have many soil and crop health benefits, such as increased nutrient levels (nitrogen, phosphorus and potassium and also micronutrients) as well as easily available carbon that will benefit the soil microbial community.

### Compost

Compost is very stable and generally not a readily available source of nitrogen, but it is important to recognize that phosphorus remains highly available. The addition of compost increases available water holding capacity by improving organic matter content and pore space that holds water. It also improves cation and anion exchange capacities, and thus the ability for nutrients to be stored and released for plant use. Composts differ in their efficiency to suppress various crop pests, although they can sometimes be quite effective.

### Regulation of Air and Water in Soil

Plants require both oxygen and water in the root zone for optimum growth. In soil, water and air are held in the pore space between soil particles and soil aggregates. The sizes of the pores that occur between and within soil aggregates determine how water and gases move in and are held by the soil. Larger pores, known as macropores, are important to promote good aeration and rapid infiltration of rainfall. Smaller pores, known as micropores, are important for absorbing and holding water. Macropores are often visible to the naked eye, while micropores between and within microaggregates. To maintain both adequate aeration and water supply for optimum plant growth, it is necessary to have both macro- and micropores in the soil. Pores in the soil are formed when soil particles clump together into a hierarchy of aggregates.

Lower bulk densities have been generally observed in soils under less anthropogenic interferences like native forests (Bini *et al*., 2013) [9], where the greater levels of soil organic matter permit a better aggregation of soil particles, improving the soil structure. As a result, an increase in soil macroporosity improves the soil permeability not only for water, but also for air and roots (Tejada *et al*., 2006) [50].

Soil organisms play an important role in developing soil aggregates and improving aggregate stability. Clay, organic matter, root hairs, organic compounds from bacteria and fungi, and fungal hyphae help “glue” soil aggregates together. Aggregate stability refers to the ability of soil aggregates to hold together against the erosive forces of water. Good aggregate stability will help maintain macropores in the soil, reduce surface crusting, promote aeration and reduce rainfall runoff, and reduce soil erosion. Aggregates also help conserve soil organic matter, as particles of organic matter that reside within aggregates are physically protected against microbial consumption. Many large soil organisms are capable of moving soil and creating macropores in the soil. These include such organisms as ants, dung beetles, and earthworms. Earthworms are probably the best-known soil organism that contributes to the development and maintenance of soil structure. The burrowing activity of earthworms benefits soil health through increased nutrient availability, better drainage, and a more stable soil structure.

Soil organic matter plays an important role in integrating many aspects of soil health. Soil organic matter can be divided into labile and stable pools, each of which has different characteristics and functions in the soil. In agricultural soils, organic matter can range from 1 to 8 percent depending on climate, soil type, and soil management practices.

The labile pool of organic matter, which accounts for 5–20 percent of the total pool of soil organic matter, includes the living biomass of soil organisms and plant roots, fine particles of organic detritus, and relatively simple organic compounds such as polysaccharides, organic acids, and other compounds that are synthesized by microbial activity or are by-products of decomposition processes. Labile organic matter is readily decomposed by microbes and is the principal energy source that fuels the soil food web. It is the principal reservoir of organic nitrogen that can be readily mineralized and made available for plant use. Polysaccharides in labile organic matter also enhance aggregate stability. When microbial consumption of labile organic matter is greater than the input of fresh organic matter into the soil, labile organic matter levels will decline. Excessive tillage of the soil can speed the decline of labile organic matter by oxygenating the soil, which increases microbial activity, and by exposing organic matter that had been protected within soil aggregates. The stable pool of organic matter, which accounts for 60–95 percent of the total pool of soil organic matter, consists of organic compounds that are relatively resistant to decomposition because of either their chemical structure, their adsorption to clay particles, or their protection within microaggregates. Stable organic matter contributes cation exchange capacity and water-holding capacity to soil. The pool of stable organic matter is increased or depleted slowly as only a small portion of the labile organic matter that cycles through the food web is stabilized into forms that are resistant to decomposition.

Organic matter inputs can be influenced by crop management, such as the use of cover crops, crop rotations, and residue management, as well as soil management, such as using organic forms of nutrients like compost and manure. The quantity of labile organic matter generally responds to changes in management practices more quickly than the quantity of stable soil organic matter, so changes in labile organic matter levels can serve as a leading indicator of long-term trends in total organic matter levels.

## Manage Nutrients

Carefully planning the timing, application method, and quantity of manure, compost, and other fertilizers will allow to meet crop nutrient demands and minimize nutrient excesses. Healthy, vigorous plants that grow quickly are better able to withstand pest damage. However, over fertilizing crops can increase pest problems. Increasing soluble nitrogen levels in plants can decrease their resistance to pests, resulting in higher pest density and crop damage. Maintaining a soil pH appropriate for the crop to be grown will improve nutrient availability and reduce toxicity. Maintaining adequate calcium levels will help earthworms thrive and improve soil aggregation.

Using diverse nutrient sources can help maintain soil health. Manure and compost add organic matter as well as an array of nutrients, but using just compost or manure to meet the nitrogen needs of the crop every year can result in excessive phosphorus levels in the soil. Combining modest manure or compost additions to meet phosphorus needs with additional nitrogen inputs from legume cover or forage crops in a crop rotation can help balance both nitrogen and phosphorus inputs.

## Soil pH

The soil pH is an important factor for soil fertility despite the fact that its values change dynamically, depending on so-called internal and external factors. It influences the buffering and filtering capacities, the quality of organic substances, nutrient accessibility for plants and the production of biomass in most crops grown. A majority of arable crops suit the range of slightly acidic to slightly alkaline soil pH – 6 to 7.5 (Krnacova *et al*., 1997) [30]. A pH value lower than 5.5 is undesirable and requires ameliorative lime treatment. The organic matter positively influences the buffering capacity of soil.

## Bacteria

Bacteria are organisms that have only one cell and are, therefore, microscopic. There are anywhere from 100 million to one billion bacteria in just a teaspoon of moist, fertile soil. They are decomposers, eating dead plant material and organic waste. By doing this, the bacteria release nutrients that other organisms could not access. The bacteria do this by changing the nutrients from inaccessible to usable forms. The process is essential in the nitrogen.

## Functions of bacteria

### Plant-Engineered Root Zone Communities

While it is a truism that soil agro-ecosystems are extremely complex, the plant root system is a rationalizing force that imposes a class of order on the chaos that is functional agricultural soil. The vast surface area provided by roots is an extraordinarily diverse habitat for a huge assortment of microorganisms ranging from transient epiphytic saprophytes to epiphytic commensals, mutualistic symbionts, endophytes, and pathogens. However, it is primarily through the general release of carbon-rich material in the form of root border cells (Hawes and Brigham, 1992; Hawes *et al*., 1998) [24, 25], or alternatively *via* the selective exudation of specific sugars, carboxylic, and amino acids (Lugtenberg *et al*., 2001) [31] that plants are able to “load-up” the root zone environment with substrates that encourage the development of cultivar-specific, plant-beneficial, microbial communities.

This is by no means a one-way process, and plant “engineered” rhizomicrobial communities can likewise initiate changes in the root biochemistry (Vessey, 2003) [53], inducing a root exudation response in the host plants that fostered them (Bolton *et al*., 1993) [10]. Thus root growth leads to substrate loading in the root zone, which in turn promotes rhizobacterial proliferation, leading to further root growth, a concomitant increase in root exudation that leads to substrate loading, and so on.

All such root–microbial exchanges can be considered a form of allelopathy and include those biochemical interactions, both inter and intraspecifically, that involve microbial-or plant-produced secondary metabolites (allelochemicals) that influence growth and development of biological systems in the soil.

### Nitrogen-Fixing Bacteria in Soil

The amount of N present on this planet as dinitrogen is approximately 4×1015 tons in the atmosphere and about 20 times that bound in sedimentary and primary rocks beneath the surface (Gallon and Chaplin, 1987). None of these sources is accessible to plants until it is fixed, i.e., converted to ammonia. Dinitrogen can be fixed by industrial processes or biologically, by some prokaryotes. Although significant amounts of nitrogen are derived from industrial fertilizers, most of the fixed nitrogen present in the world's soil and water ecosystems comes from biological $N_2$ fixation (Hernandez, 2002) [26].

Nitrogen-fixing bacteria can be symbiotic, free-living, or associative, forming casual associations with other organisms, i.e., plants. The associative diazotrophs colonize the rhizosphere and often enter the root and/or shoot interior, occupying intercellular spaces. The rhizobia–legume symbiotic relationship is the most widely studied and utilized of plant–microbe interactions (Sprent, 2001) [46]. Rhizobia residing inside nodules of legume plants take $N_2$ from air and reduce it to plant-available nitrogen. The host plant develops nodule structure, regulates $O_2$ tension, and provides organic carbon to the bacteria, while the bacteria provide the plant with the nitrogen it needs. Moreover, non symbiotic/ associative N-fixing bacteria normally live in the rhizosphere, where they can exchange fixed nitrogen with the plant for organic carbon. In this system, microbial populations respond to plant exudates, and plant exudation follows from microbial activity in the rhizosphere.

### Bacterial Endophytes and Crop Rotations

A continuous apoplastic pathway exits from the root epidermis to the shoot, which appears sufficient for movement of microorganisms from the root cortex into the xylem and from there throughout the plant. Consequently, many bacterial endophyte communities are the product of a colonizing process initiated by rhizobacteria in the root zone. In this regard, the plant host offers the microbial endophyte a relatively homeostatic, spatially diverse environment that is suitable for biotrophic mutualists, benign commensals, and necrotrophic pathogens alike (Chanway, 1996: Stone *et al*., 2000) [12, 47].

Recently, increased interest has been expressed in further defining and exploiting this relationship (Mathesius, 2003) [32], especially in those situations where endophytes are able to mitigate plant responses to environmental stress, such as those found as a result of drought, transplantation and heat (Bensalim *et al*., 1998) [7]. However, where plant endophyte populations are non complementary, inhibitory allelopathic effects can result (Sturz and Christie, 1995) [48]. It soon becomes clear that a fundamental source of potential endophytes is to be found in the soils and organic debris of previous crop plantings.

Thus, by extension, complementarity among rotation crops will involve a microbial compatibility between the newly planted crop and the resident autochthonous soil population. Consequently, it has been proposed that the yield benefits from complementary cropping systems involving, for example, legume rotations and often attributed solely to residual nitrogen and improved soil structure may also include an additional benefit from the carryover of the residual populations of endophytically competent bacteria able to promote plant growth and inhibit disease development.

### Microbes involvement in soil ethylene production and crop development

Soil ethylene can affect plant growth and is certainly a significant factor in field production of agricultural crops. Soil is itself a source of ethylene, and the amount generated can vary widely depending on the type and degree of soil amendment and other related factors. While both biological and chemical processes contribute to ethylene accumulation in soil (Arshad and Frankenberger, 2002) [2], most soil ethylene is produced by microbes.

Spore-forming bacteria living in anaerobic microsites are the primary ethylene producers. However, microbial generation of ethylene varies greatly with soil environment, the nature of substrates present in native soil organic matter, and soil amendments (Arshad and Frankenberger, 2002) [2] proposed that the "microbial nutrient status" of soils could be screened by measuring $O_2$ utilization and $CO_2$ evolution and then could be correlated to soil ethylene production.

Microbial ethylene may also function as a signaling compound in plant–microbial interactions in plant microbial-cross talk and may also play a significant role in rhizobacteria-mediated induced systemic resistance (ISR) in plants against specific pathogens *via* the jasmonate or ethylene signal-dependent pathway (Ton *et al*., 2002) [51]. Ethylene is involved in the determination of root system morphology, plant responses to abiotic and biotic stresses, and development of legume rhizobia symbiotic associations.

It may also affect the rate of root infection by phytopathogens that produce ethylene during early stages of infection. Besides soil microorganisms, plant roots contribute significant amounts of ethylene or its precursor, 1-aminocyclopropane-1-carboxylic acid (ACC), to the soil, particularly under stress.

### Fungi

Fungi are unusual organisms, in that they are not plants or animals. They group themselves into fibrous strings called hyphae. The hyphae then form groups called mycelium. They are helpful, but could also be harmful, to soil organisms. Fungi are helpful because they have the ability to break down nutrients that other organisms cannot. They then release them into the soil, and other organisms get to use them. Fungi can attach themselves to plant roots. The fungi help the plant by giving it needed nutrients and the fungi get carbohydrates from the plant, the same food that plants give to humans. On the other hand, fungi can get food by being parasites and attaching themselves to plants or other organisms for selfish reasons.

### Functions of soil fungi

**Decomposers**: Saprophytic fungi – convert dead organic material into fungal biomass, carbon dioxide ($CO_2$), and small molecules, such as organic acids.

**Mutualists:** The mycorrhizal fungi colonise plant roots. In exchange for carbon from the plant, mycorrhizal fungi help to make phosphorus soluble and bring soil nutrients (phosphorus, nitrogen, micronutrients and, perhaps, water) to the plant. One major group of mycorrhizae, the *ectomycorrhizae*, grow on the surface layers of the roots and are commonly associated with trees. The second major group of mycorrhizae are the *endomycorrhizae* that grow within the root cells and which are commonly associated with grasses, row crops, vegetables and shrubs.

**Parasites:** The third group of fungi, *pathogens* or *parasites*, causes reduced production or death when they colonise roots and other organisms.

### Algae

Algae are present in most of the soils where moisture and sunlight are available. Their number in the soil usually ranges from 100 to 10,000 per gram of soil. They are capable of photosynthesis, whereby they and obtain carbon dioxide from atmosphere and energy from sunlight and synthesise their own food.

### The major roles and functions of algae in soil

1. Playing an important role in the maintenance of soil fertility, especially in tropical soils.
2. Adding organic matter to soil when they die and thus increasing the amount of organic carbon in soil.
3. Acting as a cementing agent by binding soil particles and thereby reducing and preventing soil erosion.
4. Helping to increase the water retention capacity of soil for longer time periods.
5. Liberating large quantities of oxygen in the soil environment through the process of photosynthesis and, thus, facilitating submerged aeration.
6. Helping to check the loss of nitrates through leaching and drainage, especially in uncropped soils.
7. Helping in the weathering of rocks and the building up of soil structure.

### Protozoa

These are colourless, single-celled animal-like organisms. They are larger than bacteria, varying from a few microns to a few millimetres. Their population in arable soil ranges from 10,000 to 100,000 per gram of soil and they are abundant in surface soil. They can withstand adverse soil conditions, as they are characterised by a protected, dormant stage in their life cycle.

### The major functions, roles and features of protozoa

1. Most protozoans derive their nutrition from feeding or ingesting soil bacteria and, thus, they play an important role in maintaining microbial/bacterial equilibrium in the soil.
2. Some protozoa have been recently used as biological control agents against organisms that cause harmful diseases in plants.
3. Several soil protozoa cause diseases in human beings that are carried through water and other vectors. Amoebic dysentery is an example.

### Viruses

Soil viruses are of great importance, as they may influence the ecology of soil biological communities through both an ability to transfer genes from host to host and as a potential cause of microbial mortality. Consequently, viruses are major players in global cycles, influencing the turnover and concentration of nutrients and gases.

Despite this importance, the subject of soil virology is understudied. To explore the role of the viruses in plant health and soil quality, studies are being conducted into virus diversity and abundance in different geographic areas (ecosystems). It has been found that viruses are highly abundant in all the areas studied so far, even in circumstances where bacterial populations differ significantly in the same environments.

Soils probably harbour many novel viral species that, together, may represent a large reservoir of genetic diversity. Some researchers believe that investigating this largely unexplored diversity of soil viruses has the potential to transform our understanding of the role of viruses in global ecosystem processes and the evolution of microbial life itself.

### Nematodes

Not microorganisms (strictly speaking), nematode worms are typically 50 microns in diameter and one millimetre in length. Species responsible for plant diseases have received much attention, but far less is known about much of the nematode community, which play beneficial roles in soil. An incredible variety of nematodes have been found to function at several levels of the soil food web. Some feed on the plants and algae (the first level), others are grazers that feed on bacteria and fungi (second level), and some feed on other nematodes (higher levels).

Free-living nematodes can be divided into four broad groups based on their diet. Bacterial-feeders consume bacteria. Fungal-feeders feed by puncturing the cell walls of fungi and sucking out the internal contents. Predatory nematodes eat all types of nematodes and protozoa. They eat smaller organisms whole or attach themselves to the cuticle of larger nematodes, scraping away until the prey’s internal body parts can be extracted.

Like protozoa, nematodes are important in mineralising, or releasing, nutrients in plant-available forms. When nematodes eat bacteria or fungi, ammonium is released because bacteria and fungi contain much more nitrogen than the nematodes require.

Nematodes may also be useful indicators of soil quality because of their tremendous diversity and their participation in many functions at different levels of the soil food web.

### Actinomycetes in soil health management

Actinomycetes are soil microorganisms like both bacteria and fungi, and have characteristics linking them to both groups. They are often believed to be the missing evolutionary link between bacteria and fungi, but they have many more characteristics in common with bacteria than they do fungi. Actinomycetes give soil its characteristic smell. They have also been the source of several significant therapeutic medicines.

Decomposition of organic matters Actinomycetes are the main group of soil microorganisms that play a major role in recycling of organic matters in environment by production of hydrolytic enzymes (Behal, 2000) [5]. As a decomposer the actinomycetes specialize in breaking down tough cellulose and lignin found in wood and paper and the chitin found in the exoskeletons of insects. The breakdown of these materials makes nutrients once again available to plants. During the process of composting mainly thermophilic and thermo tolerant actinomycetes are responsible for decomposition of the organic matter at elevated temperatures.

Actinomycetes as plant growth promoting bacteria Actinobacteria commonly inhabit the rhizosphere, being an essential part of this environment due to their interactions with plants. Such interactions have made possible to characterize them as plant growth-promoting rhizobacteria (PGPR). As PGPR, they possess direct or indirect mechanisms that favor plant growth. Actinobacteria improve the availability of nutrients and minerals, synthesized plant growth regulators, and specially, they are capable of inhibiting phytopathogens (Tanaka and Omura, 1993) [49].

Different activities that are performed by actinobacteria have been studied, such as phosphate solubilization, siderophores production, and nitrogen fixation. Furthermore, actinobacteria do not contaminate the environment; instead, they help to maintain the biotic equilibrium of soil by cooperating with nutrients cycling. The aforementioned is directly related to the quality and productivity of crops. Moreover, different aspects of these microorganisms have been studied (Gomez-Escribano *et al.*, 2016) [23], such as production of metabolites that improve plant growth, resilience against unfavorable environmental conditions, and beneficial and synergic interactions with arbuscular mycorrhizal fungi. Taking into account the above-mentioned activities, actinobacteria can be considered as possible soil health manager and a plant fertilizers.

**Table 1:** Soil health management suggestions for soil physical properties

| S. No. | Parameters | Short term management | Long term management |
|---|---|---|---|
| 1 | Available water capacity | *Addition of stable organic materials<br>*Addition of biochar or compost | *Reduce tillage<br>*Rotation with sod crop<br>*Incorporate high biomass cover crop |
| 2 | Surface hardness | *Use of some mechanical soil loosers (strip till, aerators, broadfork, spader)<br>*Grow shallow rooted cover crops<br>*Use a living mulch or interseed cover crop | *Shallow-rooted cover/rotation crops<br>*Avoid traffic on wet soils<br>*Avoid excess traffic/tillage/loads<br>*Use controlled traffic patterns |
| 3 | Sub-Surface hardness | *Use targeted deep tillage (subsoiler, chisel plough, spader)<br>*Plant deep rooted cover crops | *Avoid disk plough that create pans<br>*Avoid heavy loads<br>*Reduce traffic when sun soil is wet |
| 4 | Aggregate stability | *Incorporate fresh organic matter<br>* Grow shallow rooted cover crops<br>*Add green manure and manures | *Reduce tillage<br>*Use a surface mulch<br>*Rotation with sod crops |
| 5 | Organic matter | *Addition of stable organic materials<br>*Addition of biochar or compost | *Reduce tillage<br>*Rotation with sod crop<br>*Incorporate high biomass cover crop |

**Table 2:** Soil health management suggestions for soil chemical properties

| S. No. | Parameter | Short term management | Long term management |
|---|---|---|---|
| 1 | Low soil pH | *Addition of lime as per the soil test report<br>*Addition of gypsum in addition to lime if aluminum is high<br>*Use less ammonium or urea | *Test soil annually and add “maintenance” lime as per the soil test recommendations to keep pH in range<br>*Raise organic matter to improve buffering capacity |
| 2 | High soil pH | *Add elemental sulphur/ gypsum as per the soil test report | * Test soil annually<br>*Use higher percentage of ammonium or urea |
| 3 | Low extractable Phosphorus | *Add phosphorus amendments as per the soil test recommendation<br>*Grow cover crops to recycle fixed P.<br>*Adjust pH to 6.2-6.5 to free up fixed P. | *Promote mycorrhizal population<br>*Maintain pH 6.2-6.5<br>*Grow cover crops to recycle fixed P. |
| 4 | High extractable Phosphorus | *Stop adding manure and compost<br>*Choose low or no P fertilizer blend<br>*Apply only 20 lbs/acre P starter P if necessary<br>*Apply P at or below crop removal rate | *Use cover crops that accumulate P and export to low P fields |
| 5 | Low extractable potassium | *Add wood ash, fertilizer, manure, or compost per soil test recommendations<br>*Use cover crops to recycle fixed K.<br>*Choose a high K fertilizer blend | *Test soil annually and add “maintenance” K as per the soil test recommendations each year to keep K consistently available. |
| 6 | Low minor elements | *Add chelated micronutrients as per soil test recommendation<br>*Do not exceed pH 6.5 for most crops | *Promote mycorrhizal population<br>*Improve organic matter<br>*Decrease soil P |
| 7 | High minor elements | *Raise soil pH to 6.2-6.5<br>*Do not use fertilizers with micronutrients | *Maintain a pH of 6.2-6.5<br>*Monitor irrigation or improve drainage<br>*Improve soil calcium levels |

## Examples of the economic benefits of maintaining and improving soil health

1. Better plant growth, quality, and yield
2. Reduced risk of yield loss during periods of environmental stress (e.g., heavy rain, drought, pest or disease outbreak)
3. Better field access during wet periods
4. Reduced fuel costs by requiring less tillage
5. Reduced input costs by decreasing losses, and improving use efficiency of fertilizer, pesticide, herbicide, and irrigation applications.

## Conclusion

Soil is a vital natural source and has an economic and eco-social potential. High doses of organic fertilisers had a positive effect on soil productivity, and thus, indirectly maintaining soil pH, the available nutrient content and retention of humus in soil. Farmers are generally aware of the need to replenish the soils but are hampered by socio-economic constraints. Widespread nutrient deficiencies and deteriorating soil health are the cause of poor soil health, reduced productivity and profitability. Adoption of site-specific balanced and integrated nutrient management system involving major, secondary and micronutrients, organic manures, bio-fertilizers and amendments can improve the soil health. Simultaneously, environment safety, investments in the fertilizer sector for sustained supplies of fertilizers, utilizing indigenously available nutrient sources developing new efficient fertilizer products, effective soil testing service to back up precise fertilizer use, spreading awareness amongst farmers on benefits of balanced fertilization can bring significant improvement in soil health for safe environment and better agricultural productivity. Analysis of physical, chemical and biological characteristics of soil simultaneously is required to evaluate sustainability of different management practices. Collectively, soil microorganisms play an essential role in decomposing organic matter, cycling nutrients and fertilising the soil. Without the cycling of elements, the continuation of life on Earth would be impossible, since essential nutrients would rapidly be taken up by organisms and locked in a form that cannot be used by others. The reactions involved in elemental cycling are often chemical in nature, but biochemical reactions, those facilitated by organisms, also play an important part in the cycling of elements. Soil microbes are of prime importance in this process and are also important for the development of healthy soil structure. Soil microbes produce lots of gummy substances (polysaccharides and mucilage) that help to cement soil aggregates. This cement makes aggregates less likely to crumble when exposed to water.

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