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Role of Microorganisms in Nutrient Mobilization and Soil Health - A Review

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Microorganisms represent the largest and most diverse biotic group in soil, with an estimate of one million to one billion microorganisms per one gram of agricultural top soil. Soil health is defined as the capacity of soil to function as a vital living system, by recognizing that it contains biological elements that are key to ecosystem function within land use boundaries. In the context of agriculture, it may refer to its ability to sustain productivity. Microorganisms possess the ability to give an integrated measure of soil health, an aspect that cannot be obtained with physical/chemical measures and/or analyses of diversity of higher organisms. Microorganisms are key players in the cycling of nitrogen, sulfur and phosphorus, and the decomposition of organic residues. They affect nutrient and carbon cycling on a global scale. Production of extra-cellular polysaccharides and other cellular debris by microorganisms help in maintaining soil structure as well as soil health. Thereby, they also affect water holding capacity, infiltration rate, crusting, erodibility, and susceptibility to compaction. Changes in microbial populations or activity can precede detectable changes in the soil's physical and chemical properties, thereby providing an early sign of soil improvement or an early warning of soil degradation.

Key words: Bacteria, fungi, mobilization, nutrient, soil health.

A microorganism or microbe is a microscopic organism which may be a single cell or multicellular organism.Soil is a habitat for large number of organisms and organisms in soil are classified as :

1. Soil Flora-Plant kingdom
2. Soil Fauna-Animal kingdom

Soil microorganisms

Bacteria

The most dominant group of microorganisms in the soil and equal to one half of the microbial biomass in soil. They are found in neutral to slightly alkaline soils. Different bacterial genera are *Bacillus, Clostridium, Pseudomonas* .Genus *Bacillus* has largest representation in soils in terms of species.Soils with low organic matter and sandy texture have very low population.

Actinomycetes

They are intermediate group between bacteria and fungi and belong to genera *Streptomyces, Nocardia*.70% of soil actinomycetes are *Streptomyces*. Found in neutral to slightly alkaline soils.Commonly found in dry soils and less in low lands.

Fungi

They are numerous in surface layers of well-aerated and cultivated soils.Common genera in soil are *Aspergillus, Mucor, Penicillium, Alternaria, Rhizopus.* Soil fungi can grow in a wide range of soil pH but their population is more under acidic conditions.

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Algae

Abundant in habitats exposed to light and sufficient moisture.Important genera are *Anabaena, Nostoc, Aulosira.*

Protozoa

Abundant in upper layer of the soil and derive their nutrition by devouring soil bacteria.They are regulating the biological equilibrium in soil.Their population is high in soils with organic matter.

Soil Health

Soil health is defined as the continued capacity of soil to function as a vital living system, by recognizing that it contains biological elements that are key to ecosystem function within land use boundaries (Karlen *et al.*, 2001). These functions are able to sustain biological productivity of soil, maintain the quality of surrounding air and water environments, as well as promote plant, animal, and human health.

Components of soil health

Soil health-involving biological, chemical, and physical aspects is influenced by every aspect of soil and crop management.

Biological component

Soil organic matter is made up of living soil organisms and roots, combined with fresh organic residues, and well-decomposed humic materials (Magdoff, 1996). A healthy soil contains (i) an active and diverse population of organisms, (ii) high levels of relatively fresh residues that provide food sources for the organisms and (iii) high levels of humified organic matter that retains water and provides cation exchange (negatively charged) sites that retain nutrients such as Ca^{++} , Mg^{++} , and K^{+}. Soil organic matter has such a profound effect on many soil properties that organic matter management is the heart of creating soil health.

Physical component

Another aspect of soil health is the soil's physical condition-degree of compaction, amount of water storage, and drainage. When aeration, water availability, and soil strength are beyond optimum ranges, plant growth suffers. A soil's physical condition is influenced partially by organic matter because polysaccharides and polyuronides produced during decomposition help promote aggregation of soil particles. Secretions of mycorrhizal fungi are also important in promoting soil aggregation (Wright and Starr, 1998)

Chemical component

Includes the levels of available nutrients, the pH, the salt content, etc. are important determinants of soil health. Plant growth can be adversely affected by either low nutrient levels, high levels of a toxic element (such as Al), or high salt concentrations.

The biological, chemical, and physical aspects of soils all interact with, and affect, one another. For example,a very compact soil has few large pores and thus is less hospitable to organisms such as springtails, mites, and earthworms.In addition, lower levels of oxygen in compact soils may influence the forms of nutrients present and their availability (e.g.significant quantities of NO_3 may be lost under anaerobic conditions).

Role in soil health

Microorganisms possess the ability to give an integrated measure of soil health, an aspect that cannot be obtained with physical/ chemical measures and/or analyses of diversity of higher organisms. Microbes aid soil structure by physically surrounding particles and 'gluing' them together through the secretion of organic compounds, mainly sugars. Microorganisms also affect the physical properties of the soil. Production of extra-cellular polysaccharides and other cellular debris by microorganisms help in maintaining soil structure as well as soil health. Thereby, they also affect water holding capacity, infiltration rate, crusting, erodibility, and susceptibility to compaction (Elliott *et al.*, 1996). Changes in microbial populations or activity can precede detectable changes in the soil's physical and chemical properties, thereby providing an early sign of soil improvement or an early warning of soil degradation (Pankhurst *et al.*, 1995).

Ram *et al*. (1994) concluded that available P, K, Ca and Mg significantly increased over control due to incorporation of *Azolla* and pH,bulk density of the soils decreased significantly after decomposition of *Azolla* in the soil with significant increase in water holding capacity up to 12 t ha^{-1}(Table 1). Application of *Azotobacter* and phosphate solubilizing bacteria as biofertilizers are also responsible for decreasing soil pH with producing organic acids which has been earlier reported by Mohammadi and Sohrabi (2012).

Kalhapure et al. (2013) observed lower values of bulk density and higher values of infiltration rate were in the treatments where green manuring and compost are applied as organic fertilizers. Application of 25% RDF+ biofertilizers (*Azotobacter*+ PSB)+ green manuring with sunhemp+ compost resulted in lowest bulk density (1.30g/cm3) and highest infiltration rate (3.74cm/hr) after harvesting the maize crop (Table 2). This treatment also recorded maximum values of decrease in bulk density and increase in infiltration rate,respectively over the initial values of these parameters. The main reason of decreasing bulk density was aggregation of soil particle due to increasing organic matter as well as stability of aggregates which leads to increase the total pore space in soil. Islam *et al.* (2012) has been also concluded that addition of organic matter through organic fertilizers decreases the bulk density of soil. Higher bulk density (1.33g/cm3) was observed in application of 100% RDF, 25 % RDF and control treatment.

Microbes Responsible for Nutrient Mobilization

Rhizobium

Rhizobium belongs to family Rhizobiaceae, symbiotic in nature, fix nitrogen 50-100kg/ ha.Rhizobium has ability to fix atmospheric nitrogen in symbiotic association with legumes and certain non-legumes like Parasponia.It is useful for pulse legumes like chickpea, redgram, pea etc., oil-seed legumes like soybean and groundnut and forage legumes like berseem and lucerne.It colonizes the roots of specific legumes to form tumor like growths called root nodules, which acts as factories of ammonia production. Within these nodules, the differentiated, bacteroid forms fix atmospheric nitrogen and the resultant ammonia being used as a source of fixed nitrogen. This symbiosis provides the bacteria with an exclusive niche and, in return, the plants obtain a personalized nitrogen source (Andrew *et al.*, 2007). Rhizobia infect their host plants through root hairs. First they are contained within a so called infection thread and then are released from the infection thread into the cytoplasm of cells in the cortex. These bacteria are differentiated into endosymbionts namely bacteroid forms which can reduce dinitrogen into ammonia and this can be assimilated directly by host plants (Nghia and Gyurjan, 1987). Rhizobium is a gram negative bacteria and also synthesize gibberellins and auxin (Hyoung *et al.*, 2006) Enzymatic conversion of molecular nitrogen to ammonia is catalyzed by nitrogenase, an oxygen-labile enzyme complex highly conserved in free-living and symbiotic diazotrophs. The most common form of nitrogenase, referred to as Mo-nitrogenase or conventional nitrogenase, contains a prosthetic group with molybdenum, FeMoCo. Two FeMoCo are bound to the subunits of the MoFe protein. In addition,there are two other prosthetic groups containing 4Fe-4S clusters.'P-clusters'are covalently bound to cysteine residues of MoFe protein bridging and subunits. The third type of Fe-S group is linked to the Fe protein.

The result of net reduction of molecular nitrogen to ammonia is generally accounted for by the following equation:

$N_2 + 16MgATP + 8e^- + 8H^+ \text{ g } 2NH_3 + H_2 + 16MgADP + 16Pi$

Azotobacter

Azotobacter belongs to family Azotobacteriaceae, free living, and heterotrophic in nature.. It is an obligate aerobe, although it can grow under low oxygen concentration.It is a free living nitrogen fixer.Azotobacters are present in neutral or alkaline soils and *A. chroococcum* is the most commonly occurring species in arable soils. *A. vinelandii*, *A. beijerinckii*, *A. insignis* and *A. macrocytogenes* are other reported species.The population of *Azotobacter* is generally low in the rhizosphere of the crop plants and in uncultivated soils. The occurrence of this organism has been reported from the rhizosphere of a number of crop plants such as rice, maize, sugarcane, bajra, vegetables and plantation crops play an important role in the nitrogen cycle in nature, binding atmospheric nitrogen, which is inaccessible to plants, and releasing it in the form of ammonium ions into the soil. Azotobacter have a full range of enzymes needed to perform the nitrogen fixation: ferredoxin, hydrogenase and an important enzyme nitrogenase. The process of nitrogen fixation requires an influx of energy in the form of adenosine triphosphate (ATP). Nitrogen fixation is highly sensitive to the presence of oxygen, and therefore Azotobacter developed a special defensive mechanism against oxygen, namely a significant intensification of metabolism that reduces the concentration of oxygen in the cells. There is also a special nitrogenase-protective protein called Shethna, which protects nitrogenase and is involved in protecting the cells from oxygen. Homocitrate ions play a certain role in the processes of nitrogen fixation by Azotobacter. Azotobacter also synthesize some biologically active substances, including some phytohormones such as auxins, thereby stimulating plant growth. They also facilitate the mobility of heavy metals in the soil and thus enhance bioremediation of soil from heavy metals, such as cadmium, mercury and lead.

Azospirillum

Azospirillum belongs to family Spirilaceae, heterotrophic and associative in nature. In addition to their nitrogen fixing ability of about 20-40 kg/ha, they also produce growth regulating substances. Although there are many species under this genus like, *A. amazonense, A. halopraeferens, A. brasilense,* but, worldwide distribution and benefits of inoculation have been proved mainly with the *A. lipoferum and A. brasilense*. *Azospirillum* species belong to the facultative endophytic diazotrophs group which colonize the surface and the interior of roots and this kind of association is considered as the starting point of most ongoing Biological Nitrogen Fixation programs with non-legume plants world wide. The *Azospirillum* form associative symbiosis with many plants particularly with those having the C4 dicarboxyliac path way of photosynthesis (Hatch and Slack pathway), because they grow and fix nitrogen on salts of organic acids such as malic, aspartic acid. *A.lipoferum* is reported to be associated with the roots of C4 plants like maize, while *A. brasilense* is associated with C3 plants like rice and wheat. The *Azospirillum* colonizing the roots not only remains on the root surface but also a sizable proportion of them penetrates into the root tissues and lives in harmony with the plants. They do not, however, produce any visible nodules or out growth on root tissue.Patel *et al.* (1991) found that there was a significant impact of culture treatments of *Azospirillum* (Table 3) on nitrogen content of pearl millet. Nitrogen content owing to C_1 and C_2 was higher than that of C_0.

Azolla anabaena

These belongs to eight different families, phototrophic in nature, fix 20-30 kg N/ha in submerged rice fields as they are abundant in paddy, so also large quantities for low land rice production. Soil N and BNF by associated organisms are major sources of N for low land rice (Wani and Lee ,1995) .BGA forms symbiotic association capable of fixing nitrogen with fungi, liverworts, ferns and flowering plants, but the most common symbiotic association has been found between a free floating aquatic fern, the Azolla and *Anabaena azollae* (BGA). Azolla contains 4-5% N on dry basis and 0.2-0.4% on wet basis and can be the potential source of organic manure and nitrogen in rice production. The important factor in using Azolla as biofertilizer for rice crop is its quick decomposition in the soil and efficient availability of its nitrogen to rice plants. Besides N-fixation, these biofertilizers or biomanures also contribute significant amounts of P, K, S, Zn, Fe, Mg and other micronutrient. The fern forms a green mat over water with a branched stem, deeply bilobed leaves and roots. The dorsal fleshy lobe of the leaf contains the algal symbiont within the central cavity. Azolla can be applied as green manure by incorporating in the fields prior to rice planting.They reduce molecular atmospheric nitrogen to ammonium which can then be utilized for amino acid and protein biosyntheis. Heterocyst formation is an important aspect to nitrogen fixation. The filamentous cells of bacteria differentiate into heterocysts when the cells are deprived of dissolved inorganic nitrogen. A heterocyst consists of a thick cell wall and only contains photosystem I for ATP production. Photosystem II is degraded to prevent O_2 production.Nitrogenase sequestered within these cells transforms dinitrogen into ammonium at the expense of ATP. Carbohydrate, probably in form of sucrose is synthesized in vegetative cells and moves into heterocysts. In return, nitrogen fixed in heterocysts moves into the vegetative cells in form of amino acids.

Phosphate solubilizing microorganisms (PSMS)

A diverse group of soil microflora was reported to be involved in solubilizing insoluble phosphorous complexes enabling plants to easily absorb phosphorous (Tripura *et al.*, 2005). Several fungal and bacterial species, popularly called as PSMs assist plants in mobilization of insoluble forms of phosphate.Phosphate solubilizing bacteria constitute 1 to 50 % and fungi 0.1 to 0.5 % of the total respective population in soil (Chen *et al.*, 2006). Strains from bacterial genera *Pseudomonas, Bacillus, Rhizobium* and *Enterobacter* and *Aspergillus* and *Penicillium* from fungal genera (Xiao *et al.*, 2011). There are considerable populations of phosphate-solubilizing bacteria/ fungi in soil and in plant rhizospheres. These include both aerobic and anaerobic strains, with a prevalence of aerobic strains in submerged soils. A considerably higher concentration of phosphate solubilizing bacteria is commonly found in the rhizoplane and rhizosphere in comparison with non rhizosphere soil (Raghu and Macrae 2000). The soil bacteria belonging to the genera *Pseudomonas* and *Bacillus* and Fungi are more common.

Role of p solubilizing bacteria in p solubilization

The introduction of efficient microbes (P solubilizers) in the rhizosphere has been found to increase the availability of phosphorus from both applied and native soil phosphorus. The microbial property of dissolving interlocked

Table 1. Changes in available P, K, Ca ,Mg,pH, bulk density and water holding capacity of soil due to incorporation of *Azolla*

Azolla (t/ha)	P(Mg kg^{-1})	K(Mg kg^{-1})	Ca(%)	Mg(%)	Ph	BD(Mg m^{-3})	WHC (kg kg^{-1})
0	13.53	112.30	0.36	0.06	7.8	1.33	0.39
6	16.65	117.20	0.37	0.08	7.8	1.32	0.40
12	17.53	122.43	0.44	0.09	7.6	1.30	0.42
18	19.18	125.03	0.49	0.10	7.5	1.29	0.41
24	20.05	127.53	0.58	0.11	7.4	1.28	0.42
$CD_{(P = 0.05)}$	2.14	1.2	0.05	0.01	0.03	0.007	0.012

Source : Ram *et al*.(1994)

Table 2. Effect of different treatments on physico- chemical properties of soil after harvest of maize and comparison between initial and after harvest status of these properties (pooled)

Treatment	pH	Bulk density (g/cm^3)	Infiltration rate (cm/hr)
T_1: 100% RDF	8.1	1.33	3.17
T_2: 25% RDF	8.2	1.33	3.17
T_3: Compost	7.8	1.31	3.58
T_4: Green manuring with sunhemp	7.9	1.32	3.54
T_5: Biofertilizers (Azotobacter+ PSB)	7.8	1.33	3.27
T_6: 25% RDF+ Biofertilizers (Azotobacter+ PSB)+ green manuring with sunhemp+ compost	7.8	1.30	3.74
T_7: 25% RDF+compost	7.8	1.31	3.58
T_8: 25% RDF+green manuring with sunhemp	7.9	1.32	3.55
T_9: 25% RDF+ Biofertilizers (Azotobacter+PSB)	7.8	1.33	3.29
T_{10}: Biofertilizers (Azotobacter+ PSB)+ green manuring with sunhemp + compost	7.8	1.30	3.74
T_{11}: Control	8.2	1.33	3.10
$CD_{(P=0.05)}$	0.15	0.03	0.42

Source : Kalhapure *et al.* (2013)

phosphates appears to have an important implication in Indian agriculture and same hs been documented by many investigators (Singh *et al*. 2005, Afzal 2006, Arun 2007). Primarily there are two schools following of thought interpreting the mechanism of P-solubilization by microorganisms (Phosphate solubilizers), (Arun 2007).

- Solubilization by production of organic acid
- Solubilization by production of phosphatase enzymes

Table 3. Effect of inoculation of *Azospirillum* cultures on pearl millet

AzosprillumCulture	N content (%) Grain	Fodder
Control (C_0)	1.73	0.84
BF 0002 (C_1)	1.78	0.84
BF 0003 (C_2)	1.79	0.93
CD at 5%	NS	0.03

[Patel *et al.*, 1991]

Mineral phosphate solubilization by organic acids

(Organic acids and P Solubilization)

Several reports have examined the ability of different bacterial species to solubilize insoluble inorganic phosphate compounds, such as almunium and iron bound phosphate, tricalcium phosphate, dicalcium phosphate, hydroxyapatite, and rock phosphate. The major microbiological means by which insoluble-P compounds are

Table 4. Effect of combined biofertilizers inoculation on N, P uptake in soil

Treatment	Uptake (kg/ha) N	P	Available N after harvest	Available P after harvest
T_1 Control	58.1	3.62	132.7	19.0
T_2 Azotobacter	66.0	4.90	146.3	20.1
T_3 Rhizobium	75.1	6.08	155.4	20.0
T_4 PSB	68.2	6.81	135.0	28.9
T_5 Rhiz. + PSB	84.0	8.52	158.0	24.0
T_6 Rhiz + Azto.	77.9	6.36	165.5	19.5
T_7 Azot. + PSB	75.7	7.85	151.9	24.5
T_8 Riz. + PSB + Azot.	86.2	9.18	172.4	24.8
C.D. (P = 0.05)	6.12	0.73	4.2	2.6
C.V. (%)	4.80	6.27	1.7	9.9

[Source : Gupta, 2006]

Table 5. Effect of biofertilizers on available nitrogen and phosphorus content of black cotton soil during the cropping period

S. No.	Treatments	Nitrogen (kg/ha) DAG 0	30	60	90	120	Phosphorus (kg/ha) DAG 0	30	60	90	120
1.	*Azospirillum*±75% of NP	134	142	181	182	181	7.1	7.3	8.0	8.1	8.0
2.	Phosphobacteria± 75% of NP	134	139	169	171	170	7.1	10.3	11.0	11.1	11.0
3.	Azophos± 75% of NP	134	142	178	180	179	7.1	10.1	10.6	10.8	10.7
4.	Mycorrhiza± 75% of NP	134	145	176	177	176	7.1	10.3	11.0	11.0	10.9
5.	Azophos±Mycorrhiza±75% of NP	134	153	181	184	182	7.1	10.5	11.0	11.2	11.1
6.	Recommended NPK (40 : 20 : 0 kg/ha)	134	137	175	176	175	7.1	10.3	\10.9	10.9	10.8
7.	Control (uninoculated)	134	133	131	132	132	7.1	7.1	7.2	7.1	7.0
	S.E. ±		1.811	1.108	2.084	2.086		0.212	0.215	0.180	0.197
	C.D. (P=0.05)		3.946	2.414	4.541	4.544		0.460	0.469	0.393	0.429

[Source : Ramalakshmi *et al.*, 2008]

mobilized is by the production of organic acids, accompanied by acidification of the medium. The organic and inorganic acids convert tricalcium phosphate to di and monobasic phosphates with the net result of an enhanced availability of the element to the plant. The type of organic acid produced and their amounts differ with different organisms. Tri and di-carboxylic acids are more effective as compared to mono basic and aromatic acids. Aliphatic acids are also found to be more effective in P-solubilization compared to phenolic, citric and fumaric acids. The analysis of culture filtrates of PSMs has shown the presence of number of organic acids including citric,fumaric, lactic, 2-ketogluconic, gluconic, glyoxylic and ketobutyric acids. These acids may also compete for fixation sites of Al and Fe insoluble oxides, on reacting with them, these acids stabilize them and are called 'chelates'.

Organic phosphate solubilization by phosphatase enzymes

(*Enzymes and P Solubilization*)

Organic phosphate solubilization is also called mineralization of organic phosphorus, and it occurs in soil at the expense of plant and animal remains, which contain a large amount of organic phosphorus compounds. Almost half of the microorganisms in soil and plant roots possess P mineralization potential under the action of phosphatases. Alkaline and acid phosphatases use organic phosphate as a substrate to convert it into inorganic form (Beech *et al*., 2001). Principal mechanism for mineralization of soil organic P is the production of acid phosphatases (Hilda and Fraga, 2000). Release of organic anions, and production of siderophores and acid phosphatase by plant roots/microbes or alkaline phosphatase enzymes hydrolyze the soil organic P or split P from organic residues. Mixed cultures of PSMs *Bacillus, Streptomyces, Pseudomonas* etc. are most effective in mineralizing organic phosphate. General sketch of P solubilization in soil is shown in Figure 1.

A significant increase in available nitrogen and phosphorus was observed in soil after harvest (Table 4) in treatment PSB over control (Gupta, 2006).

Mycorrhizae

Mycorrhiza is the mutualistic symbiosis (non-pathogenic association) between soil-borne fungi with the roots of higher plants (Sieverding, 1991). In this association the fungal partner can provide the plant with enhanced access to water and nutrients due to the extended area for their acquisition through the extraradical hyphal network. They are able to produce enzymes involved in the hydrolysis of nitrogen and phosphorus compounds from the organic matter in the soil and contribute to the weathering of minerals, e.g., by the release of organic acids. The plants, in return, provide carbohydrates for fungal growth and maintenance.It has been estimated that between 4 and 20% of net photosynthates could be transferred from the plant to its fungal partner (Morgan *et al.* 2005). Three main components are involved in VAM association: 1) the soil, 2) the fungus and 3) the plant.Its primary function is the absorption of resources from the soil. AMF have been shown to improve productivity in soils of low fertility and are particularly important for increasing the uptake of slowly diffusing ions such as PO_4^{3-} . Immobile nutrients such as P, Zn and Cu (Liu *et al.*, 2002) and other nutrients such as Cadmium (Guo *et al.*, 1996). Under drought

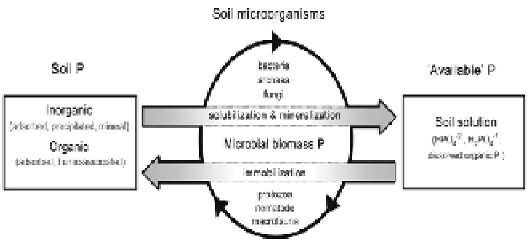

Fig. 1. Adopted from Richardson *et al.* (2009)

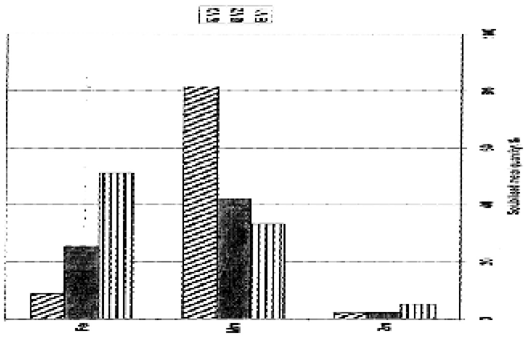

Fig. 2. Solubilised metal quantity by *Bacillus megaterium*

conditions the uptake of highly mobile nutrients such as NO^{3-} can also be enhanced by mycorrhizal associations (Subramanian and Charest, 1999). Improved P nutrition has been shown to increase in infertile and P fixing soils of the tropics (Dodd, 2000).Mycorrhizal fungi can also improve absorption of N from NH_4^+ -N mineral fertilizers, transporting it to the host plant (Johansen *et al.*, 1993).There was significant increase in the soil available nitrogen and phosphorus in the biofertilizer inoculated plots over the uninoculated control (Table 8). The available nitrogen was higher in the co inoculation of *Azophos* and mycorrhiza with 153, 181, 184 and 182 kg ha^{-1} at 30, 60. 90 and 120 DAG. Higher soil phosphorus content of 10.5,11.0,11.2 and 11.1 kg ha^{-1} at 30, 60. 90 and 120 DAG respectively was also observed in the same treatment respectively (Ramalakshmi *et al.*, 2008)

Manganese Solubilizers

The availability of manganese (Mn) in the rhizosphere is affected by two major factors : redox condition and pH. Some rhizosphere bacteria (*Bacillus, Pseudomonas, and Geobacter*) can reduce oxidized Mn^{4+} to $Mn^{2+,}$ which is the chemical form that is metabolically useful for plants. The reaction is as follows:

$MnO_2 + 4H^+ + 2e^- g\ Mn^{2+} + 2H_2O$ ...(1)

In this reaction two points are important, the reduction of Mn requires electrons and protons. Electrons are supplied by the decomposition of carbonaceous compounds and protons can be supplied by the proton excretion system of root cells. Consequently, the activity of Mn-reducers is highly favored in the rhizosphere. Applications of organic matter also can favor the reduction of Mn (Hue, Vega and Silva, 2001).*Gaeumannomyces graminis*, like many other soil borne pathogenic fungi, is a powerful oxidizer of Mn that impairs the lignification of root at infection sites Effective rhizosphere Mn-reducers(e.g., *Pseudomonas* sp.) could have beneficial effects not only on plant nutrition but also on biocontrol of pathogens. In addition, roots and rhizosphere bacteria can produce chelating-agents (phenolic compounds, organic acids) that form soluble complex with Mn and other elements avoiding the reprecipitation of Mn . In contrast, in flooded soils where the availability of Mn^{2+} can be high, the Mn oxidization by rhizosphere bacteria would favor plant growth.

Iron Solubilizers

The dynamics of iron in the rhizosphere is very similar to that of manganese. Soil Fe is present in oxidized forms Fe^{3+} as a component of the structure of insoluble minerals Goethite (FeOOH) or hematite (Fe_2O_3) .Rhizosphere bacteria (*Bacillus, Pseudomonas, Geobacter, Alcaligenes, Clostridium,* and *Enterobacter*) can reduce Fe^{3+} to Fe^{2+}, the form required by plants. Electrons and protons are available in the rhizosphere and consequently iron is reduced, however it can be reprecipitated (Mullen,1999). The reactions of reduction are as follows:

$FeOOH + 3H^+ + e^- g\ Fe_2^+ + 2H_2O$ ...(2)

$Fe_2O_3 + 6H^+ + 2e^- g\ 2Fe_2^+ + 3H_2O$ ...(3)

Under Fe-deficiency, rhizosphere bacteria, particularly *Pseudomonas fluorescent*, produce chelating agents (siderophores) that form soluble complexes with Fe^{2+} and that are available for these bacteria.(Scher,1986) found in Fusarium-suppressive soils that *Pseudomonas putida* produced a siderophore that sequestered iron. The complex siderophore-Fe can only be used by *P. putida* but not by Fusarium, which requires iron to synthesize enzymes that degrade the plant cell walls. However, when Fe-EDTA (an iron fertilizer) was applied, the biocontrol was lost because Fusarium could use this fertilizer.

Stefanescu *et al.* (2010) noted the biosolubilization capacity of *Bacillus megaterium* of Mn (80%), Fe (60%) and zinc (20%).

CONCLUSION

Solubilization of nutrient by microorganisms proves to be beneficial and economical because of high cost of chemical fertilizers and widening gap between there supply and demand.Microbial inoculants are ecofriendly and environmentally safe of low cost technology, improve productivity, reduce environmental pollution.Microbes play a vital role as organic fertilizers in facilitating uptake of nutrients in a crop.They are beneficial in maintaining the physical,chemical and biological components of soil.

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