A SEMINAR PAPER ON

ROLE OF MICROORGANISM IN SOIL FERTILITY AND CARBON SEQUESTRATION

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Abstract

Soil microorganism are vital part of soil and microbial mass vary with soil depth. So availability of nutrients also vary with soil depth. Almost every chemical reactions in soil is done by microbes and make nutrients available for plant and crops uptake. They play an active role in soil fertility hence all of the bio-geochemical cycle mediated by microbes such as nitrogen ,phosphorus, carbon cycle etc. By the decomposition of organic matter, microbes recycle the nutrients in soil. Nitrogen fixation is occurred by microbes either free living or non-freeliving microorganism. *Rhizobium* is the most common symbiotic bacteria whch can fix nitrogen biologically. Some bacteria such as *Micrococcus* spp., *Enterobacter aerogens, Pseudomona*s *capacia* and some funji like *Aspergillus niger, A flavus, A. japonicas, Penicillium* sp., and also actinomycetes like *Streptomyces* can solubilize p and make available for plant. Micorrhiza help plant to uptake nutrients from deeper horizon specially p. Micorrhiza mediated nontoxification of some inorganic pollutant like As, Cd, Pb ,Cu. Organic fertilizer(Compost) and biofertilizer are made by microbes helps to improve soil fertility and these are very eco-friendly. In recent past there is an another important fuction of microbes has been invented, that is role of microbes in carbon sequestration. Soil is a large sink for storing atmospheric carbon. Since carbon is the main reason for global warming ,microbes play a great role by storing carbon in soil. Some ectomicorrhiza and bacteria can fix carbon.Carbon can persist in humas for long time by the humification process.

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CHAPTER I

INTRODUCTION

Microorganisms play veryuseful role in soil fertility. Usually people think that microbes are agents of disease, but, they perform many other beneficial functions in soil. The beneficial microorganisms help in the decomposition of organic residues, toxic substances and other pollutants and add to the soil fertility (Afzal, 2012). The role they play in improving the soil fertility has become a subject of more investigations during the recent past.

Capacity of soil to supply the essential plant nutrients in available form and in a proper balance for healthy plant growth is called soil fertility. Soil fertility depends on the presence of inorganic substances, organic substances, water and air, as well as, on the presence of microbes (Basta, 2011).

A renowned microbiologist Jacob Lipman, remarked, "A soil lack of microorganisms is dead soil". Soil is not a dead mass. Fertile soil contains a wide variety of microbes which include different types of bacteria, fungi, protozoa, algae and actinomycetes. Mostly they are found in rhizosphere where they decompose organic matter to humus which is the store house of nutrients and influences soil fertility. Microorganisms are responsible for making up numerous transformations, which changes plant nutrients to readily available forms and make and stabilize desirable soil structure for luxuriant plant growth Phosphorus Solubilizing bacteria and fungi play an important role in converting insoluble phosphatic compound such as rock phosphate, bone meal etc particularly the chemically fixed soil phosphorus into available form. Mycorrhiza plays a very important role in supplying nutrients to the crop plants by improving soil fertility through increasing root surface area. Soil organic matter holds more than 95% of soil nitrogen, 5-60% of total phosphorus and 30% of soil sulfur. The benefits of soil microorganisms are realized through soil management practices or cropping systems that maximize their activities in their soil habitat, composting and application of effective microorganisms as inoculants or biofertilizers (Omar, 2009).

Microorganisms have also role in carbon sequestration. Which a most important topic is in now days, sinceAmount of carbon is increasing day by day. Over the past 150 years amount of carbon has increased by 30%.

We know that there is direct relationship between increased levels of carbon and global warming. So how can we reduce carbon from atmosphere it's a burning question. One of the granted proposals is carbon storage in soil which is one part of carbon sequestration.

Carbon sequestration refers the process of removal of carbon the atmosphere and storage in soil, ocean and vegetation. Although oceans store most of the Earth's carbon, soils contain approximately 75% of the carbonpool on land. Carbon cycle is dominated by the balance between photosynthesis and respiration. Carbon is transferred from the atmosphere to soil by 'carbon-fixing' autotrophic organisms; theyalso make carbon dioxide (CO2) into organic material. The objectives of the study are-

- To review the role that play microorganisms in N-fixation and P-solubilization,
- To review the role of Mycorrhiza in improving soil fertility,
- To review the role of microorganisms in heavy metal uptake and pollutants degradation and
- To reviewrole of microorganism in soil carbon sequestration

CHAPTER II

MATERIALSAND METHODS

This seminar paper is exclusively a review paper so all of the information has been collected from the secondary sources. During preparation of this paper I went through various relevant books, journals, proceedings, reports, publications etc. Findings related to my topic have been reviewed with the help of the library facilities of Bangabandhu Sheikh MujiburRahman Agricultural University (BSMRAU) and Bangladesh Agricultural Research Institute (BARI). Information also collected from Bangladesh Agricultural Research Council (BARC). I have also searched related internet web sites to collect information. I got valuable suggestion and information from my major professor and course instructors. After collecting all the available information, I myself compiled and prepared this seminar paper.

CHAPTER III

REVIEW AND DISCUSSION OF THE FINDINGS

The soil fertility improving functions of soil microorganisms include release of plant nutrients such as P,K and Zn from insoluble inorganic forms, decomposition of organic residues and release of nutrients, formation of beneficial soil humus by decomposing organic residues and through synthesis of new compounds ,production of plant growth promoting compounds and improvement of plant nutrition through symbiosis.

Fertile soil contains all of essential nutrients require for plant growth and development in available form. The conversion of complex molecular compounds into ionic forms is carried out by microorganisms either directly or indirectly. (Table1).

Table1.Essential plant nutrient in soil and their available form

Element name	Chemical symbol	Available form to plants	%Concentration in dry tissue
Nitrogen	N	NO_3^-, NH^{4+}	1.5
Potassium	K	K^+	1.0
Phosphorus	P	$H_2PO_4^-$,HPO_4^{2-}	0.2
Calcium	Ca	Ca^{2+}	0.5
Magnesium	Mg	Mg^{2+}	0.2
Sulfur	S	SO_4^{2-}	0.1
Zinc	Zn	Zn^{2+}	0.002
Iron	Fe	Fe^2+, Fe^{3+}	0.01
Manganese	Mn	Mn^{2+}	0.005
Copper	Cu	Cu^{2+}	0.0006
Boron	B	H_3BO_3	0.002
Molybdenum	Mo	MoO_4^{2-}	0.00001
Chlorine	Cl	Cl^-	0.01
Oxygen	O	O_2,H_2O	45
Carbon	C	CO_2	45
Hydrogen	H	H_2O	6

Source: FAO, 2004.

Distribution of microorganisms in soil

There are many microorganisms live in soil and they perform many activities. Among them the number of bacteria per gram soil is highest, then actinomycetes and fungi. The number of microorganisms varies according to depth of soil (Table2). The highest number of bacteria (7800000+195000) lived in top soil which is much higher (only 1000) than sub soil or deeper soil.

Table2.Distribution of Microorganisms in soil according to soil depth

Depth	Microorganisms per gram of soil			
CM	**Aerobic Bacteria**	**Anaerobic Bacteria**	**Actinomyces**	**Fungi**
3-8	7800000	1950000	2080000	119000
20-25	1800000	379000	245000	50000
35-40	472000	98000	49000	14000
65-75	10000	1000	5000	3000
135-	100	400		3000

Source: Alexander, 2008

Nitrogen fixation by microorganisms

A relatively small amount (<1% of total) of ammonia is produced by lightning. Some ammonia also is produced industrially (about 50×10^6 MT) by the Haber-Bosch process, using an iron-based catalyst, very high pressures and fairly high temperature (400-550^0 c and 200 atm). But the major conversion of N_2 into ammonia, and thence into proteins, is achieved by microorganisms in the process called nitrogen fixation. The total biological nitrogen fixation (about 175×10^6MT**)** is estimated to be twice as much as the total nitrogen fixation (about 80×10^6 MT) by non-biological processes (Table3).

Table3. Some estimates of the amount of nitrogen fixed on a global scale

Type of fixation	N_2 fixed (10^{12} g per year, or 10^6 metric tons per year)
Non-biological	
Industrial	about 50
Combustion	about 20
Lightning	about 10
Total	**about 80**
Biological	
Agricultural land	about 90
Forest and non-agricultural land	about 50
Sea	about 35
Total	**about 175**

Source: Kennedy *et al.*, 2009.

The nitrogen-fixing organisms

All the nitrogen-fixing organisms are prokaryotes (bacteria). Some of them live independently of other organisms - the so-called free-living nitrogen-fixing bacteria. Others live in intimate symbiotic associations with plants or with other organisms (e.g. *Rhizobium).*

Symbiotic nitrogen fixation

Legume symbioses

The most familiar examples of nitrogen-fixing symbioses are the root nodules of legumes (peas, beans, clover, etc.).

Fig1. Clover root bearing naturally occurring nodules of *Rhizobium.*

Table4. A short list of *Rhizobium* species that fix nitrogen symbiotically and their corresponding hosts

Rhizobium species	Host plants
Bradyrhizobiumjapanicum	*Glycine max*(soybean)
R. phaseoli	*Phaseolus vulgaris*(common bean)
R. meliloti	*Medicago sativa*(alfalfa)
R. trifolii	*Melilotus*sp. (sweet clovers)
R. trifolii	*Trifolium*sp.

Source: Peoples *et al.*, 2007

N_2– Fixators

When Azolla-Anabaena inoculated to rice at field conditions showed yield increase1.5 t/ha which is 50% higher than control field.Similarly*Cyanobacteria, Azotobacter, R.leguminosarum* inoculated field showed yield increase 29%,20% and 2-22% (Table5) respectively

Table 5. Increase in rice grain yield and estimated amounts of fixed $N_2$by different N_2fixing systems

N_2– Fixators	**Increase in rice yield**		**Estimated amount of N_2**
	Amount	**(%)**	
Azolla-Anabaena	1.5 t ha^{-1}	50	48.2 kg ha^{-1}
Cyanobacteria	1.4 t ha^{-1}	29	24.2 kg ha^{-1}
Azotobactersp	0.4–0.9 t ha^{-1}	7-20	11–15 kg ha^{-1}
Rhizobium leguminosarum	0.6–7.9 g pot^{-1}	2-22	23–31 mg

Source: Ladaha ***et al.*, 2004**

Phosphorus-solubilizing microorganisms

Microorganisms solubilize P through production of low molecular weight organic acids in which hydroxyl and carboxyl groups chelate cations that are associated with complexedforms of P (Ca, Al and Fe) thus rendering phosphate soluble in both basic and acid soils and directly dissolve mineral phosphates from Al-P and Fe-P complexes as a result of anionexchange of PO_4^{3-} with acid anion. The organic acids and proton release mechanisms by microorganisms also decrease the pH in basic soils and thus solubilize P from the calcium phosphate (Ca-P).

Substantial amounts of P solubilized by some selected microbial species/strains as reported by a number of authors are presented in Table6.

Table6. Phosphorus solubilizing microorganisms

Bacteria	Fungi	Actinomycetes
Enterobacteraerogenes	*Aspergillusflavus*	
Pseudomonas cepacia	*Penicilliumradicum*	
Bacillus licheniformis	*A. Niger*	*Streptomyces*
Micrococcus spp.	*Penicillium variable*	
Enterobacterintermedium	*A. Japonicas*	

Source: Hayat *et al.*, 2007.

In a study scientist showed that *Arthrobacter*sp. solubilized P about 550 mg/L in their life time which is higher than that of *Aspergillusniger(*400 mg/L) ,*Chryseobacterium*sp.(289.8 mg/L),*Burkholderia*sp.(167.2 mg/L) and*Pantoea*sp.(479 mg/L). Substantial amounts of P solubilized by some selected microbial species/strains as reported by a number of authors are presented in Table 7.

Table7. Some amounts of P solubilized by selected species of microorganism

Mechanism	**Amount of P Solubilized (mg/L)**	**Microbial species/strains**	**References**
Production of organic acids(citric acid and lactic acid)	519.7	*Arthrobacter*sp.	Okoko*et al.*,2007
Production of organic acids	400	*Aspergillusniger*	Edwards *et al.*,2009
Production of organic acids	293	*Enterobacter cloacae*	Giller*et al.*,2012
Production organic acids (citric acid)	289.8	*Chryseobacterium*sp.	Sangingaet *al.*,2012
Production of acids;	167.2	*Burkholderia*sp.	Oppermanet *al.*,2008
Production of organic acids	479	*Pantoea*sp.	Rannaegymanet *al.*,2009

Phosphorus Mobilization

Microorganisms play critical roles in soil P dynamics including mineralization and immobilization of organic P. The positive influences of soil microorganisms are on mineralization of organic P and solubilization of P from its fixed or precipitated forms including P from rock phosphate.

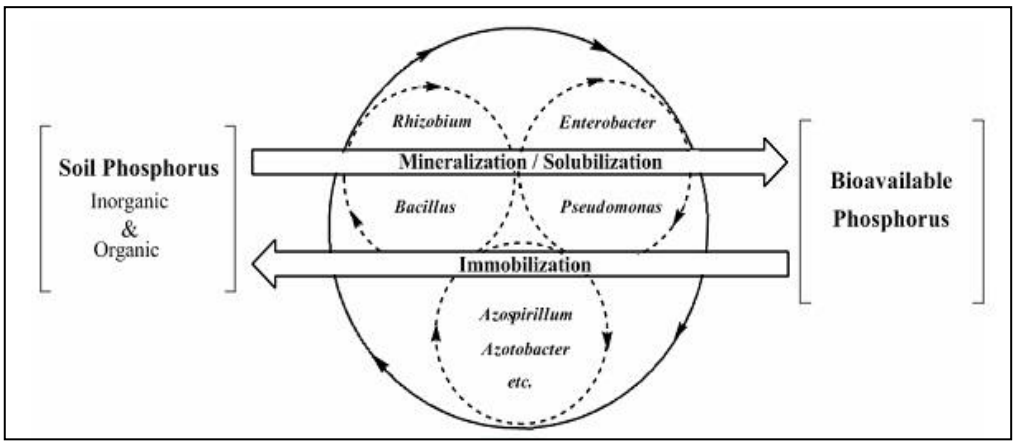

Fig2. Schematic diagram of soil phosphorus mobilization and immobilization by bacteria.**Source: Khan *et al.*, 2012.**

There are many bacteria that amass P from insoluble mineral phosphate substrates. A study showed that some bacteria such as *Bacillus polymyxa* ,*Pseudomonasstriata* ,*Bacillus circulansetc* grow on insoluble substrate(Hydroxyapatite) could amass 87,143 and 65ppm P respectively(Table8)

Table8. Total P accumulation in cultures of different bacterial species grown on insoluble mineral phosphate substrates

Bacterial strain	Substrate			Reference
	Ca3(PO4)2 (ppm)	**Hydroxyapatite (ppm)**	**Rock phosphate(ppm)**	
Bacillus polymyxa	116	87	17	Bishop *et al.*,2009
Pseudomonas striata	156	143	22	Riccio*et al.*,2008
Burkholderiacepacia	35	Nd	Nd	Suslov*et al.*,2003
Rhizobium sp.	Nd	300	Nd	Kloeppe*et al.*,2003
Rhizobium meliloti	Nd	165	Nd	Bishop *et al.*,2009
Bacillus circulans	11	65	13	Glick *et al.*,2002

Source: www.bashanfoundation.org

Effect of *Bacillus* sp. on cotton yield and plant height

Phosphate solubilizing *Bacillus* sp enhanced the seed cotton yield and plant height (Table 9). The highest seed cotton yield was produced with *Bacillus* inoculation (1733.3 kg ha-1) at 90 kg P ha-1. Bacterial inoculation produced higher seed cotton yield at all P levels compared to their general control condition. Similarly, bacterial inoculation produced also higher plant height than their usual controls. Data regarding NP content in cotton leaves was put on (Table 10). Inoculation with *Bacillus* sp produced highest N-content (1.707%) at 90 kg P ha-1. Higher N and P-content in cotton leaves was observed with inoculated treatments as compared to un-inoculated ones.

Table9. Inoculation effect of*Bacillus* sp. on seed yield and plant height of cotton

Treatments	Seed cotton Yield (kg ha^{-1})		Plant Height (cm)	
kg P ha-1	**Un-inoculated**	**Inoculated**	**Un-inoculated**	**Inoculated**
30	1377.7	1489.0	152.5	156.5
60	1544.3	1666.7	154.5	158.7
90	1611.3	1733.3	157.2	160.2

Source: Qureshi*et al.*, 2012

Table10. Inoculation effect of *Bacillus* sp. on NP **content in cotton leaves**

Treatments	N-content (%)		P-content (%)	
kg P ha-1	**Un-inoculated**	**Inoculated**	**Un-inoculated**	**Inoculated**
30	1.627	1.660	0.227	0.243
60	1.660	1.683	0.250	0.273
90	1.670	1.707	0.257	0.277

Source: Qureshi*et al.*, 2012

Inoculation with *Bacillus sp* enhanced the availability of P at every case than un-inuculated treatments.

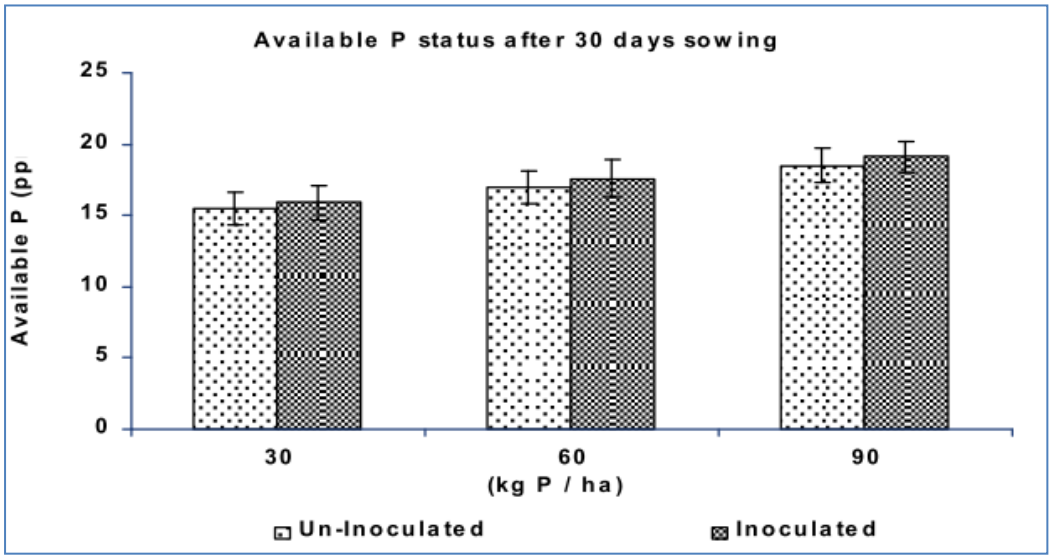

Fig3.

Available P status after 30 days of sowing cotton (inoculated with *Bacillus sp*).

Effects of PSRB and AMF inoculation on tomato plant

PSRB and AMF significantly enhanced the growth of tomato plant and increase uptake of P (Table 11).PSRB and AMF inoculation produced higher growth and P uptake compared to their general control. Inoculation with PSRB+AMFtogetherly produced highest P-content in both shoot(134.41g/plant) and root(16.7g/plant) (Table11).

Table11.Effects of *Enterobacteragglomerans* (PSRB) and *Glomus.etunicatum* (AMF) inoculation on tomato plant growth and P uptake (75 days after inoculation)

Treatment	Shoot dry weight (g per plant)	Root dry weight (g per plant)	Total P (g per plant)	
			Shoot	**Root**
Control	4221	429	11.6	2.5
PSRB	4849	510	12.5	3.2
AMF	4762	557	13.7	3.6
PSRB + AMF	54,56	6,77	27.44	16.7

Source: Kim Kim et al, 2009.

Fertility improvement by micorrhizal fungi

Mycorrhizas are refers to mutually beneficial associations of fungi with roots. Mycorrhizas are very important in the uptake of nutrients such as P, N, K, Cu, Zn and Ca by plants especially in soil where these nutrients are present in low amount. P is the most limiting

nutrient in tropical soils, mycorrhizas are very important for improving P nutrition particularly for that soil. The thin mycorrhizal hyphae are able to penetrate soil pores (Kirkby and Mengel, 2009). Studies have shown that the heavily mycorrhizal root of cassava enables it to grow well in phosphate-deficient soils where other crops fail to grow (Wild, 1993). In alkaline soils, mycorrhiza have ability to prevent iron and manganese deficiencies.

Fig4. Showing mycorrhizal association

Source: Igual,2013

Shoot dry weight enhanced when the *Cassia* plants treated with mycorrhiza at a range of soil P levels than non-mycorrhizal treatment.

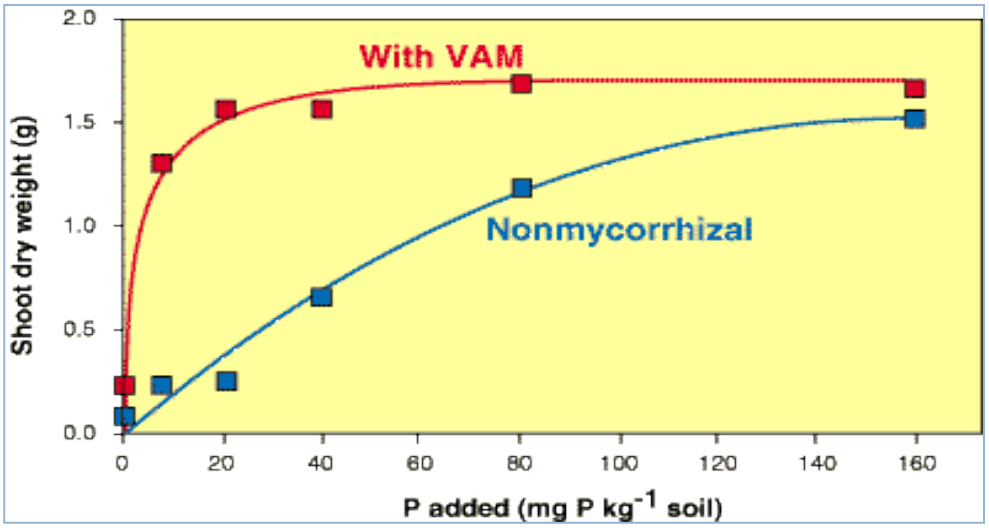

Fig5.Response curve was produced by growing mycorrhizal and nonmycorrhizal plants *Cassia* at a range of soil P levels.

Source: Sharma *et al.*, 2009

Table12. Mycorrhiza increase soil fertility by

Direct positive effects upon	Lessen negative effects from
• **Uptake of immobile nutrients** • **Drought tolerance** • **Soil macroaggregates formation and stabilization** • **Soil organic matter**	• Root pathogens • Leaching loss of nutrients • Microbial immobilization of nutrients

Source: Sharma *et al.*, 2009

A study showed that wheat plant treated with Mycorrhiza absorbed higher rate of both macro and micro nutrients than non Mycorrhizal wheat plant (Table13).

Table13. AR (µg mg-1) of macroelements (P, Ca and Mg) and microelements (Cu, Zn and Mn) in mycorrhizal (+M) and nonmycorrhizal (-M) wheat plants

AM	Macro elements			Micro elements		
	P	Ca	Mg	Zn	Cu	Mn
-M	0.47	7.10	2.22	0.026	0.013	0.047
+M	0.58	7.20	2.24	0.044	0.015	0.049

Source: Cornejo*et al.*, 2008

Scientist showed that mycorrhiza are the effective nontoxifier of soil pollutants. There are several mechanisms such Phytoextraction and Phytostabilization are used by mycorrhiza during non toxification of pollutants such as As Cd, Cu, Pb etc. (Table14).

Table14.Mycorrhiza mediated nontoxification of some inorganic pollutants in soils their mechanisms.

Pollutant	Mechanism	Reference
As	Phytoextraction	Trotta*et al.*, 2006
Cd	Phytostabilization	owska*et al.*, 2012
Cu	Phytostabilization	Cheng *et al.*, 2007
Pb	Phytostabilization	Janouskova*et al.*, 2006

Source: British Microbiology Research Journal, 3(4): 724-742, 2013

Actinomycetes

Actinomycetesare necessary for the breakdown of certain components in organic matter.*Frankia*is a genus of actinomycetes. They form nitrogen-fixing root nodules with several woody plants of different families.

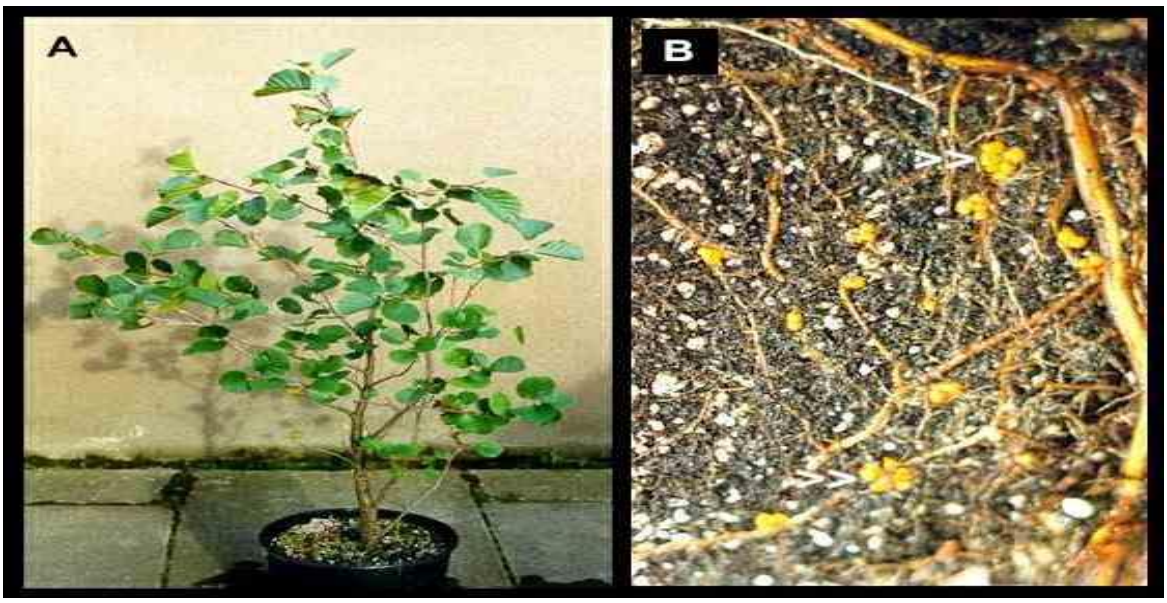

Fig6. Tree bearing the orange-yellow coloured nodules (arrowheads) containing *Frankias*

Source: Siddique., 2008

Microorganisms act as a pool of nutrients

Organic matter acts as nutrient reservoir for the plants. One of the most important pools of organic matter is the microbial biomass. The microbial biomass is a relatively available reservoir of plant nutrients such as nitrogen and phosphorus (Marumoto, 2006). Although the size of the microbial biomass is relatively small (e.g., its nitrogen content constitutes only 1 to 5 percent of the total organic nitrogen in soil), the nutrients within this pool are recycled rapidly within the soil profile, perhaps 8 to 10 times per year (Coleman, 2007). The amount of nitrogen in microbial biomass in agricultural soils ranges from 36 to 344 pounds per acre (40 to 385 kg/ha) (Paul and Vorone , 2006).

Microorganisms act as agents of change

The major groups ofsoil microorganisms are bacteria, fungi, and protozoa. Bacteria and fungi are responsible for the conversion of organic compoundsto their mineral components, a processcalled mineralization. The mineralizers includemicrobes that split complex and large

plant moleculesintosmaller molecules. Many other agriculturally important functionsare carried out by soil microorganisms. Important groups include the nitrifying bacteria (*Nitrosolobus*, *Nitrobacter*, *Nitrosomonas*) that are involved in the conversion of ammonium to nitrate. This conversion makes the nitrogen more available for plants. Mycorrhizal fungi make phosphorus more accessible to plants.

Involvement of Microorganisms in the Composting Process

Composting is a controlled decomposition of organic residues or waste to a state in which the composted material can be safely handled, stored and/or applied to land without adverse effects to the environment. It is a process that creates humus like organic materials. Composting mainly happensbecause of microbial activities. Microbes decompose organic materials through production of various extracellular enzymes such as peptidases, cellulases, hemicellulases and pectinases.(Table15) presents results of the impacts of compost use on yields of different crops inEthiopia.

Table15. Average yields by treatment with compost in kg/ha for 5 crops

Crop	Average yields (kg/ha)	
	Check	**Compost**
Barley	1115	2349
Wheat	1228	2494
Maize	1760	3748
Sorghum	1338	2497
Field pea	1527	1964

Source: Kennedy., 2012

Role of microorganisms in removing heavy metals

Microorganisms play vital roles in removing heavy metals which are harmful for plant and also for human health. They detoxify heavy metals by breaking down their bonds and convert into simpler molecules which are nontoxic both for plants and animals. They also remove toxic heavy metals by direct uptake from the soil.They uptake heavy metals upto 10-170% of their dry weight (Table16).

Table16. Microorganisms and uptake of heavy metals

Microorganisms	Elements	Uptake(% dry weight)
Citrobacter spp.	Co and Ni	25 and 13
Bacillus spp.	Cd	170
Chlorella vulgaris	Zn and Cu	15 and 14
Rhizopusarrhizus	Au	10
Aspergillusniger	Hg	58

Source: Kennedy *et al.*, 2013

Toxic pesticides degradation by microbes

A substantial decline of the residual lindane at different inoculum concentrations was observed within 0-2 weeks of incubation whereas the compound did not disappear from the uninoculated sterile control. Maximal pesticide depletion (56.0%) was observed at 4gcells Kg^{-1}soil (Table17)

Table17. Effect of inoculum size on the lindane removal by Streptomyces sp.in sterile soil samples, after 4 weeks of incubation

Inoculum size g Kg^{-1}soil	Lindane removal (%)
0.5	24.4
1.0	30.0
2.0	45.8
4.0	**56.0**

Source: Benson *et al.*, 2011

Biofertilizer and soil fertility improvement

Indiscriminate use of synthetic fertilizers has led to the pollution and contamination of the soil, has polluted water basins, destroyed microorganisms and friendly insects, making the crop more prone to diseases and reduced soil fertility.Depleting feedstock/fossil fuels (energy crisis) and increasing cost of fertilizers. This is becoming unaffordable by small and marginal farmers, depleting soil fertility due to widening gap between nutrient removal and supplies, growing concern about environmental hazards, increasing threat to sustainable agriculture. Besides above facts, the long term use of biofertilizers is economical, ecofriendly, more efficient, productive and accessible to marginal and small farmers over chemical fertilizers.

Table 18. Some commonly used biofertilizers with their active ingredient

Products	Active Ingredient	Use
ENRHIZO	*Rhizobium sp.*	Atmospheric nitrogen fixation for legumes.
ENFOSFO-P	*Bacillus polymyxa*	Converts non-available form of phosphorus to available form.
ENPOTASH	*Frateuriaaurantia*	Mobilize potash and make available to roots.
ENSULF	*Thiobacillusferrooxidans*	Enhances sulphur availability to plants.
ENZINC	*Thiobacillusthiooxidans*	Mobilize zinc and make available to roots.
ENFER	*Acidithiobacillus*	Mobilizes Ferrous in Soil

Source:Mohammadi, 2012

Seed yield increased drastically when rhizobia biofertilizer applied in the soybean field. Yield response increased as the P application increased.

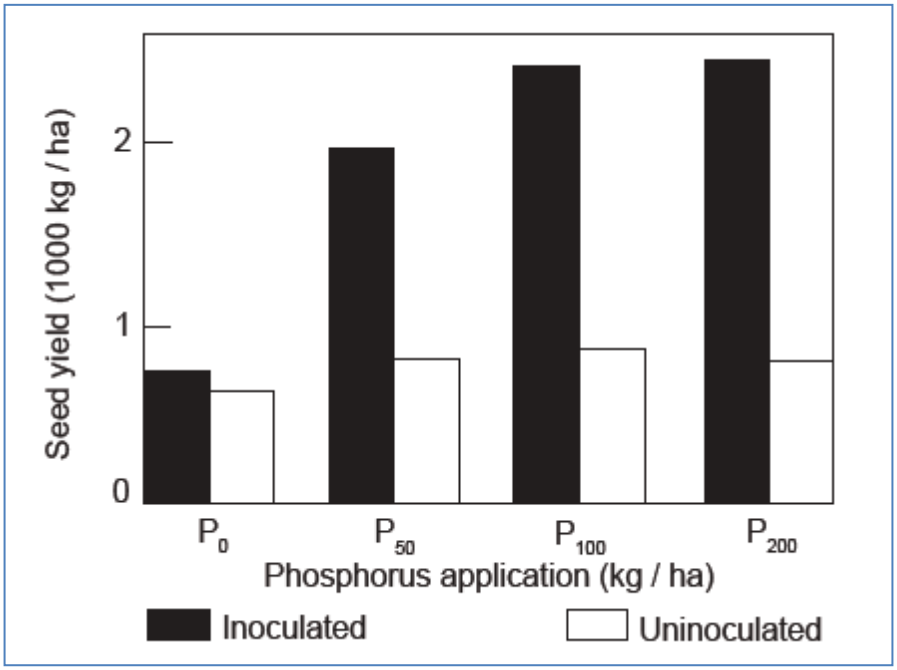

Fig7. Response of a soybean crop in Hawaii to inoculation with rhizobia biofertilizer with various levels of phosphorus fertilizer added.

Source :Uchida*et al.*,2008.

Biofertlizer Saves Chemical Fertilizer

A study conducted at Gujarat in India showed that a huge amount N and P saved when biofertilizer applied in the crop fields (Table19). 20-40 kg N/ha saved when *Azotobacterchroococcum*applied in sorghum field. The highest N (100 kg N) saved by the application of *Acetobacterdiazotrophicus*in sugarcane fields. 20-50kg P_2O_5 saved when*Bacilluscirculans* applied in the cowpea field (Table19).

Table19.Fertilizer saved when biofertilizer applied and their recommended crops

Type	Biofertilizer	Recommended Crop	Fertilizer Saving/ ha
N fixers	*Azollapinnata*(fresh)	Low land rice	30-50 kg N
	Azotobacterchroococcum	Pearl millet, sorghum	20-40 kg N
	BGA	Low land rice	30-50 kg N
	Rhizobium spp.	Pigeon pea and Chickpea	30-50 kg N
	Azospirillumlipoferum	Maize and sesame	20-40 kg N
	Acetobacterdiazotrophicus	Sugarcane	100 kg N
PSM	*Bacillus circulans*	Cow pea	20-50kg P_2O_5
	Bacillus brevis	Wheat	
	Bacillus coagulans	Sorghum	
	Torulopsoraglobosa	Maize	

Source: Basta*et al.*, 2010

Carbon Sequestration

Atmospheric carbon-di-oxide is increasing due to human sources of carbon dioxide emissions ,industrialrevolution,destroy of forest,burning of coal,gas,fossil fuel etc.So scientists are trying to invent the way of removal of extra carbon from the earth. And the carbon sequestration is the most accepted way. Plant use carbon dioxide from atmosphere for photosynthesis and emit carbon di oxide by respiration.

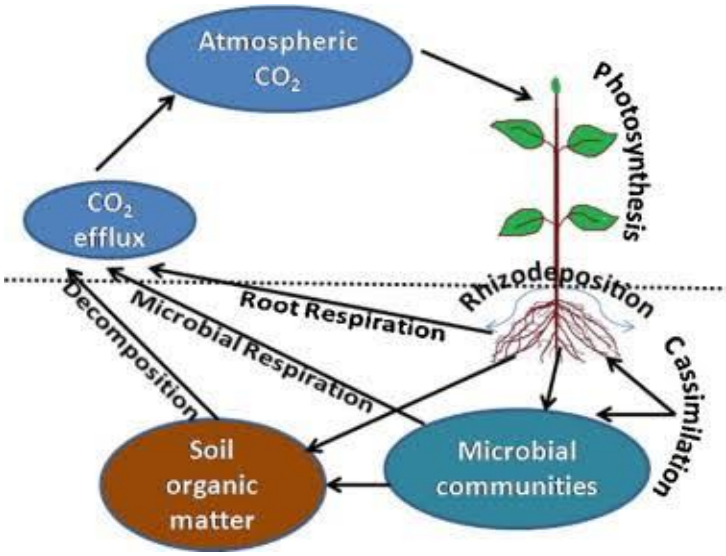

Fig8: Plant associated microorganism and carbon

When input of carbon in plant is higher than the output of carbon by plant then net carbon sequestration is occurred. In soil carbon is stored as soil organic carbon as a part of soil organic matter.

Soil carbon sequestration is a process in which carbon dioxide is removed from atmosphere and stored in the soil carbon pool.Carbon sequestration is mediated by soil microbes. Where the mcobial mass is higher, c sequestration is higher in that soil than the soil which have less microbial mass.Microbial mass is influenced by land management,plant diversity and also influenced carbon storage in soil.Soil under organic farming condition accumulate more carbon than soil under conventional farming condition,even though organically farmed soil may be tilled frequently and incorporated with more less carbon rich residues.

It also found that higher biodiversity of plants increase the root mass which is responsible for higher soil microbes. And higher soil microbes accumulate higher carbon than bare land or less vegeted area.(source;USDA-funded research at Michigan State University's Kellogg Biological Station)

Carbon Sequester Micorrhizal fungi

These fungi are associated with plant roots and getssuger from root exudation.They use sugers and help plants to uptake more water and nutrients. By eating sugersmicorrhizal fungi deposits carbon containing residues in surrounding soil. Ectomiccorhizal fungi help to store 50%- 70%carbon in soil(Averill,c,et al)

Fig9: Fruting body ectomicorrhizal fungi from genus *Amantia*

Sequester Bacteria There are some aerobic bacteria such as Knallgasbacteria(chemolithoautotrophs). As a carbon source some anaerobic bacteria and archaea(e.g., acetogenicbacteria,carbonmoxideutilizer,methanogenogens) use carbon dioxide and can fix C.

Humification

If photosynthesis is higher than the plant and microbes respiration then more carbon will get stored in humas by humification process. Humas is a stableproduct which is produced by organic matter degradation by microbes. Carbon can persist in carbon rich humas for long periods.

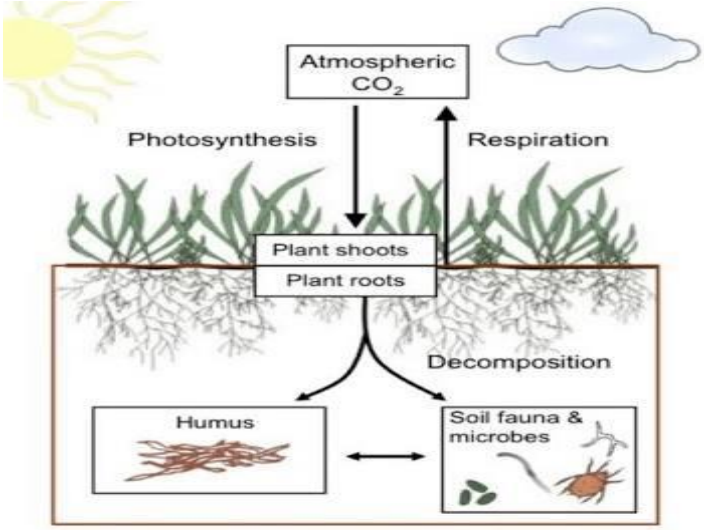

Fig10: Soil carbon storage by Humification

Challenges Faced in Exploiting Soil Microorganisms

There are a number of factors that derail maximization of beneficial microbial activities. Apart from climatic factors, there are a number of anthropogenic or social factors that affect biological functions and soil productivity. Chianu*et al.* noted the following some of the main challenges faced in exploiting beneficial activities of soil microorganisms for improving soil fertility and productivity:

- Absence or very weak institutions, policy and budgetary support for research.
- Limited knowledge of inoculation.
- Poorly developed marketing channels and infrastructure and limited involvement of the private sector in the distribution of inoculants.
- Limited farmer awareness about and access to inoculants.
- Lack of development of technology in this field.

CHAPTER IV
CONCLUSIONS

From this review it is noted that soil microorganisms have a huge contribution in soil fertility and carbon sequestration. This is achieved through a number of ways. Biological nitrogen fixation is an economically attractive and ecologically sound route for augmenting nutrient supply. The commonly reported *Rhizobium*/legume symbiosis contributes substantial amounts of biologically fixednitrogen to cropping systems and significantly benefits crops that follow in rotation. Soilmicroorganisms such as bacteria and fungi contribute to plant phosphorus nutrition throughsolubilization of fixed or precipitated phosphorus from complexes with Al and Fe in acidicsoils and calcium complexes in alkaline soils. Phosphate solubilizing rhizospheric bacteria has a high potential to be used in the management of P deficient soils.

Mycorrhizal associations are reported to contribute to plantphosphorus nutrition through increasing root surface area for soil exploration, production ofphosphorus solubilizing enzymes and organic acids. Mycorrhizal fungi and bacteria alsosolubilize other nutrients such as zinc, copper, and calcium.Microorganisms also contributeto soil fertility improvements through their roles in composting. Soil microorganisms arecurrently isolated, studied and packaged as biofertilizers and used to supplement chemicalfertilizers.The relevance of biofertilizers is increasing rapidly since chemical fertilizers (nitrogenous fertilizers) damage the environment. In contrast, biofertilizers lead to soil enrichment and are compatible with long-term sustainability. Further they are ecofriendly and pose no danger to the environmentAgain,SOC is a vital components of soil and have important on terrestrial ecosystem. From interaction amongthe dynamic ecological processes of photosynthesis,respiration,decomposition which are mediated by microbes ,net carbon are store in soil. Carbon dioxide is increased greatly by human activities,but now human activities provide an opportunity for sequestering carbon back into soil. Carbon sequestration also improve soil quality by maintaining and increasing soil organic matter adds to soil fertility, water retention and crop production. It can be noted that thorough exploitation of microbial activities can contribute tobalanced fertilization and carbon storage for long term which help in improving long term soil health.

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