Review Article

SOIL MICROBES ARE SHAPED BY SOIL PHYSICO-CHEMICAL PROPERTIES: A BRIEF REVIEW OF EXISTING LITERATURE

Abstract: Soil consists of very complex, inter-related community of microorganisms which interact with one another, and with plants and animals, forming a complex web of biological activity. The microbial community structure and functions in soil are influenced by physico-chemical properties of soils. In this review, we investigate the existing body of research exploring studies which have explored how microbes are shaped by soil properties.

Comment [LGS1]: The title does not portray the content of the review very well. I suggest changing it.

Comment [LGS2]: Very simple and non-standard abstract recommended by the magazine.

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1. Introduction

"Biodiversity"- or biological diversity- is a term used to explain the variety of life on Earth. The Convention on Biological Diversity (CBD) defined biodiversity as "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species, and of ecosystems." The diversity of the living organisms has created a support system in our biosphere, which has been used to develop and sustain all ecosystems.

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Biodiversity is mainly classified into:-

(a) Genetic Diversity : the variety in the genetic make-up among individuals within a species.

(b) Species Diversity : the variety among the species or distinct types of living organisms.

(c) Ecosystem Diversity : the variety between the ecosystems like forests, deserts, grasslands, lakes, oceans, wetlands and other biological communities.

(d) Functional diversity : the biological and chemical processes of function such as energy flow and matter cycling needed for the survival of species and the biological communities (http://www.cyen.org/innovaeditor/assets/Biodiversity_module.pdf).

The soil biodiversity refers to the mix of living organisms in the soil, which interact with one another, and with plants and animals, forming a complex web of biological activity.

Soil is a complex, inter-related community of soil organisms, which influence, yet are partially determined by the physico-chemical properties of the soil (Kennedy and Smith, 1995). Soil microorganisms play a pivotal role in various biogeochemical cycles. They also influence above-ground ecosystems by contributing to plant nutrition (Timonen *et al*., 1996), plant health (Smith and Goodman, 1999), soil structure (Wright and Upadhyaya, 1998; Dodd *et al*., 2000) and soil fertility.

Although microbial population in a soil is considered as a characteristic property, the extent and nature of it is continually subject to changes that are occurring in nature. Therefore, microbiological properties are more sensitive than soil physico-chemical properties, to changes in management and environmental conditions. Changes in the composition of soil microflora are fundamental in assessing the functional integrity of soil (Insam, 2001). Soil microbial diversity determines soil fertility, productivity, and ecological stability (Nannipieri *et al*., 2003). The idea of biodiversity and ecosystem stability being intimately connected is a core dogma of early ecosystem theory. Tilman (1982) stated that when an area is barren in terms of resource availability, it cannot sustain many species and its productivity would be low. Yachi and Loreau (1999) said that species richness enhances the performance of ecosystem, by buffering against disturbances. Hence, understanding of microbial diversity is a necessity, in an age when we are facing threats of soil degradation and soil erosion.

Comment [LGS5]: End the introduction for the purpose of review and how the sessions will be divided.

1.1 Factors influencing the occurrence and distribution of soil microflora

Some notable factors, in this study, which manipulate the soil microbial population are environment, soil nutrient status, soil pH, soil texture, rhizosphere and host plants. Their effects and influences in soil are briefly reviewed.

a. Environment

Comment [LGS6]: Include numerical data of the papers reviewed. The text is very focused on whether it had an influence or not, whether it correlated positively or negatively, providing a very superficial idea. These quantitative data can be inserted in the text, in tables and / or figures.

Climatic changes alter species distribution and affect the interactions among organisms (Wookey *et al*., 2009; Dasgupta et al., 2020). These interactions can be beneficial or antagonistic or may have little or no functional impact. The nature and extent of these interactions may change with environmental stress (Vandenkoornhuyse *et al*., 2015). Barros *et al*. (1995) studied the effect of moisture on soil microbial activity. He reported a positive correlation between the percentage humidity, total heat evolution and microbial growth rate constant, all measured by microcalometric method. Soil drying effectively reduces the substrate flow to microbial cells. With the gradual drainage of soil pores, the water films on soil surfaces become thinner, leaving a more difficult path for the substrate molecules to diffuse into cells (Olsen and Kemper, 1968). The relative importance of cytoplasmic dehydration versus diffusional limitations in controlling rates of nitrification in soil was studied by Stark and Firestone (1995). They reported decline in the activity of nitrifying bacteria at low soil water content.

An integrative measurement of microbial activity in soils is the efficiency by which microbes convert assimilated carbon into biomass carbon. It is called the microbial growth efficiency (Y). Changes in rainfall patterns and soil water content influences Y and affects nutrient cycling at ecosystem level (Six *et al*., 2006). The accumulation and decomposition of litter in soils under forests depend on climatic conditions. Rigobelo and Nahas (2004) evaluated the effect of monthly rainfall and temperature, organic matter, total organic carbon and soil moisture on total bacteria, in a *Eucalyptus*- cultivated and *Pinus*- cultivated oxisol. They reported a positive correlation of organic matter, organic carbon and soil moisture on the total bacteria and dehydrogenase activities. Besides, all parameters in *Eucalyptus* soil were higher than *Pinus* soil, most probably due to higher soil pH and fertility status.

An increase in 5°C in a temperate forest altered the relative abundances of soil bacteria and increased the bacterial-to-fungal ratio of the community (DeAngelis *et al*., 2015). It has been reported that microbially-mediated processes (like N-mineralisation), which are very conspicuous, are more tightly correlated with abiotic factors like temperature and moisture than the composition of microbial community in soil. This may be since a variety of microbes drive these processes (Hooper *et al*., 2005).

Ram *et al*. (2013) studied the seasonal variation in microbial populations at different depths of normal and sodic soils of Varanasi, and found that winter season favoured an increase in population of soil bacteria and fungi, and summer season favoured soil actinomycetes in both sodic and normal soils. Subba Rao (1982) reported higher phosphate solubilising bacterial count in soil under moist climate than under hot and dry climates in arid regions. Microbial studies related to climate change have been done in certain cases in India (Jain *et al*, 2009; Rasul, 2008), but they have not focussed on microbial diversity changes with respect to environment. Bhowmik *et al*. (2008) showed that climate affects the phyto-diversity and microbial diversity of soils in Arunachal Pradesh. Dasgupta (2016) found that soil culturable bacterial, fungal and actinomycetal populations did not significantly vary among the different agro-ecological sub-regions of West Bengal, although they did show variations in correlation patterns with soil properties from one region to another.

In general, microbial population and diversity is higher in mild and moist climate (Rangaswami and Bagyaraj, 1993) than hot and dry conditions. The direct influence of climate on microbial status is well-reviewed (Henry, 2012; Chen *et al*., 2014) but the indirect effects are less acknowledged. They have huge significance in stimulation and mediation of important ecological interactions, and it is highly essential to explore the systems and mechanisms underlying these complex interactions.

b. Soil nutrients

Comment [LGS7]: Insert quantitative data of the papers reviewed. Improve the structure of the text. Some works are only cited what they evaluated but the results of them are not reported, which leaves the reader without proper information.

Soil nutrient status is an important parameter which determines the proliferation of microbes in soil. Conversely, the microbes determine the soil nutrient status (Rangaswami and Bagyaraj, 1993). Microbial community composition, in most cases, is sensitive to the levels of nitrogen, phosphorus and potassium in soil (Allison and Martiny, 2008). It has been observed, that in unmanaged ecosystems, increasing N input suppresses the soil microorganisms (Liu and Greaver, 2010). Geisseler and Scow (2014) analysed the responses of soil microorganisms to mineral fertiliser using data from long-term fertilisation trials in cropping systems. They reported a 15 per cent increase in microbial biomass in fertiliser application trials above unfertilised control trials. Fertilisation tended to reduce microbial biomass carbon in soils with a pH below 5, but it had significantly positive effects at higher soil pH values.

The soil organic matter (SOM) is a vital component of the soil which determines the soil health due to many essential functions it provides and supports (Weil and Magdoff, 2004). Main indicators for evaluating SOM status are the soil organic carbon (≈50% of SOM), organic nitrogen and readily mineralisable C and N (Haynes *et al*., 2008). Decrease in SOM leads to decreased biodiversity and soil fertility, loss of soil structure, increased soil erosion and soil compaction (Gregorich *et al*., 1994). The soil organic carbon is a familiar and direct indicator of ecosystem performance. Most of the bacteria, fungi and actinomycetes have been shown to have positive correlation with the organic carbon content of soil (Nath and Banerjee, 1989; Ragab *et al*., 1993).

Comment [LGS8]: The SOM is very important. The ideal is to go deeper into this subject, relating all the important functions of SOM in the physical and chemical conditions of the soil with the microorganisms of the soil. I suggest inserting a sub-topic that deals only with SOM.

Swer *et al*. (2011) studied the fungal population and diversity in organically amended soils of Meghalaya. They reported significant positive correlation between fungal populations and organic carbon in organic plots. Koorem *et al*. (2014) studied how soil nutrient content influences abundance of soil microbes, in a herb-rich spruce forest. They reported that abundance of arbuscular mycorrhizal fungi was negatively related to soil phosphorus and positively influenced by soil nitrogen content.

Nutrients like calcium, magnesium and sodium are constituents of microbial cells. Das et al. (1991) stated that actinomycetes and fungi in soil showed positive correlation with available K^{+}, exchangeable Ca^{2+}, Mg^{2+} and the cation exchange capacity (CEC) of soil. Bashan and Vazquez (2000) observed that increased levels of Ca in soil had detrimental effects on *Azospirillum* in soils. Magnesium leads to increased sporulation of oligotrophic bacteria, and also counters the toxicity caused by increased levels of cadmium in soils (Wyszkowska and Wyszkowski, 2002). Markovitz and Sylvan (1961) studied the effect of sodium sulphate and magnesium sulphate on heteropolysaccharide synthesis in Gram-negative soil bacteria. Vincent (1962) studied the influence of Ca and Mg on the growth of *Rhizobium trifolii*. He reported that deficiency of Ca, in presence of Mg, caused reduction in growth rate, the level of maximum growth and the proportion of viable cells. Shortage of Mg, in presence of Ca, did not significantly affect the growth rate, but proportion of viable organisms was markedly decreased.

Comment [LGS9]: What are the results? Conclusions?

Princic *et al*. (1998) studied the effects of different ammonium concentrations on the community structure of nitrifying bacteria from wastewater. Martikainen (1985) reported that nitrifiers require sufficient Ca, Mg, P and Fe for sufficient growth. Patil *et al*. (2011) reported that increased P-application in soil leads to growth of phosphorus solubilising bacteria, in maize fields.

Comment [LGS10]: What are the results? Conclusions?

Nutrient requirement for microorganisms varies from one group to another. Heterotrophs show increased growth in organically rich soils (Dinesh *et al*., 2003). Autotrophs show less dependence on organic carbon. Increase in Mg^{2+} in soil triggers the proliferation of actinomycetes, whereas the increase in Ca^{2+} accentuates the proliferation of fungi. Small-scale resource heterogeneity is very important in determining the plant productivity, which influences the soil microbes (Day *et al*., 2003).

c. Soil pH

One of the most influential factors affecting the microbial community of soil is pH. pH strongly influences abiotic factors like carbon availability, nutrient availability and solubility of metals. Soil pH also influences biotic parameters like biomass of fungi and bacteria. Normally bacteria and actinomycetes are positively correlated with soil pH (Das *et* *al*., 1991), whereas fungi show negative correlation with soil pH (Gupta *et al*., 1980; Rousk *et al*., 2009). Rousk *et al*. (2009) reported approximately 30-fold increase in fungal importance when pH was reduced from 8.3 to 4.5. This shift in fungal and bacterial importance along pH gradient resulted in decreased carbon mineralisation.

Soil pH has been included in soil health tests to assess impacts of land use change and agricultural practices (Gil *et al*., 2009; Pattison *et al*., 2008). Many crops grow best if pH is close to neutral (pH 6.0-7.5). In acidic soils, calcium, magnesium, NO_3^--nitrogen, phosphorus, boron and molybdenum are deficient, while aluminium and manganese are abundant (often at toxic levels to plants). Phosphorus, iron, copper, zinc and boron are normally deficient in alkaline soils (Smith and Doran, 1996). Nitrification and nitrogen fixation are inhibited by low pH. Various diseases of plants are also influenced by pH (eg: potato scab caused by *Streptomyces scabies*, which is more severe in pH more than 5.2. Take-all disease of wheat, caused by *Gaeumannomyces graminis* is favoured by alkaline pH. Clubroot of mustard caused by *Plasmodiophora brassicae* is a major problem in acidic soils of pH 5.7 or lower) (Smith and Doran, 1996; Garbeva *et al*., 2004; Wharton *et al*., 2007).

Nicol *et al*. (2008) studied the influence of soil pH on the diversity, abundance and transcriptional activity of ammonia-oxidising archaea and bacteria. The community structure and phylogeny of ammonia-oxidising bacteria and archaea, across a soil pH gradient of 4.9-7.5, was determined by amplifying 16S rRNA and amoA genes followed by denaturing gradient gel electrophoresis (DGGE) and sequence analysis. Rousk *et al*. (2010) reported a doubling of bacterial diversity between pH 4 and 8. In contrast, the relative abundance of fungi was weakly related to soil pH. Martyniuk and Martyniuk (2002) reported that soil populations of *Azotobacter* spp. rarely exceed several thousand cells per gram of neutral or alkaline soils, and in acid soils (pH<6.0), these bacteria are generally absent or occur in very low numbers. *Azospirillum* spp. optimally exist in soil at pH near neutrality (Dobereiner *et al*., 1976), and drying the soil or increasing soil pH can reduce the adsorption of cells to soil particles (Bashan and Levanony, 1989). However, the growing of wheat decrease soil pH. That is because plant exudates influence the soil solution (Bashan, 1999).

Comment [LGS11]: What are the results? Conclusions?

Dancer et al. (1972) reported that in soil pH range of 4.7 to 6.6, ammonification rates did not vary appreciably, but it had significant effect on the rate of nitrification. Rate of NO_3^- accumulation decreased with decrease in soil pH. Ste-Marie and Pare´ (1999) studied soil pH effects on net nitrification on boreal forest stands. Increase in forest floor pH had a positive effect on net nitrification while acidification depressed it. Phosphorus solubilisers secrete organic and inorganic acids, which solubilise inorganic P and decrease the pH in basic soils (Stevenson, 2005).

Soil pH is a function of parent material, vegetation and climate which helps us identify trends in change for a number of soil biological and chemical functions (Dalal and Moloney, 2000).

d. Soil texture

Soil texture refers to the weight proportion, or the relative proportion, by weight percentage of sand, silt and clay. It plays a key role in carbon storage and influences nutrient retention and availability. It also governs availability for growth and important soil biological processes (Hamarashid *et al*., 2010; Jarvis, 2007; Reynolds *et al*., 2002). Hamarashid *et al*. (2010) studied the effects of soil texture on microbial populations in soils. The results obtained showed that clay loam and silty clay loam soils had the highest bacterial populations, while sandy loam and silty loam recorded the least populations. No significant differences were noticed among the total fungi values. Chau *et al.* (2011) reported that the bacterial species richness increased significantly with the coarseness of the soil. The increase in species richness in coarser soils was likely due to the increased number of isolated water films in soils with larger pores, suggesting that pore-scale hydrologic regime constrains bacterial richness in soil.

Hassink et al. (1993) reported that the percentage of mineralized organic nitrogen was higher in sandy soils than in loams and clays; this was not observed for carbon. The C/N (carbon by nitrogen) ratio of the microbial biomass was higher in sandy soils than in loams and clays and was positively correlated with the nitrogen mineralization rate per unit of microbial biomass nitrogen. This agrees with the concepts of food webs that N mineralization is positively correlated with the C/N ratio of the consumer (bacteria) for a given C/N ratio of the substrate (organic matter). Hassink (1994) reported a positive relationship between the amount of organic N in the soil and the clay + silt content. The relationship was affected by the groundwater table. There was a negative relationship between the percentage of soil N mineralizing during incubation and the clay + silt content of the soil. The amount of organic C was only positively correlated with soil texture in the soils with a high water table, but the relationship was less clear.

Carney and Matson (2005) mentioned that fine-textured soils support more microbial biomass than coarse textured soils. Heritage *et al*. (2003) stated that sandy soils cannot retain water very well and drain very quickly. Clay loam preserves water and retains soil nutrients for a longer time. This greatly influences microbial populations in soil.

e. Rhizosphere and host plants

Rhizosphere is characterised by greater microbial activity where most microflora along with their beneficial and harmful activities are present. Microbial activity is limited by the availability of carbon (Anderson and Domsch, 1978). In the rhizosphere there is a constant supply of readily available carbon sources to the heterotrophic microorganisms. As a result, microbial activity, population and biomass in the rhizosphere of plants differ markedly from non-rhizosphere soils (Cheng *et al*., 1993; Cheng *et al*., 1996).

Alphei *et al*. (1996) found that the microbial biomass in the rhizosphere of wood-barley (*Hordelymus europaeus* L.) was almost double that of non-rhizosphere samples. Microbial respiration was also found to be higher in soils near roots than in soils away from roots. Other studies revealed that nutrients added to soil were rapidly immobilised by rhizosphere bacteria with only small portions returned to soil after the carbon supply ceased (Anderson *et al*., 1978; Cole *et al*., 1978; Coleman *et al*., 1978). The constant supply of carbon compounds from plant roots fuels the complex interactions among rhizosphere organisms as well as between microorganisms and plants. Protozoa and microbial feeding nematodes are known to be the most important grazers of microflora in terrestrial ecosysyems (Bamforth, 1985; De Ruiter *et al*., 1993). Despite the crucial importance of interaction between roots (root exudates), microorganisms and their predators for plant growth, the knowledge of these interactions is still very rudimentary and poorly understood (Zwart *et al*., 1994).

Lange *et al*. (2015) showed that higher plant diversity increases rhizosphere carbon inputs into the microbial community resulting in both increased microbial activity and carbon storage. Increases in soil carbon were related to the enhanced accumulation of recently fixed carbon in high-diversity plots. They showed that that elevated carbon storage at high plant diversity is a direct function of the soil microbial community, indicating that the increase in carbon storage is mainly limited by the integration of new carbon into soil and less by the decomposition of existing soil carbon.

The plant species, plant community diversity and microbial interactions significantly impact the soil microbial communities, but the effects are not explored in detail as of yet. Increasing plant community richness significantly altered soil bacterial community composition and was negatively correlated with bacterial diversity. Concentrations of soil carbon, organic matter, nitrogen, phosphorus, and potassium were similarly negatively correlated with bacterial diversity, whereas the proportion of antagonistic bacteria was positively correlated with soil bacterial diversity (Schlatter *et al*., 2015). Host variation, among cultivars or plant genotypes, affects the level of imoact of beneficial as well as harmful microorganisms in soil. For example, *Rhizobium* sp. infects only the legumes, whereas the arbuscular mycorrhizal fungi infect a wider array of plant species (Smith and Goodman, 1999). Greater rhizosphere effect of plants was observed in bacteria than in actinomycetes and fungi (Rouatt and Katznelson, 1961). Similarly, Edward and Tripathi (1972), Shetty and Patil (1975) studied how *Azotobacter* population in soils vary with different host plants. Dobereiner and Depolli (1980) reported various *Azospirillum* species in the rhizosphere of cereals. Yahya and Al Azawi (1989) reported that soil samples of vegetable crops had highest phosphate solubilising bacteria population, followed by legumes, grasses, cereals and orchards.

Rhizosphere and host plants seen to affect the multitude of bacteria, fungi, actinomycetes, protozoa, viruses etc. in soil, and this field of soil biology needs to be explored in depth.

2. Microbial diversity as shaped by soil properties

Microbial diversity in soil exceeds that of eukaryotic organisms. One gram of soil may harbour upto 10 billion microorganisms of possibly thousands of different species (Rosello-Mora and Amann, 2001). Microbial diversity encompasses different levels of biological organisations. It includes genetic variability within taxons (species), and the number (richness) and relative abundance (evenness) of taxons and functional groups (guilds) in communities (Torsvik and Ovreas, 2002).

Tiedje *et al*. (2001), Ranjard and Richaume (2001) and Sessitsch *et al*. (2001) studied the impact of soil structure and spatial isolation on microbial diversity. Soils subjected to proper agricultural practices, show stable aggregation of microbes in micropores (Ranjard and Richaume, 2001). Particle size has a higher impact on microbial diversity and community structure than factors like pH or organic nutrient content. The type and amount of available organic substrates strongly influence the abundance of microbial groups and their functional diversities in soils (Fede *et al*., 2001; Grayston *et al*., 2001).

Smit *et al*. (2001) reported that bacterial biomass did not change significantly among seasons, but culturing and molecular fingerprinting showcased variations in community compositions. Loreau *et al*. (2001) reported that with increasing soil microbial diversity, there is a concurrent increase in productivity upto a certain level. Beyond that level, further increase in diversity results in decrease in plant production. Marcel *et al*. (1998) revealed that mycorrhizal fungal diversity determines plant biodiversity, ecosystem variability and productivity.

Reeve *et al*. (2010) investigated the role of gene frequency and diversity, measured by microarray analysis, on soil processes. Soil physical, chemical and biological analyses were conducted including functional gene microarrays (FGA). Soil physical and chemical characteristics were primarily determined by soil textural type (coarse vs. fine-textured), but biological and FGA measures were more influenced by management (organic vs. conventional). Organically managed soils consistently showed greater functional activity as well as FGA signal intensity (SI) and diversity. Overall FGA SI and diversity were correlated to total soil microbial biomass. Functional gene group SI or diversity were correlated to related soil chemical and biological measures such as microbial biomass, cellulose, dehydrogenase, ammonium, and sulphur. Management was the dominant determinant of soil biology as measured by microbial gene frequency and diversity, which paralleled measured microbial processes.

Zhou *et al*. (2002) reported that in a site richer in organic carbon, microbial communities exhibited the uniform distribution pattern regardless of soil water content and depth. The uniform distribution implies that competition does not shape the structure of these microbial communities. Studies based on mathematical modelling suggested that spatial isolation could limit competition in surface soils, thereby supporting the high diversity and a uniform community structure. Carbon resource heterogeneity may explain the uniform diversity patterns observed in the high-carbon samples even in the saturated zone.

Microbial diversity has a positive effect on the cycling of nutrients and ecosystem processes. Microbial diversity ensures that all organic compounds are recycled in the biosphere (Waldrop *et al*., 2000).

Harish Kumar (2005) studied the microbial diversity of 6 agro-climatic zones of Karnataka and calculated the Simpson index and Shannon-Wiener index of wetland, dryland and orchard ecosystem. He reported high biodiversity in dryland ecosystem of Eastern Dry Zone and wetland ecosystem in Eastern Dry Zone.

Wani *et al.* (2006) studied microbial diversity associated with Lonar soda lake in India. 16S rDNA genes were amplified by PCR using primers specific to domains Bacteria and Archaea. After RFLP analysis, 44 unique phylotypes were obtained, out of which 34% were firmicutes, 29.5% proteobacteria, 6.8% actinomycetes, 4.5% *Deinococcus thermus*, 13.3% cytophages-flavobacterium-bacteroidetes, 6.8% planctomycetes, 4.5% cyanobacteria and 2.27% spirochetes.

Ramanathan et al. (2008) studied the fungal and bacterial diversity with respect to behaviour of nutrients in the sediments of Sundarbans mangroves. *Aspergillus* and *Penicillium* were reported to be the most abundant fungal species in all the three sampling locations. The study also revealed that the existing environmental conditions plays a significant role in the proper determination of microbial diversity, as well as the behaviour of soil nutrients.

Srivastava *et al.* (2014) undertook a study with an objective to investigate the impacts of bioclimates, soil depth, cropping systems, land use systems and management practices on the distribution of culturable microbial populations in the soils of Indo-Gangetic Plains. The research spanned 11 agro-ecological sub-regions encompassing states like West Bengal, Tripura, Uttarakhand, Uttar Pradesh, Bihar, Punjab and Haryana. They reported that bacterial and fungal populations are strongly and negatively correlated with soil depth. Sub-humid (moist) bioclimatic system recorded higher microbial population than sub-humid (dry) and semi-arid bioclimatic systems. Legume-based cropping system had higher microbial population than cereal or vegetable-based cropping.

3. Conclusions:

Comment [LGS12]: For a literature review, the authors still need to score their criticisms (points that need to be improved) on the subject addressed. Should the conclusion answer your objectives, that is, according to the review carried out, which and how the physical and chemical properties in the soil influence its microbiology?

Understanding the dynamics of soil microbial communities, structure and functions, and the factors that affect those dynamics is crucial for comprehending the processes affecting soil fertility and productivity in various ecosystems. In the wake of increasing awareness regarding sustainable agriculture and development, we are realising that we can exploit soil microbes to sustain ecosystem productivity for a significant amount of time. To that end, we need to build upon our understanding of how soil microbiomes are influenced by soil properties, so that we can better judge their roles under land-use and climate change.

References:

Comment [LGS13]: Format and standardize the references according to the magazine's norm.

Allison, S. D. AND Martiny, J. B. H., 2008, Resistance, resilience, and redundancy in microbial communities. *P. Natl. Acad. Sci*., **105** : 11512-11519.

Alphei, J., Bonkowski, M. AND Scheu, S., 1996, Protozoa, Nematoda and Lumbricidae in the rhizosphere of *Hordelymus europaeus* (Poaceae): Faunal interactions, response of microorganisms and effects on plant growth. *Oecologia*, **106** : 111–126.

Anderson, J. P. E. AND Domsch, K. H., 1978, A physiological method for the quantitative measurement of microbial biomass in soils. *Soil Biol. Biochem*., **10** (3) : 215-221.

Anderson, R. V., Coleman, D. C., Cole, C. V. AND Elliott, E. T., 1978, Effect of the nematodes *Acrobeloides* sp. and *Mesodiplogaster lheritieri* on substrate utilization and nitrogen and phosphorus mineralization in soil. *Ecology*, **62** : 549–555.

Bamforth, S. S., 1985, Symposium on "Protozoan Ecology": The role of protozoa in litters and soils. *J. Eukaryot. Microbiol*., **32** (3) : 404-409.

Barros, N., Gomezorellana, I., Feijoo, S. AND Balsa, R., 1995, The effect of soil moisture on soil microbial activity studied by microcalorimetry. *Thermochim. Acta*. **249** : 161–168.

Bashan, Y. AND Levanony, H., 1989, Factors affecting adsorption of *Azospirillum brasilense* Cd to root hairs as compared with root surface of wheat. *Can. J. Microbiol*. **35** : 936-944.

Bashan, Y., 1999, Interactions of *Azospirillum* spp. in soils- a review. *Biol. Fert. Soils*, **29** : 246-256

Bashan, Y AND Vazquez, P., 2000, Effect of calcium carbonate, sand, and organic matter levels on mortality of five species of *Azospirillum* in natural and artificial bulk soils. *Biol. Fertil. Soils*, **30** : 450-459.

Bhowmik, S. N., Singh, R. K. AND Bhardwaj, R., 2008, Microbiological analysis of fermented ethnic foods of *Adi* tribe of Arunachal Pradesh and effect of refrigeration on yeast. *Proc. Nation. Sem*. Community Based Sustainable Natural Resources Management and Development in North-East India, Pasighat, Arunachal Pradesh, 26- 27th April, 2008.

Carney, K. M. AND Matson, P. A., 2005, Plant communities, soil microorganisms, and soil carbon cycling: does altering the world belowground matter to ecosystem functioning? *Ecosystems*, **8** : 928–940.

Chau, J. F., Bagtzoglou, A. C. AND Willig, M. R., 2011, The effect of soil texture on richness and diversity of bacterial communities. *Environ. Forensics*, **12** : 333-341.

Chen, S., Zou, J., Hu, Z., Chen, H. AND Lu, Y., 2014, Global annual soil respiration in relation to climate, soil properties and vegetation characteristics: summary of available data. *Agr. Forest. Meteorol*., **198** : 335-346.

Cheng, W., Coleman, D. C., Carroll, C. R. AND Hoffman, C. A., 1993, In situ measurement of root respiration and soluble carbon concentrations in the rhizosphere. *Soil Biol. Biochem*., **25** : 1189-1196.

Cheng, W., Zhang, Q., Coleman, D. C., Carroll, C. R. AND Hoffman, C. A., Is available carbon limiting microbial respiration in the rhizosphere? *Soil Biol. Biochem*., **28** (10) : 1283-1288.

Cole, C. V., Elliott, E. T., Hunt, H. W. AND Coleman, D. C., 1978, Trophic interactions in soils as they affect energy and nutrient dynamics V. phosphorus transformations. *Microb. Ecol*. **4** : 381–387.

Coleman, D. C., Anderson, R. V., Cole, C. V., Elliott, E. T., Woods, L. AND Campion, M. K., 1978, Trophic interactions in soil as they affect energy and nutrient dynamics: Flows of metabolic and biomass carbon. *Microb. Ecol*., **4** : 373- 380.

Dalal, R. C. AND Moloney, D., 2000, Sustainability indicators of soil health and biodiversity. In *Management for Sustainable Ecosystems* (Eds.: Hale, P., Petrie, A., Moloney, D. and Sattler, P.), Centre for Conservation Biology, The University of Queensland, Brisbane, pp: 101–108.

Dancer, W. S., Peterson, L. A. AND Chesters, G., 1972, Ammonification and nitrification of N as influenced by soil pH and previous N treatments. *Soil Sci. Soc. Am. J*., **37** (1) : 67-69.

Das, P. K., Nath, S. AND Banerjee, S. K., 1991, Distribution of microorganisms in soils under different forest cover at different altitudes. *Indian Agriculturist*, **35** (4) : 217-223.

Dasgupta, D., 2016, Microbial diversity analysis of selected agro-ecological sub-regions of West Bengal. *M.Sc. (Agri.) Thesis*, submitted to University of Agricultural Sciences, Bangalore.

Dasgupta, D., Brahmaprakash, G. P. AND Dey, A, 2020, Plant-microbe interactions in a changing world**.** *Food and Scientific Reports*, 1 (12): 68-71.

Day, K. J., John, E. A. AND Hutchings, M. J., 2003, The effects of spatially heterogeneous nutrient supply on yield, intensity of competition and root placement patterns in *Briza media* and *Festuca ovina*. *Funct. Ecol*. **17** : 454–463.

De Ruiter, P. C., Moore, J. C., Zwart, K. B., Bouwman, L. A., Hassink, J., Bloem, J., De Vos, J. A., Marinissen, J. C. Y., Didden, W. A. M., Lebrink, G. AND Brussaard, L., 1993, Simulation of nitrogen mineralization in the below-ground food webs of two winter wheat fields. *J. Appl. Ecol*. **30** : 95–106.

Deangelis, K. M., Pold, G., Topçuoglu, B. D., Van Diepen, L. T. A., Varney, R. M., Blanchard, J. L., Melillo, J. AND Frey, S. D., 2015, Long-term forest soil warming alters microbial communities in temperate forest soils. *Front. Microbiol*., **6** (104) : 1-13.

Dinesh, R., Ghoshal Chaudhuri, S., Ganeshamurthy, A. N. AND Dey, C., 2003, Changes in soil microbial indices and their relationships following deforestation and cultivation in wet tropical forests. *Appl. Soil Ecol*., **24** (1) : 17-26.

Döbereiner, J., Marriel, I. E. AND Nery, M., 1976, Ecological distribution of *Spirillum lipoferum* Beijerinck. *Can. J. Microbiol*., **22** : 1464-1473.

Döbereiner, J. AND Depolli, H., 1980, Diazotrophic rhizocoenosis. In *Nitrogen Fixation* (Eds.: Steward, W. D. P. and Gallon, J. R.), Acad. Press, 301-333.

Comment [LGS14]: publication date?

Dodd, J. C., Boddington, C. L., Rodriguez, A., Gonzalez-Chavez, C. AND Mansur, I., 2000, Mycelium of arbuscular mycorrhizal fungi (AMF) from different genera: form, function and detection. *Plant Soil*, **226** : 131–151.

Edward, J. C. AND Tripathi, S. C., 1972, Population densities of *Azotobacter* spp. with rhizosphere and non-rhizosphere soils of some crops during *rabi*. *Allahabad Fmr*., **46** : 49-51.

Fede, K. L. D., Panaccione, D. G. AND Sexstone, A. J., 2001, Characterization of dilution enrichment cultures obtained from size-fractionated soil bacteria by BIOLOG® community-level physiological profiles and restriction analysis of 16S rRNA genes. *Soil Biol. Biochem*., **33** : 1555-1562.

Garbeva, P., Veen J. A. V. AND Elsas J. D. V., 2004, Microbial diversity in soil: selection of microbial populations by plant and soil type and implications for disease suppressiveness. *Annu. Rev. Phytopathol*., **42** : 243–270.

Geisseler, D. AND Scow, K. M., 2014, Long-term effects of mineral fertilizers on soil microorganisms – a review. *Soil Biol. Biochem*., **75** : 54–63.

Gil, S. V., Meriles, J., Conforto, C., Figoni, G., Basanta, M., Lovera, E. AND March, G. J., 2009, Field assessment of soil biological and chemical quality in response to crop management practices. *World J. Microbiol. Biotechnol*. **25** : 439– 448.

Grayston, S. J., Griffith, G. S., Mawdsley, J. L., Campbell, C. D. AND Bardgett, R. D., 2001, Accounting for variability in soil microbial communities of temperate upland grassland ecosystems. *Soil Biol. Biochem*., **33** : 533-551.

Gregorich, E. G., Monreal, C. M., Carter, M. R., Angers, D. A. AND Ellert, B.H., 1994, Towards a minimum data set to assess soil organic matter quality in agricultural soils. *Can. J. Soil Sci*., **74** (4) : 367-385.

Grishko, V. N. AND Syshchikova, O. V., 2010, Structural and functional properties of actinomycetal communities in chernozems and saline soils of Ukraine. *Eurasian Soil Sci*., **43** (2) : 202-209.

Comment [LGS15]: I didn't see this quote in the text

Gupta, R. D., Jha, K. K., Sharma, P. K. AND Sud, R. D., 1980, Distribution of microorganisms in relation to physicochemical properties of soils of Jammu and Kashmir. *J. Indian Soc. Soil Sci*., **28** : 259-262.

Hamarashid, N. H., Othman, M. A. AND Hussain, M. H., 2010, Effects of soil texture on chemical compositions, microbial populations and carbon mineralization in soil. *Egypt. J. Exp. Biol. (Bot.)*, **6** (1) : 59-64.

Harish Kumar, D. N., 2005, Microbial diversity of different agro climatic zones of Karnataka. *M.Sc. (Agri.) Thesis*, submitted to University of Agricultural Sciences, Bangalore.

Hassink, J., Bouwman, L. A., Zwart, K. B., Bloem, J. AND Brussaard, L., 1993, Relationships between soil texture, physical protection of organic matter, soil biota, and C and N mineralization in grassland soils. *Geoderma,* **57** (2) : 105-128.

Hassink, J., 1994, Effects of soil texture and grassland management on soil organic C and N and rates of C and N mineralization. *Soil Biol. Biochem*., **26** (9) : 1221-1231.

Haynes, R. J., Swift, R. S. AND Stephen, R. C., 2008, Soil organic matter quality and the size and activity of the microbial biomass: their significance to the quality of agricultural soils.

In *Soil Mineral Microbe-Organic Interaction : Theories and Applications* (Eds.: Huang, Q., Huang, P. M. and Violante, A.), Springer, Berlin Heidelberg, pp. 201-231.

Henry, H. A. L., 2012, Soil extracellular enzyme dynamics in a changing climate. *Soil Biol. Biochem*., **47** : 53-59.

Heritage, J., Evans, E. AND Killington, R., 2003, *Microbiology in action*. Cambridge University Press.

Hooper, D. U., Chapin III, F. S., Ewel, J. J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J. H., Lodge, D. M., Loreau, M., Naeem, S., Schmid, B., Setälä, H., Symstad, A. J., Vandermeer, J. AND Wardle, D. A., 2005, Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecol. Monogr*., **75** (1) : 3-35.

Insam, H., 2001, Development in soil microbiology since mid 1960s. *Geoderma*, **100** : 389–402.

Jain, S. K., Goswami, A. AND Saraf, A. K., 2009, Assessment of snowmelt runoff using remote sensing and effect of climate change on runoff. *Water Resour. Manage*., **24** (9) : 1763-1777.

Jarvis, N. J., 2007, A review of non-equilibrium water flow and solute transport in soil macropores: principles, controlling factors and consequences for water quality. *Eur. J. Soil Sci*., **58** (3) : 523-546.

Koorem K, Gazol A, Öpik M, Moora M, Saks Ü, Uibopuu A, et al. (2014) Soil Nutrient Content Influences the Abundance of Soil Microbes but Not Plant Biomass at the Small-Scale. PLoS ONE 9(3): e91998

Lange, M., Eisenhauer, N., Sierra, C. A., Bessler, H., Engels, C., Griffiths, R. I., Mellado-Vazquez, P. G., Malik, A. A., Roy, J., Scheu, S., Steinbeiss, S., Thomson, B. C., Trumbore, S. E. AND Gleixner, G., 2015, Plant diversity increases soil microbial activity and soil carbon storage. *Nat. Comms*., http://dx.doi.org/10.1038/ncomms7707.

Liu, L. AND Greaver, T. L., 2010, A global perspective on belowground carbon dynamics under nitrogen enrichment. *Ecol. Lett*., **13** (7) : 819-828.

Loreau, M., Naeem, S., Inchausti, P., Bengtsson, J., Grime, J. P., Hector, A., Hooper, D. U., Huston, M. A., Raffaelli, D., Schmid, B., Tilman, D. AND Wardle, D. A., 2001, Biodiversity and Ecosystem Functioning: Current Knowledge and Future Challenges. *Science*, **294** (5543) : 804-808.

Kennedy, A. C. AND Smith, K. L., 1995, Soil microbial diversity and the sustainability of agricultural soils. *Plant Soil*, **170** : 75-86.

Marcel, G. A., Kliromonos, J. N., Ursic, M., Moutoglis, P., Streitwolf- Engel, R., Boller, T., Wiemken, A. AND Sanders, I. R., 1998, Mycorrhizal fungal diversity determines plant biodiversity, ecosystem variability and productivity. *Nature*, **396** : 69-72.

Markovitz, A. AND Sylvan, S., 1961, Effect of sodium sulfate and magnesium sulfate on heteropolysaccharide synthesis in gram-negative soil bacteria. *J. Bacteriol*., **83** (3) : 483-489.

Martikainen, P. J., 1985, Numbers of autotrophic nitrifiers and nitrication in fertilized forest soil. *Soil Biol. Biochem*., **17** (2) : 245-248.

Martyniuk, S. AND Martyniuk. M., 2002, Occurrence of *Azotobacter* spp. in some Polish soils. *Pol. J. Environ. Stud*., **12** : 371-374.

Mohseni, M., Norouzi, H., Hamedi, J. AND Roohi, A., 2013, Screening of antibacterial producing actinomycetes from sediments of the Caspian Sea. *Int. J. Mol. Cell. Med*., **2** (2) : 64-71.

Nannipieri, P., Ascher, J., Ceccherini, M. T., Loretta, L., Giacomo, P. AND Giancarlo, R., 2003, Microbial diversity and soil functions. *Eur. J. Soil. Sci*., **54** : 655–670.

Nath, S. AND Banerjee, S.K., 1989, Distribution of microorganisms under sub alpine forest in eastern Himalayas in relation to soil attribution. *Intern. J. Trop. Agric*., **7** : 76-84.

Nicol, G. W., Leininger, S., Schleper, C. AND Prosser, J. I., 2008, The influence of soil pH on the diversity, abundance and transcriptional activity of ammonia oxidizing archaea and bacteria. *Environ. Microbiol*., **10** (11) : 2966-2978.

Olsen, S. R. AND Kemper, W. D., 1968, Movement of nutrients to plant roots. *Adv. Agron*., **20** : 91-151.

Patil, P. M., Kuligod, V. B., Hebsur, N. S., Patil, C. R. AND Kulkarni, G. N., 2011, Effect of phosphate solubilizing fungi and phosphorus levels on growth, yield and nutrient content in maize (*Zea mays*). *Karnataka J. Agric. Sci*., **25** (1) : 58-62.

Pattison, A. B., Moody, P. W., Badcock, K. A. AND Mayer, R., 2008, Development of key soil health indicators for the Australia banana industry. *Appl. Soil Ecol*., **40** (1) : 155-164.

Princic, A., Mahne, I. I., Megusar, F., Paul, E. A. AND Tiedje, J. M., 1998, Effects of pH and oxygen and ammonium concentrations on the community structure of nitrifying bacteria from wastewater. *Appl. Environ. Microbiol*., **64** (10) : 3584- 3590.

Ragab, M., Lieth, H. AND Al-Masoom, A. A., 1993, Distribution pattern of soil microbial population in salt affected soils. *Al. Ain*, United Arab Emirates, pp. 467- 472.

Ram, R. L., Maurya, B. R. AND Sharma, P. K., 2013, Seasonal variation in microbial population at different depths of normal and sodic soils of Varanasi. *Int. J. Inno. Res. Dev*., **2** (5) : 1870-1880.

Ramanathan, A. L., Singh, G., Majumdar, J.,Samal, A. C., Chauhan, R., Ranjan, R. K., Rajkumar, K. AND Santra, S. C., 2008, A study of microbial diversity and its interaction with nutrients in the sediments of Sundarban mangroves. *Ind. J. Mar. Sci*., **37** (2) : 159-165.

Rangaswami, G. AND Bagyaraj, D. J., 1993, *Agricultural microbiology*. Prentice Hall of India Learning Private Limited, New Delhi.

Ranjard, L. AND Richaume, A., 2001, Quantitative and qualitative microscale distribution of bacteria in soil. *Res. Microbiol*., **152** (8) : 707-716.

Rasul, G., 2008, ICIMOD and the Himalayan region–responding to emerging challenges. International Centre for Integrated Mountain Development, Nepal. 1-151.

Reeve, J. R., Schadt, C. W., Carpenter-Boggs, L., Kang, S., Zhou, J. AND Reganold, J. P., 2010, Effects of soil type and farm management on soil ecological functional genes and microbial activities. *ISME J*., **4** (9) : 1099-1107.

Reynolds, W. D., Bowman, B. T., Drury, C. F., Tan, C. S. AND Lu, X., 2002, Indicators of good soil physical quality: density and storage parameters. *Geoderma*, **110** : 131-146.

Comment [LGS16]: I didn't see this quote in the text

Rigobelo, E. C. AND Nahas, E., 2004, Seasonal fluctuations of bacterial population and microbial activity in soils cultivated with *Eucalyptus* and *Pinus. Sci. Agr.*, **61** : 88-93.

Rosello-Mora, R. AND Amann, R., 2001, The species concept for prokaryotes. *FEMS Microbiol. Rev*., **25** (1) : 39-67.

Rouatt, J. W. AND Katznelson, H.,1961, A study of the bacteria on the root surface and in the rhizosphere soil of crop plants. *J. Appl. Bacteriol*., **24** : 164-171.

Rousk, J., Brookes, P. C. AND Bååth, E., 2009, Contrasting soil pH effects on fungal and bacterial growth suggests functional redundancy in carbon mineralisation. *Appl. Environ. Microbiol.*, **75** : 1589–1596.

Rousk, J., Bååth, E., Brookes, P. C., Lauber, C. L., Lozupone, C., Caporaso, J. G., Knight, R. AND Fierer, N., 2010, Soil bacterial and fungal communities across a pH gradient in an arable soil. *ISME J*., **4** : 1340-1351.

Schlatter, D. C., Bakker, M. G., Bradeen, J. M. AND Kinkel, L. L., 2015, Plant community richness and microbial interactions structure bacterial communities in soil. *Ecology*, **96** (1) : 134-142.

Sessitsch, A., Weilharter, A., Gerzabek, M. H., Kirchmann, H. AND Kandeler, E., 2001, Microbial population structures in soil particle size fractions of a long-term fertilizer field experiment. *Appl. Environ. Microbiol*., **67** : 4215–4224.

Shetty, K. S. AND Patil, R. B., 1975, Isolation of Azotobacter from rhizosphere of barley, chilli and rice. *Indian J. Microbiol*., **32** : 345-352.

Six, J., Frey, S. D., Thiet, R. K. AND Batten, K. M., 2006, Bacterial and fungal contribution to carbon sequestration in agroecosystems. *Soil Sci. Soc. Am. J.*, **70** : 555–569.

Smit, E., Leeflang, P., Gommans, S., Van Den Broek, J., Van Mil, S. AND Wernars, K., 2001, Diversity and seasonal fluctuations of the dominant members of the bacterial soil community in a wheat field as determined by cultivation and molecular methods. *Appl. Environ. Microbiol*., **67** (5) : 2284-2291.

Smith, J. L. AND Doran, J. W., 1996, Measurement and use of pH and electrical conductivity for soil quality analysis. In *Methods for assessing soil quality*. Soil Science Society of America Special Publication, **49**: 169-182.

Smith, K. P. AND Goodman, R. M., 1999, Host variation for interactions with beneficial plant-associated microbes. *Annu. Rev. Phytopathol*., **37** : 473– 491.

Srivastava, A. K., Velmourougane, K., Bhattacharyya, T., Sarkar, D., Pal, D. K., Prasad, J., Sidhu, G. S., Nair, K. M., Sahoo, A. K., Das, T. H., Singh, R. S., Srivastava, R., Sen, T. K., Chatterji, S., Chandran, P., Ray, S. K., Patil, N. G., Obireddy, G. P., Mahapatra, S. K., Anil Kumar, K. S., Das, K., Singh, A. K., Reza, S. K., Dutta, D., Mandal, C., Mandal, D. K., Srinivas, S., Tiwary, P., Karthikeyan, K., Venugopalan, M. V., Raychaudhuri, M., Kundu, D. K., Mandal, K. G., Kumar, A., Kar, G., Durge, S. L., Kamble, G. K., Gaikwad, M. S., Nimkar, A. M., Bobade, S. V., Anantwar, S. G., Patil, S., Gaikwad, K. M., Sahu, V. T., Bhondwe, H., Dohtre, S. S., Gharami, S., Khapekar, S. G., Koyal, A., Sujatha, Reddy, B. M. N., Sreekumar, P., Dutta, D. P., Gogoi, L., Parhad, V. N., Halder, A. S., Basu, R., Singh, R., Jat, B. L., Oad, D. L., Ola, N. R., Wadhai, K., Lokhande, M., Dongare, V. T., Hukare, A., Bansod, N., Kolhe, A., Khuspure, J., Kuchankar, H., Balbuddhe, D., Sheikh, S., Sunitha, B. P., Mohanty, B., Hazarika, D., Majumdar, S., Garhwal, R. S., Sahu, A., Mahapatra, S., Puspamitra, S., Gautam, N., Telpande, B. A., Nimje, A. M., Likhar, C. AND Thakre, S., 2014, Impacts of agro-climates and land use systems on culturable microbial population in soils of the Indo-Gangetic Plains, India. *Curr. Sci.*, **107** (9) : 1464-1469.

Stark, J. M. AND Firestone, M. K., 1995, Mechanisms for soil moisture effects on activity of nitrifying bacteria. *Applied Environ. Microbiol.*, **61** (1) : 218-221.

Ste-Marie, C. AND Paré, D., 1999, Soil, pH and N availability effects on net nitrification in the forest floors of a range of boreal forest stands. *Soil Biol. Biochem.*, **31** : 1579-1589.

Stevenson, F. J., 2005, *Cycles of Soil: Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients*. John Wiley and Sons, New York.

Swer, H., Dkhar, M. S. AND Kayang, H., 2011, Fungal population and diversity in organically amended agricultural soils of Meghalaya, India. *J. Org. Sys.*, **6** (2) : 3-12.

Subba Rao, N. S., 1982, Biofertilizers. *Interdisciplinary Sci. Rev.*, **7** : 220-229.

Tiedje, J., Cho, J., Murray, A., Treves, D., Xia, B. AND Zhou, J., 2001, Soil is teeming with life: New frontiers in soil science. In *Sustainable Management of Soil Organic Matter* (Eds.: Rees, R. M., Ball, B., Campbell, C. and Watson, C. A.), CAB International, Wallingford, UK, pp. 393-412.

Tilman, D., 1982, *Resource competition and community structure*. Princeton University Press, Princeton, New Jersey.

Timonen, S., Finlay, R. D., Olsson, S. AND Soderstrom, B., 1996, Dynamics of phosphorous translocation in intact ectomycorrhizal systems: non-destructive monitoring using a B-scanner. *FEMS Microbiol. Ecol.*, **19** : 171– 180.

Torsvik, V. AND Ovreas, L., 2002, Microbial diversity and function in soil: from genes to ecosystems. *Curr. Opin. Microbiol.*, **5** (3) : 240-245.

Vandenkoornhuyse, P., Quaiser, A., Duhamel, M., Van, A. L. AND Dufresne, A., 2015, The importance of the microbiome of the plant holobiont. *New Phytol.*, **206** (4) : 1996–1206.

Vincent, J. M., 1962, Influence of calcium and magnesium on the growth of *Rhizobium*. *J. Gen. Microbiol.*, **28** : 658-663.

Waldrop, M. P., Balser, T. C. AND Firestone, M. K., 2000, Linking microbial community composition to function in a tropical soil. *Soil Biol. Biochem.*, **32** : 1837- 1846.

Wani, A. A., Surakasi, V. P., Siddharth, J., Raghavan, R. G., Patole, M. S., Ranade, D. AND Shouche, Y. S., 2006, Molecular analyses of microbial diversity associated with the Lonar soda lake in India: an impact crater in a basalt area. *Res. Microbiol.*, **157** (10) : 928-937.

Weil, R. R. AND Magdoff, F., 2004, Significance of soil organic matter to soil quality and health. In *Soil organic matter in sustainable agriculture* (Eds.: Magdoff, F. and Weil, R.R.), CRC Press, Boca Raton, FL, pp. 1-43.

Wharton, P., Kirk, W., Berry, D. AND Snapp, S., 2007, Potato diseases: *Rhizoctonia* stem canker and black scurf of potato. Bulletin E-2994, Michigan State University Extension.

Wookey, P. A., Aerts, R., Bardgett, R. D., Baptist, F., Brathen, K. A., Cornelissen, J. H. C., Gough, L., Hartley, I. P., Hopkins, D. W., Lavorel, S. AND Shaver, G. R., 2009, Ecosystem feedbacks and cascade processes: understanding their role in the responses of Arctic and alpine ecosystems to environmental change. *Glob. Change Biol.*, **15** : 1153–1172.

Wright, S. F. AND Upadhyaya, A., 1998, A survey of soils for aggregate stability and glomalin, a glycoprotein produced by hyphae of arbuscular mycorrhizal fungi. *Plant Soil*, **198** : 97–107.

Wyszkowska, J. AND Wyszkowski, M., 2002, Effect of cadmium and magnesium on microbiological activity in soil. *Pol. J. Environ. Stud*., **11** (5) : 585-591.

Yachi, S. AND Loreau, M., 1999, Biodiversity and ecosystem productivity in a fluctuating environment: the insurance hypothesis. *Proc. Natl. Acad. Sci*., **96** : 1463‑1468.

Yahya, A. I. AND Al Azawi, S. K., 1989, Occurrence of phosphate solubilising bacteria in some Iraqi soils. *Plant Soil*., **117** : 135-141.

Zhou, T., Yi, C. X., Shi, P. J. AND Luo, J. Y., 2002, A feedback mechanism research on the carbon cycle and temperature of terrestrial surface system. *Geogr. Res*., **21** (1) : 45-53.

Zwart, K. B., Kuikman, P. J. and Van Veen, J. A., 1994, Rhizosphere protozoa: their significance in nutrient dynamics. In *Soil protozoa* (Ed.: Darbyshire, J. F.), Wallingford, UK: CAB International, 93–122.