International Journal of Agricultural Sciences
Volume 17 | Issue 2 | June, 2021 | 729-739 ■ ISSN : 0973-130X
DOI:10.15740/HAS/IJAS/17.2/729-739
Visit us : *www.researchjournal.co.in*

A Review

Role of soil microbiota in soil fertility

Monalisa Dhall[1], Bandana Mishra[1], Saurav Barman[2] **and** Praveen Boddana*
Department of Plant Pathology, M.S. Swaminathan School of Agriculture, Centurion University of Technology and Management, R Sitapur, Paralakhemundi, Gajapati (Odisha) India
(Email: bpraveen@cutm.ac.in)

Abstract : Long- term adoption of total agricultural approach which negatively influences the soil prolificacy, soil microbiome and may compromise the feature and amount of crop mass production. In agriculture, soil is a critical part, in which the original sources of nutrients for grow crops and the microorganisms is very important to improve soil texture or soil health for healthy growing crops. Soil microbiota are an energetic component of soil and showed varieties useful activities in the soil system. Soil richness is the characteristic limit of a soil to give the fundamental plant supplements in sufficient sums and legitimate extents for plant development. There is an enormous chance to upgrade soil ripeness through microorganisms, as organisms are "inherent" soil controllers and impetuses adding to reusing of supplements into accessible inorganic structures and give early admonition of land corruption. The core interest of this part is on the possibility of utilizing organisms as decomposers of (cellulose, protein and lignin), formers (humus, nitrate and nitrite), nitrogen fixers, ammonifiers, oxidizers (iron, hydrogen and sulfur), phosphorus solubilizers and denitrifiers. In this specific circumstance, the components *viz.,* natural toxins and environmental change that limit the improvement of soil richness. Today's, there is great trial for the agricultural system in which growing the human population is a great problem in the land breakdown and decrease the microbial population that's why enhance the soil fertility and plant growth rate decreases. Therefore, in this review we describe the benefits of soil microbiota to maintain soil fertility.

Key Words : Soil prolificacy, Soil microbiome, Ammonifier, Oxidisers, Solubulizer, Denitrifiers

View Point Article : Dhall, Monalisa, Mishra, Bandana, Barman, Saurav and Boddana, Praveen (2021). Role of soil microbiota in soil fertility. *Internat. J. agric. Sci.*, **17** (2) : 729-739, **DOI:10.15740/HAS/IJAS/17.2/729-739.**

Article History : Received : 03.03.2021; **Accepted :** 19.03.2021

Introduction

Agricultural land is important part for food creation, sanctuary and fiber for humanity. In monetary advancement of many non-industrial nation's horticulture assumes a powerful part and furthermore gives independent work. As per many plant physiologists, the dirt is the significant wellspring of plant supplements, yet soil quality is essential for farming creation and quality is improved by soil microscopic organisms, parasites and protists. The microbial biosphere is the biggest pool of biodiversity on earth. In other words, microorganisms can be considered as soil apparatus to reuse to the

*** Author for correspondence**
[1]Department Of Botany, School of Applied Science, Centurion University of Technology and Management, R Sitapur, Paralakhemundi, Gajapati (Odisha) India
[2]Department of Soil Science and Agricultural Chemistry, M.S. Swaminathan School of Agriculture, Centurion University of Technology and Management, R Sitapur, Paralakhemundi, Gajapati (Odisha) India

supplements. The nature of soil and its systems of support can be improved by soil organisms inside the soil framework.The breakdown of natural matter like creature remains and plant remains will be very much arranged by soil microorganisms, the development of soil structure, and the pace of biogeochemical cycling is additionally constrained by soil organisms in the dirt. Microorganisms are key soil segments that control agro-environment working. Soil microorganisms give supplements by mineralizing natural matter (Hodge *et al.*, 2000), control soil natural carbon capacity (Moorhead and Sinsabaugh, 2006). Examination of the connections between microbial local area piece and biological system functioning has gotten developing consideration lately, and it is currently all around perceived that microbial variety influences biological system cycles like essential profitability (Van Der Heijden *et al.*, 2008), natural carbon cycling (Bell *et al.*, 2005), protection from perturbations (Dang *et al.*, 2005) and concealment of soilborne pathogens (Van Bruggen *et al.*, 2006). Various investigations, besides, brought up that development the executives practices like culturing system (Shi *et al.,* 2013), treatment (Fierer *et al.,* 2012) and bother the board (Wei *et al.,* 2016) significantly influence soil microbial diversity and its ordered piece.

Plant-related soil microorganisms play a pivotal job in plant development and advancement like supplement cycling and harvest profitability. Soil microbial elements decide the possibility of soil crop profitability. While the collaboration of plant and organisms is main consideration for controlling biological system working, these plant–microorganisms associations fluctuate extraordinarily and rely on accessibility of supplement and. Plant development advancing organisms for the most part utilized for plant development advancement through different methods, for example, plant development guideline and nitrogen obsession. A microbiota involves all microorganisms, including infections, microscopic organisms, archaea, protozoa and parasites that are available in an uncommon climate, which is normally examined along with its host and general climate like plant, creature gut and soil, though a microbiome incorporates all the living microorganisms (infections, microbes, archaea and lower and higher eukaryotes), their genomic successions, and the ecological conditions encompassing the whole territory. Organisms are exceptionally different and richly present in the Earth's biological system, and can get by in outrageous conditions. Microorganisms are firmly connected with their living climate and ecological changes can adjust distinctive microbial species. Hence, unique harvest plant species can specifically collect different microorganisms in their rhizosphere, phyllo sphere, and endosphere. Studies have uncovered that the microbiota related with plants is urgent in deciding plant execution and wellbeing, on the grounds that certain advantageous organisms improve plant development and protection from stresses. Soil richness is a key segment which administers the working of a rural environment. Soil is an intricate framework containing surface, natural matter, soil microbial biomass, air, water and others. Soil working is a marker of soil microbial variety and harvest profitability potential. In general, soil fruitfulness is the capacity of a dirt to give plant supplement to trim. Therefore, the present review describes the role of soil microbes in soil fertility.

Microbial diversity and its interaction with plant-Soil system:

Soil microorganisms like microbes, green growth, organisms, actinomycetes, protozoa and the infective specialists such as infections are the bodies inside the huge assets of exercises of infinitesimal variety. These soil microorganisms perform numerous important capacities just as some hurtful effects. In the soil profile, the effect of soil biota is diverse and troublesome since a similar activity may be destructive or positive relying upon its position. On the other hand, plants show an alternate scope of cooperation with these soil dwelling microorganisms which expands the full assortment of natural prospects (serious, shifty, unbiased, commensal and mutualistic). Be that as it may, concurring to current circumstance, the easing pathogenic impacts such as contamination and herbivory are more contemplated. As the communications among plant and tiny networks are inclined by different agronomic administrations and organic factors dominatingly in the current circumstance of overall unrest, the impact of biological pressure angles should be thought of, as they influence legitimate administration of the connections between crop-microbiome. The soil development with an undeniable level of soil richness is a consequence of more than many years of soil "development" this assertion isn't unexpected due to the mind-boggling collaborations among microorganisms and plant-soil framework. The connection among organisms and plants inside the soil framework shown in this (Fig. 1).

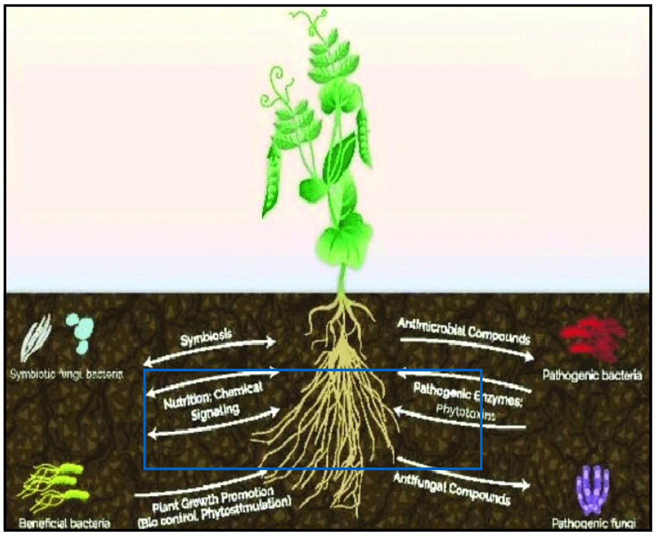

Fig. 1: Interaction between microbial communities and plants

Beneficial aspects of some microbes:

The soil richness and its development from mineral bedrock includes a diverse cooperation of compound, physical furthermore, organic cycles. The improvement pace of the soil is constrained by certain variables like geology, environment, time, bedrock type, plants and microorganisms that is the reason the situation with supplements is controlled by the quality and distinguishing proof of organisms in soil. Soil microorganisms make a connection among soil and roots, supplements reusing, natural matter deterioration and respond quickly to any varieties that happen in the biology of soil by proceeding as ideal pointers for distinct capacities in the environmental factors of soils. To expand plant yield, a scope of non-advantageous microorganisms (*Azotobacter, Azospirillum, Bacillus, Klebsiella* sp.) and harmonious microorganisms (*Rhizobium* sp.) are currently being utilized internationally (Fig. 2). The living constituents of soil natural matter is microbial biomass. Mean while, organisms are important in decreasing the issues that are identified with the use of substance manures and pesticides, they are broadly being applied in regular farming area and natural agribusiness. Microbial biomass influences supplement stockpiling, supplement changes and cycling as the dynamic segment of natural matter.

Organisms in soil :

The soil is overflowing with a huge number of living life forms, which make soil a live and dynamic framework. The soil organic entities are characterized into two gatherings: (1) soil verdure, mostly having a place with the plant realm and (2) soil fauna, subsequently having a place with the animals of the world collectively. These soil living beings not just assistance in the soil developmental measure/soil arrangement, but at the same time are liable for various transformations and furthermore work with the accessibility of plant supplements to the harvest. The joined natural materials are disintegrated with the assistance of soil biota and converted it into an absorbed type of plant supplement. The exercises of the organic entities are influenced by the soil climate, soil fruitfulness status and the accessible substrate in soil. The soil living beings are additionally isolated into subgroups: macro-organisms, those that are adequately large to be seen with an unaided eye and microorganisms, organic entity little in size and can't be seen by the unaided eye, requiring amplification (for

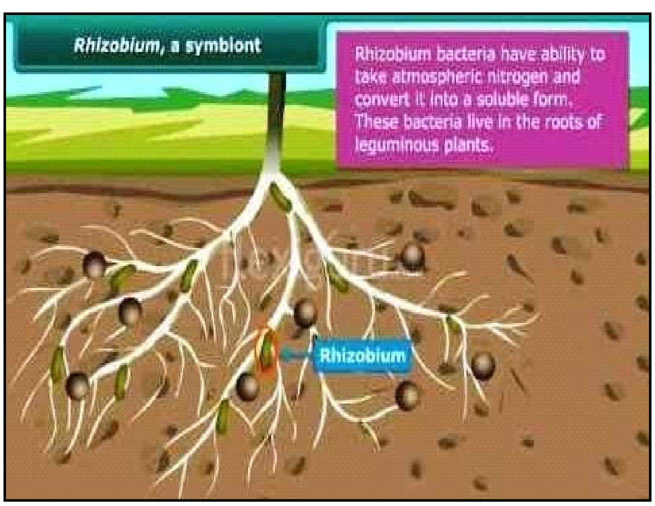

Fig. 2: Role of Rhizobium in soil fertility

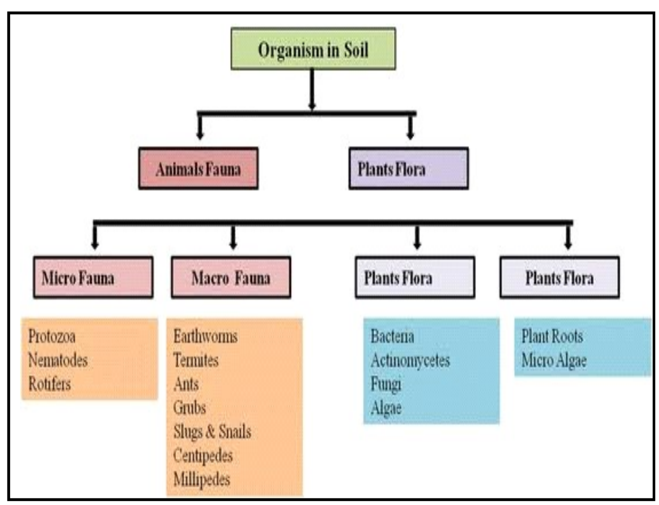

Fig. 3: Organisms in soil

example magnifying lens). Not with standing, these living beings are likewise separated into different gatherings on the premise of food materials utilized, or premise of temperature and sub-atomic oxygen taken for breath.

Micro and macro-organisms present in soil :

Soil microorganisms assume a significant part in soil nature and plant supplement transformation across the worldwide soils. It intercedes the soil climate and influences the soil wellbeing. All in all, fauna and vegetation having size under 0.1 mm are known as microorganisms. They are effectively engaged with soil supplement change and plant supplement cycles in the soil plant continuum. The populace and variety of soil microorganisms change in a wide reach and are influenced by the richness level, natural matter, the presence of harmful substances and climatic components. They are minute in size and can't be seen with the unaided eyes. In a dirt having around 109 soil microorganisms, with the assistance of a magnifying lens, can see just 1 % of the all-out populace.

Soil microbiology is the investigation of life forms in soil, their capacities and what they mean for soil properties. Soil microorganisms can be delegated microscopic organisms, actinomycetes, growths, green growth, protozoa and infections. Each of these bunches has various attributes that characterize the life forms and various capacities in the soil it lives in. Significantly, these organic entities don't exist in disengagement; they cooperate and these connections impact soil ripeness so much or more than the organic entity's individual activity.

Bacteria :

Taking into account soil ripeness the board, microorganisms assume a massive part to eliminate the rural harvest yield stagnation and furthermore oversee soil wellbeing. It is a solitary cell living being, otherwise called the easiest and littlest type of life on earth. It is a light of exploration to create biofertilizers and decrease the compost reliance on chemical manures. Its augmentation rate is high and has a fast reaction to changes in natural conditions. The shape and size of microbes fluctuate for instance as round, winding and pole like. In soil, pole molded microorganisms are more prevailing. Microbes are creatures that have just a single cell and are, subsequently, minute. There isany place from 100 million to one billion microscopic organisms in a teaspoon of sodden, fertility of soil. By doing this, the microbes discharge supplements that different living beings couldn't get to. The microbes do this by changing the supplements from difficult to reach to usable structures. The measure is fundamental in the nitrogen cycle which is increase the soil health.

Nematode :

In the line of microfauna, the nematodes are close to protozoa in plenitude. It is ordinarily called eelworms or threadworms, because of the limited long bodies. It is minuscule in size, and can't be seen by the unaided eyes. 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.

Fungi :

Parasites are uncommon life forms; in that they are not plants or creatures. They bunch themselves into sinewy strings called hyphae. The hyphae then structure bunches called mycelium which are under 0.8mm wide however, can get up to a few meters. They are useful, yet could likewise be destructive, to soil organic entities. Growths are useful on the grounds that they can separate supplements that different creatures can't. They at that point discharge them into the dirt, and different creatures will utilize them. Growths can connect themselves to plant roots. Most plants develop much better when this occurs. This is a helpful relationship called mycorrhizal. The parasites help the plant by giving it required supplements and the growths get carbs from the plant, something very similar food that plants provide for people. Then again, growths can get food by being parasites and connecting themselves to plants or different living beings for selfish reasons.

A portion of the capacities acted in soil by parasites are:

– Decomposers: –saprophytic growths – convert dead natural material into parasitic biomass, carbon dioxide (CO_2), and little atoms, like natural acids.

– Mutualists: – Mycorrhizal parasites – colonize plant roots. In return for carbon from the plant, mycorrhizal growths help to make phosphorus dissolvable and bring soil supplements (phosphorus, nitrogen, micronutrients and maybe, water) to the plant. One significant gathering of mycorrhizae, the ectomycorrhiza, developson superficial level layers of the roots and are normally connected with trees.

Algae :

Algae growths are available in the majority of the soils where dampness and daylight are accessible. Their number in the soil for the most part goes from 100 to 10,000 for each gram of soil. They are fit for photosynthesis, whereby they what's more, get carbon dioxide from environment and energy from daylight and blend their own food. The significant jobs and elements of algae growth in soil are:

– Assuming a significant part in the support of soil ripeness, particularly in tropical soils.

– Adding natural make a difference to soil when they bite the dust and hence expanding the measure of natural carbon in soil.

– Going about as a solidifying specialist by restricting soil particles and along these lines lessening and forestalling soil disintegration.

– Assisting with expanding the water maintenance limit of soil for longer time-frames.

– Freeing huge amounts of oxygen in the dirt climate through the cycle of photosynthesis and, accordingly, working with lowered air circulation.

– Assisting with checking the deficiency of nitrates through filtering and seepage, particularly in un-trimmed soils.

– Aiding in the enduring of rocks and the structure up of soil structure.

Protozoa :

These are dismal, single-celled creature like organic entities. They are bigger than microorganisms, differing from a couple of microns to a couple of millimeters. Their populace in arable soil goes from 10,000 to 100,000 for every gram of soil and they are bountiful in surface soil. They can withstand unfavorable soil conditions, as they are portrayed by an ensured, torpid stage in their life cycle.

The most significant capacities and highlights of protozoa is getting their sustenance from taking care of or ingesting soil microorganisms and, consequently, they assume a significant part in keeping up microbial/bacterial balance in the soil.

Earthworm in soil fertility:

Earthworm assumes a significant part to improve soil fertility in an assortment of ways. For model, earthworm the supplements from somewhere down in the soil and store them on the soil surface as castings, subsequently check draining of supplements. Night crawlers (Earthworm) blend soil layers and join natural matter into the soil. These blending permits the scattering of the natural matter through the soil and makes the supplements held in it accessible to plants and improves the fertility of the soil. Night crawlers add to soil fertility by improving soil construction, blending and plowing the soil, expanding humus arrangement and expanding the accessible plant supplements. Night crawlers eat a lot of litter however just a little part of processed material (5-10%) is absorbed by the night crawlers and the rest are discharged out in the type of night crawler cast which are rich in NPK, micronutrients and advantageous soil microorganisms.

Termites :

In the list of macro-organisms towards the job in soil ripeness or soil wellbeing, termites track down a significant spot. It has cellulose decay microorganisms in the gut, and processes the safe pieces of soil natural matter. It assists with changing the soil surface due to arrangement of hills and development of the dirt part of soil from earth. It too alters the nature and dissemination of natural matter. Its excreta have less natural matter substance than worm projects.

Plant roots:

A plant root establishes the significant piece of the plant body regarding mass and capacities. Over 80 per cent of photosynthates are delivered into soil through plant roots. It goes about as a wellspring of food materials for soil organic entities, improves the soil physical, compound and natural properties and upgrades the harvest profitability and quality. It has a colossal part in soil arrangement, ripeness and profitability and can likewise be considered as one of the soilsmacro-organisms. The impact of root is fundamentally portrayed by the rhizosphere zone exercises and its current circumstance.

Role and function of soil microbiota :

Altogether, soil microorganisms assume a fundamental part in disintegrating natural matter, cycling supplements and treating the dirt. Without the cycling of components, the continuation of life on Earth would be unthinkable, since fundamental supplements would quickly be taken up by creatures and secured a structure that can't be utilized by others. The responses engaged with basic cycling are regularly synthetic in nature, yet biochemical responses, those worked with by life forms; likewise have a significant impact in the cycling of components. Soil organisms are of prime significance in this cycle.

Soil organisms are additionally significant for the advancement of sound soil structure. Soil organisms produce bunches of sticky substances (polysaccharides and adhesive, for instance) that help to solidify soil totals. This concrete makes totals more averse to disintegrate when presented to water. Parasitic fibers additionally settle soil structure on the grounds that these threadlike designs branch out all through the soil, in a real sense encompassing particles also, totals like a hairnet. The growths can be considered as the "strings" of the soil texture. It should be focused on that organism for the most part apply little effect on changing the actual physical structure of the soil; that is performed by larger organisms.

Conditions:

We can see that solid soils contain tremendous quantities of organisms and significant amounts of microbial biomass. This converts into a huge potential for microbial movement when soil conditions (accessible carbon sources, dampness, air circulation, temperature, causticity/alkalinity and accessible inorganic supplements, for example, nitrogen), are great. The potential for action should be focused on the grounds that, under typical circumstances, the microbial populace doesn't get a consistent stockpile of promptly accessible substrates to support delayed high paces of development.

Practically all soil creatures (with the exception of certain microbes) need exactly the same things that we need to live: food, water and oxygen. They eat a carbon-based food source, which gives every one of their supplements, including nitrogen and phosphorus. They require a clammy territory, with admittance to oxygen noticeable all-around spaces in soil. These reasons clarify why 75% of soil creatures are found in the best five centimeters of soil. It additionally clarifies, not withstanding, why a significant number of our agrarian soil microorganism populaces are drained. Lamentably, some of the horticultural practices that were standard in Australia up until the 1980s, such as unnecessary land leeway, the consuming of stubble, improper manure application and over-culturing, have corrupted soils and created conditions like saltiness, fermentation, soil primary decrease and desertification.

Remediation:

While in numerous spaces, our farming soils are as yet viewed as under danger, in ongoing many years, changes to the cultivating rehearses itemized above are assisting with making better soils. As of not long ago, this was thought about the best way to improve natural fruitfulness. Making the correct conditions and organisms will come also, then again, if the conditions are not right, endeavors to acquaint useful organisms are bound with fall flat. As of late, in any case, logical exploration has made critical progress in the vaccination of soils and seeds with useful bacterial and, specifically, mycorrhizal growths to improve yields and to advance better soils. While still in a beginning phase of advancement, field preliminaries have been positive and may, in the future, lead to a wide scope of advantages dependent on improved soil organic fertility.

Role of soil micro organisms in nutrients cycling :

Nutrient cycling is a fundamentally important process to the ecological functioning of all the Earth's biomes. Conceptually, nutrient cycles involve a defined, typically bounded, Compartment which nutrients enter and leave via a range of pathways and within which They are transformed via a myriad of chemical and biochemical reactions. In soil systems, a large proportion of these transformations are mediated by biota. Organisms require Nutrients to build structural components of which they are comprised, and for the Biochemistry that underpins metabolic processes. Nutrient cycling transformations Invariably involve the capture, storage or release of energy. In agricultural systems, if the quantities of nutrient elements removed by crop offtake and lost via other pathways exceed the input rates of such elements, then the system is Essentially not sustainable, since pools of such nutrients will in time be depleted. The timescale here will be governed by input and output rates, and pool size, all of which can to Some extent be managed. The compartment of immediate concern in this respect is the Minimal management unit, typically the field, but in a policy context, the concept is pertinent at larger scales such as the farm, catchment, region or arguably national and international. The corollary also applies – if inputs exceed outputs, then there will be a net accumulation. Since such concepts are time-dependent, it may be possible to run systems in "deficit" for Periods, followed by accumulative phases, notwithstanding that there may be variable efficiencies associated with this, and that tipping points, where recovery is not possible, are not exceeded.

Carbon cycle :

Plants and photo /chemo autotropic microorganisms convert atmospheric carbon into organic carbon source for their food in soil. Therefore, the soil becomes the largest carbon pool on earth's surface. The reverse process *i.e.*, decompose of organic material built in plants and microns were carried out by organic carbon utilizing heterotrophic microorganisms as a substrate for their metabolism and energy sources. The remaining C is liberated as metabolites or CO_2 to the atmosphere. The decomposition product termed as soil organic carbon (SOC) is the largest pool within the terrestrial C cycle with an annual turnover of about 60 Gt. During the SOC formation, the organic materials were either mineralized to CO_2 or humified. Since the SOC affects plant growth by serving as energy source and by influencing nutrient availability through mineralization, it is one of the most important constituents of the soil. It is understood that microbes transfer the Cprimarily for their survival. Under toxic conditions, *i.e.,* in surface of soil and toxic layers of wetland systems, aerobic methane-oxidizing bacteria play the role whereas under waterlogged anoxic soils, CO_2 is reduced by hydrogenotrophic archaea and methanogenicbacteria; Typically, microbial C accounts for a minimum of 1001,000 μg g-1 in arable soils and a maximum of 50010,000 μg g-1 in forest soils with the intermittent values in other ecosystems such as grasslands and semiarid regions. Besides the considerable variations, microbial biomass C generally accounts for about 0.9-6% of total organic C with an indirect relationship for increasing soil depth. Formation of soil organic matter (SOM), a major fraction containing SOC is aided by the decomposition process through various lytic enzymes including, amylase, glucosidase, proteases, cellulase, chitinase and phenol oxidase. These enzymes convert the complex macromolecules into low molecular weight compound for the ready assimilation of microbial components or for their transformation into CO_2 for energy. Though the enzymes were released from plants / animals /microorganisms, the latter. Among the microbial groups, fungi are reported to have higher enzyme activity than bacteria. Role of these lytic enzymes in maintaining soil health is previously reviewed by and hence a brief note on some essential enzymes is described here.

Amylase :

Starch hydrolyzing enzyme breaks the complex polysaccharides and releases low molecular weight simple sugars which acts as an energy source for microorganisms and it is confirmed by the positive correlation between as enzyme activity and SOM.

Cellulase :

Cellulose in plant debris is degraded by a group of enzymes called cellulase into glucose, cellobiose and high molecular weight oligosaccharides. Soil fungus is the major contributors of this enzyme activity. Report of Arinze and Yubedee (2000) supports this by documenting negative correlation between increasing fungicide concentration in agricultural soils and cellulase activity. Previous studies by Vincent and Sisler (1968) and Atlas *et al.* (1978) also documented the same effects.

Chitinase :

Chitin is a major component of fungal cell wall, exoskeleton of insects and many arthropods. As already quoted, the higher fungal biomass present in soils will be degraded by the chitinase after the cell death with the release of simple organic molecules. Besides contributing for nutrient cycling, it serves majorly for the control of soil borne fungal phytopathogens such as *Sclerotium rolfsii* and *Rhizoctonia solani. Th*is indirectly helps in increasing plant growth and yield (El-Tarabily *et al.,* 2000 and Sindhu and Dadarwal, 2001).

Oxidase:

In contrast to the hydrolytic enzymes, oxidases were produced for a variety of functions including ontogeny, defence and the acquisition of C and N by microorganisms (Sinsabaugh, 2010). Representative of these enzymes include fungal laccases and prokaryotic laccase-like enzymes.

Dehydrogenase :

It is related during microbial respiration, where it oxidizes soil organic matter by transferring protons and electrons from substrates to acceptors and the activity depends on soil type and soil air–water conditions.

Sequential changes in climatic conditions and Related ecosystem factors in the current situation Affect all of the nutrient cycles. Hence, the Research trend has been directed towards (1) Effect on climate change including seasonal variations; (2) effect of fertilizers, soil amendment on long-term and short-term Scales and (3) effect of SOM etc. It is understood that, Though the importance of soil microorganisms for global C cycling is well known; only few Research attempts have been made to evaluate the Chemical and microbiological views of C cycling.

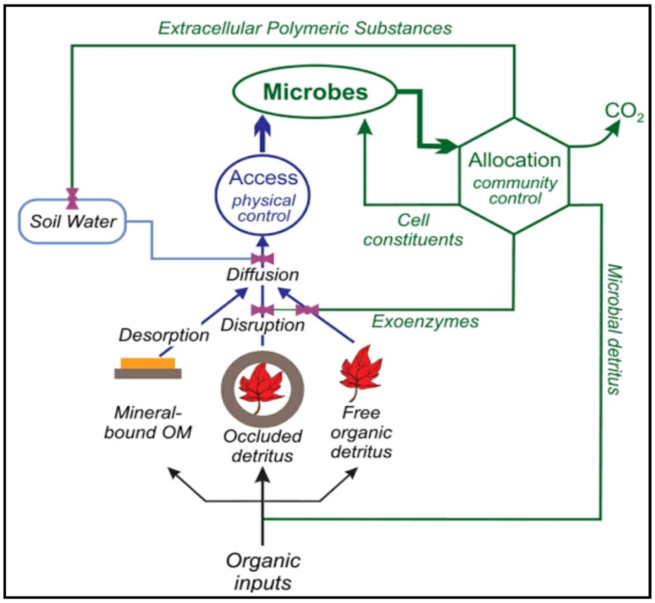

Fig. 4: Microbial controls over carbon cycling in soil

Nitrogen cycle :

Nitrogen (N), an essential element for the synthesis of amino acids and nucleotides is required by all forms of life in large quantities. It is also Involved in several respiratory energy metabolisms in which N compounds may serve as either Oxidant or reductant. Atmosphere is the largest Reservoir of N (78 %) in the form of triple bonded N 2 gas, though it is not freely available to most Living organisms. It is accessible only by N 2 fixing bacteria and archaea which pave the way for other organisms to use the fixed N for its incorporation into their biomass. This fixed N constitutes Less than 0.1 % of the N 2 pool and is able to limit the primary production in both terrestrial and Marine ecosystems. Within the organisms, N Exist in most reduced forms and during the cell Lysis it is nitrified to nitrate which in turn denitrified to N 2 gas. So, a balanced N cycle requires the Dual action of assimilatory (N fixation and incorporation into biomass) and dissimilatory (recycling of fixed nitrogen to N 2) transformation.

The first step in N cycle, assimilation, *i.e.*, N Fixation (also known as biological nitrogenfixation, BNF) is aided by a group of bacteria called Diazotrophs including cyanobacteria, green sulphury bacteria, Azotobacteraceae, rhizobia and Frankia at various ecosystems in which the formers three occurs by/through non-symbiotic process and the latter two through symbiotic process. BNF occurs through a cascade of reactions Involving complex enzymes systems and Accounts for about 65 % of N currently used in Agriculture. Major quantity of N fixed under the control of legume–rhizobia is harvested as grains. The left-out N in the soil, roots and shoot residues Supports the succeeding crops for N supply. Hence legume–rhizobial symbiosis substantially Reduces the N requirement from external sources. However, N fixation efficiency of legumes depends on the host genotype, rhizobial efficiency, soil conditions, And climatic factors. BNF is an energy demanding process through Which atmospheric N is converted to plant usable Organic N and plays an important role in the N Cycle. This can be understood by the complexityof the enzyme nitrogenase, a major enzyme Involves in the nitrogen fixation, which has two Components – dinitrogenase reductase, the iron Protein and dinitrogenase (metal cofactor). The Iron protein provides the electrons with a high Reducing power to dinitrogenase which in turnReduces N 2 to NH 3. Based on the availability Metal cofactor, three types of N fixing systems *viz.,* Mo-nitrogenase, V-nitrogenase and Fe-nitrogenase were documented. Complexity of nitrogen fixation can be further understood by participation of multiple gene clusters as follows: (1) nodulation (including nodA - acyltransferase, nodB- chitooligosaccharide deacetylase, nodC- N-acetylglucosaminyltransferase, nodD- transcriptional regulator of common nod genes, nodPQ, nodX, nod EF, nodIJ- Nod factors transports, NOE- synthesis of Nod factors substituents, nol genes - several functions in synthesis of Nod factors substituents and secretion); (2) nitrogen fixation (including nifA, nifHDK- nitrogenase, fixLJ, nifBEN- biosynthesis of the Fe-Mo cofactors, fix K- transcriptional regulator, fixABCX- electron transport chain to nitrogenase, fixGHIS- copper uptake and metabolism, fdxN- ferredoxin and fix - NOPQ- cytochrome oxidase) and (3) other essential elements (including hup- hydrogen uptake, exopolys saccharide productions, gln- glutamine synthase, nfe- nodulation efficiency and competitiveness, dct- dicarboxylate transport, ndv-β-1,2 glucan synthesis, plslipopolysaccharide production. It is a well-known fact that rhizobia belong to the families Rhizobiaceae (excluding the Frankiasp.), Bradirhizobiaceae and Phyllobacteriaceae. Rhizobia have a unique association with root nodules of leguminous plants and induce plant growth in many ways. They also have capacity to induce plant growth of non-leguminous plants. The number of species reported in Rhizobiaceae family increased considerably from 8 in 1980 to 53 in 2006. Besides its role in efficient N fixation, they have multiple plant growth promoting traits such as mineral enhancing capacity, phytohormone production and alleviating biotic and abiotic stress. All these help in developing formulation of rhizobial inoculants to achieve substantial increases in legume nodulation, grain and biomass yield, nitrogen fixation and post-crop soil nitrate levels for succeeding crops. It is reported that, inoculation of soybean with rhizobial inoculants showed substantial increases in nodulation, grain and biomass yield and N fixation. Besides the rhizobia, the associative and free-living nitrogen fixing bacteria were also formulated and commercialized as bio fertilizers. The genus *Azospirillum*, an associative N fixing bacteria comprises nearly 15 species: *A. lipoferum, A. brasilense, A. amazonense, A. halopraeferannse, A. largimobile, A. dobereinerae, A. oryzae, A. melinis, A. canadense, A. zeae, A. rugosum, A. palatum, A. picis* and *A. thiophilum.* Also reported for its multiple plant growth promoting traits. The next important genus is Azotobacter, a free-living nitrogen fixer which comprises of seven species:chroococcum, *A. vinelandii, A. beijerinckii, A.paspali, A. armeniacus, A. nigricans* and *A. salinestri*. Besides the N fixing capacity, this genus has the history of more than 35 years in promoting plant growth through multiple Phytohormone production, enzymes, enhanced membrane activity, proliferation of the root system, enhanced water and mineral uptake, mobilization of minerals, mitigation of environmental stress factors, and direct and indirect biocontrol against numerous phytopathogens. The N fixed in the form of ammonium during assimilation process, is further dissimilated by two-step microbial process, *i.e.*, nitrification (the aerobic oxidation of ammonium to nitrite and then to nitrate) and denitrification (the respiratory anaerobic reduction of nitrate via nitrite, nitric oxide, and nitrous oxide to N 2, coupled with the oxidation of organic matter, hydrogen, or reduced iron or Sulphur species). Nitrification is further carried out by two sets of microbial groups:

– Ammonia oxidizers (nitrosifiers) which convert ammonia to nitrite by activity of ammonia mono oxygenase, e.g., Nitrosomonas, Nitrosospira and Nitrosococcus

– Nitrite oxidizers (the true nitrying bacteria) which convert nitrite to nitrate by the activity of nitrite oxidoreductase, e.g. Nitrobacter and Nitrococcus.

Though the physiology of nitrogen fixation process is reasonably well characterized, still research studies on the phylogenetic diversity of rhizobial species in the context of common core symbiotic genes and invasive mechanisms behind the symbiotic process are going on.

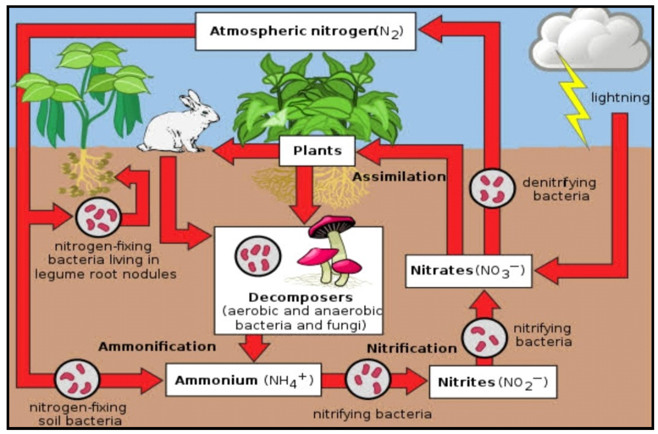

Fig. 5: Role of microbes in nitrogen cycling

Sulphur cycle :

The sulphur (S) present in soil (>95 % of total S) is in the bound form with organic molecules, and it is not directly available to the plants, *i.e.*, inorganic S which constitutes about only 5 %. This minimal part of available S in agricultural soils leads to S deficiency symptoms in plants. Besides the contribution of plant and animal-derived organic S mainly mediated by microbial process via immobilization of inorganic S to organic S, interconversion of various organic S forms, mineralization of inorganic Sulphur in order to support plant growth. Rhizospheric microbes are the major players in allowing plants to access soil organoSulphur. Besides the mineralization and immobilization, oxidation and reduction reactions also influence S cycling. Oxidation of elemental S and inorganic S compounds to sulphate is carried out by chemoautotrophic (*Thiobacillus* sp., T. *ferrooxidans* and *Thiooxidans*) and photosynthetic (Green and purple bacteria, Chlorobium and Chromatium bacteria. Besides this, heterotrophic bacteria such as Bacillus, Pseudomonas , and Arthrobacter, fungi such as Aspergillas and Penicillium and some actinomycetes are also reported to oxidize sulphur compounds. The process of sulphate/sulphuric acid formation has the following advantages: (i) it is the anion of strong mineral acid (H 2 SO 4)which can render alkali soils fi t for cultivation by correcting soil pH; and (ii) solubilize inorganic salts containing plant nutrients and thereby increase the level of soluble P, K, Ca, Mg, etc. for plant nutrition. Dissimilatorysulphate reduction also occurs in order to balance the contents, where sulphate-reducing bacteria such as Desulfovibrio, Desulfatomaculum and Desulfomonas play the key roles through the enzyme activity of desulfurases/bisulphate reductase. Among them, Desulfovibriodesulfuricans can reduce sulphates at rapid rate in waterlogged/flooded soils, while Desulfatomaculum – a thermophile obligate anaerobes – can reduce sulphates in dry land soils (Tang *et al.*, 2009). Though many studies have been conducted to evaluate the role of microbes in S cycle, now the research focus has been moved in to deal with enzymes, organisms, pathways, comparative approaches, symbiosis, and environments factors related to the S nutrition.

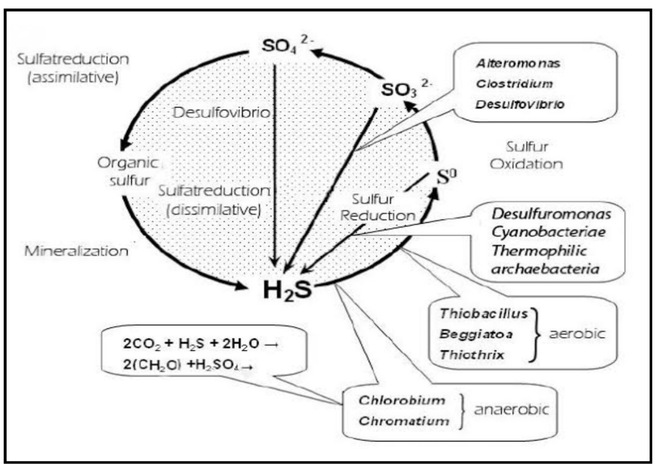

Fig. 6: Sulphur solubilization in soil by the microbes

Phosphorous cycle:

Phosphorous (P) is a key component of nucleic acids, energy molecule ATP and membrane component phospholipids. P accounts for about 0.2%0.8 % of the plant dry weight, but only 0.1 % of this P is available for plants from soil. The P content of agricultural soil solutions are typically in the range of 0.01%3.0 mg P L “1 representing a small portion of plant requirements. The remaining must be obtained through intervention of biotic and abiotic processes where the phosphate solubilizing activity of the microbes has a role to play. Soil microbes help in P release to the plants that absorb only the soluble P like monobasic (H 2 PO 4”) and dibasic (H 2 PO 42") forms. Many bacteria (*Pseudomonas* and *Bacillus*), fungi (*Aspergillus*, *Penicillium* and *Trichoderma*) and actinomycetes (Streptomyces and Nocardia) are noticed for P solubilizing capacity and enhancement of plant growth. This is aided by the synthesis of protons and organic acids, the significant contributors for solubilization of metal compounds though the excretion of other metabolites, siderophore also contribute to the solubilization process. Low molecular organic acid – 2-ketogluconic acid – with a P-solubilizing ability has been identified in *R. legumin Sarum* and *R. meliloti*. Mineralization of organic P takes place by several enzymes of microbial origin, such as acid phosphatases, phosphohydrolases phytase, phosphonoacetate hydrolase (D-α-glycerophosphatase. Other mineral 9 Future elements also turn into their available form by any of the above mechanism.

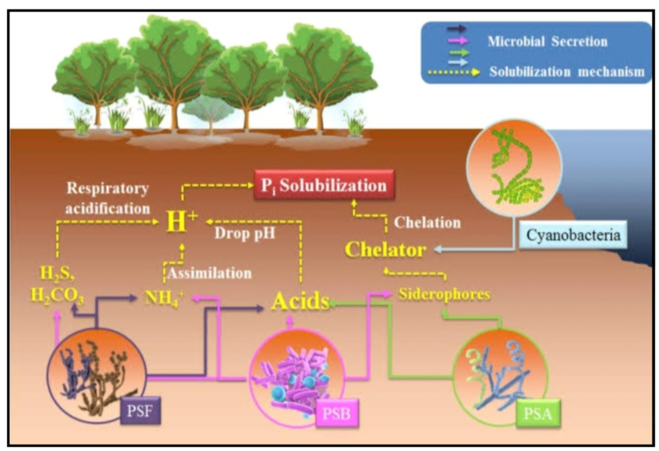

Fig. 7: Role of phosphors solubilizing bacteria in solubilization of organic phosphors in soil

Conclusion :

Bacteria are the smallest and most hardy microbe in the soil and can survive under harsh or changing soil conditions. Bacteria are only 20–30% efficient at recycling carbon, have a high N content (10 to 30% N, 3–10 C:N ratio), a lower C content, and a short life span. There are basically four functional soil bacteria groups including decomposers, mutalists, pathogens and lithotrophs. Decomposer bacteria consume simple sugars and simple carbon compounds, while mutualistic bacteria form partnerships with plants including the nitrogen-fixing bacteria (Rhizobia). Bacteria can also become pathogens to plants and lithotrophic bacteria convert nitrogen, sulfur, or other nutrients for energy and are important in nitrogen cycling and pollution degradation. Actinomycetes are classified as bacteria but are very similar to fungus and decompose recalcitrant (hard to decompose) organic compounds. Bacteria have the ability to adapt to many different soil microenvironments (wet vs. dry, well oxygenated vs. low oxygen). They also have the ability to alter the soil environment to benefit certain plant communities as soil conditions change.Soil microorganisms also have a great role at the rhizosphere region that they help the plant in mineral uptake and by solubilizing the essentials micro and macro molecules of the soil in simpler form. They are the soil engineers by making it's more fertile and enriched with nutrients that plants and animals need for their grow and development.

Future outlook :

Microbes have multiple functions and features in influencing soil health and also in promoting plant growth and controlling diseases. Hence maintenance of beneficial microbial load will help in replacing inorganic fertilizer, pesticides and artificial plant growth regulators which have numerous side effects to sustainable agriculture. Beside this, understanding the responses of terrestrial ecosystems to global climatic changes and modern agricultural practices remains a major challenge, since soil has a mixed interaction with physical, chemical and biological component along with the influence of water, air/atmosphere, soil amendments etc. So, research in each of this context individually and also in combination at various ecosystem levels is necessary.

REFERENCES

Bell, T., Newman, J. A., Silverman, B. W., Turner, S. L. and Lilley, A. K. (2005). The contribution of species richness and composition to bacterial services. *Nature,* **436**(7054) : 1157-1160.

Dang, C. K., Chauvet, E. and Gessner, M. O. (2005). Magnitude and variability of process rates in fungal diversitylitter decomposition relationships. *Ecol. Lett.*, **8**(11) : 1129-1137.

Fierer, N., Lauber, C. L., Ramirez, K. S., Zaneveld, J., Bradford, M.A. and Knight, R. (2012). Comparative metagenomic, phylogenetic and physiological analyses of soil microbial communities across nitrogen gradients. *The ISME J.*, **6** (5) 1007-1017.

Hodge, A., Robinson, D. and Fitter, A. (2000). Are microorganisms more effective than plants at competing for nitrogen?. *Trends in Plant Science,* **5** (7) : 304-308.

Moorhead, D. L. and Sinsabaugh, R. L. (2006). A theoretical model of litter decay and microbial interaction. *Ecological Monographs,* **76** (2) : 151-174.

Shi, Y., Lalande, R., Hamel, C., Ziadi, N., Gagnon, B. and Hu, Z. (2013). Seasonal variation of microbial biomass, activity, and community structure in soil under different tillage and phosphorus management practices. *Biology & Fertility of Soils*, **49** (7) : 803-818.

Van Bruggen, A. H., Sharma, K., Kaku, E., Karfopoulos, S., Zelenev, V. V. and Blok, W. J. (2015). Soil health indicators and Fusarium wilt suppression in organically and conventionally managed greenhouse soils. *Applied Soil Ecology,* **86** : 192-201.

Van Der Heijden, M. G., Bardgett, R. D. and Van Straalen, N. M. (2008). The unseen majority: soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. *Ecology letters,* **11**(3): 296-310.

Wei, F., Passey, T. and Xu, X. (2016). Amplicon-based metabarcoding reveals temporal response of soil microbial community to fumigation-derived products. *Applied Soil Ecology,* **103** : 83-92.

17th Year
★ ★ ★ ★ of Excellence ★ ★ ★ ★ ★