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ECO-RESTORATION OF DEGRADED LANDS THROUGH MICROBIAL BIOMASS: AN ECOLOGICAL ENGINEER

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ABSTRACT

Land degradation is of concern in many countries. In restoration planning, to allow the restoration to be undertaken in a systematic way, it is essential that goals, objectives, and success criteria are clearly established. In order for timely and effective interventions to be made to reverse this degradation it is necessary to have objective measurements of ecosystem status. As the microorganisms are actively involved in litter breakdown, cycling of nutrients, formation of stable micro-aggregates and structural development so, it plays an important role in the functioning of any soil ecosystem. This review also gives brief description of soil microbes and their role in eco-restoration of degraded land.

INTRODUCTION

The Society for Ecological Restoration's [1] defines ecological restoration as follows: 'Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. The ecosystems of the earth have been continuously disturbed due to human activities [2-3]. Soil ecosystem changes with the degree of disturbance shown by figure 1. Biotic and physical environment and processes such as transfer of energy and material between organism and the physical environment characterized the ecosystem [4]. Among the physical, chemical, biological, hydrological and geological part of earth, the basic micro-counterpart i.e. microorganism plays a significant role in the terrestrial ecosystems. Microorganisms are ubiquitous in the environment that are found on the earth where there is water, hot springs on the ocean floor and deep inside rocks within the earth's crust [5-6]. Microbes act as a source and sink of nutrients and play critical role in nutrient conservation in dry tropical environment [7]. More than 40 % of the terrestrial vegetated surface of the earth has been directly disturbed and reduced natural productive capacity through overgrazing, deforestation, agriculture, overexploitation for fuel wood, urban and industrial use [8].

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In order to improve world food security and maintain environmental quality many studies have been investigated the consequences of land degradation. It is well known that land degradation decreases soil fertility as a result of loss of soil organic matter and nutrients [9-11] and reduces soil microbial biomass and activity [12-13]. Indeed, some previous studies in degraded lands from tropical regions showed decreased soil microbial biomass and activity in the short-term after slash-and-burn practices in the Eastern Amazonia [14] and Northeastern Semi Arid regions of Brazil [12]. However, restoration practices, such as improving soil properties and increasing vegetation cover, may be a promising approach for the restoration of soil productivity and sustainability [8]. Also, land restoration can alter ecosystem function by changing biological status i.e. changes in microbial biomass and organic matter decomposition [15]. However, there is little knowledge about development of soil microbial properties which was developed after starting agricultural and mechanical restoration practices like sowing of plant species and the building of terraces for water storage and avoiding soil erosion. In the USA, for instance, some restoration practices focus on the use of agricultural techniques, such as tillage and herbicide application to control exotic annuals before seeding with native perennials with strong effects on soil microbial communities [15]. In order to obtain stabilization, pollution control, visual improvement and removal of threats to human beings, restoration of a degraded land can be done by microorganisms. It involves different processes shown by figure 2.

The present chapter includes reports related with degradation of land that decreases soil microbial properties and how the restoration is done to recover soil microbial properties and their stability.

TYPE OF MICROBIAL BIOMASS AND THEIR HABITAT

The status of microbial ecosystem can be assessed through the genetic characteristics of the soil microbial community and it also gives the idea about quality of the soil and the progress of restoration after degradation [16-17]. To control the microbial community, soil organic carbon and pH were the most important factors and soil total nitrogen was a potentially important factor for soil microbial composition and function, as well as soil moisture, cation exchange capacity and physical structure to a lesser extent. The changes in vegetation, management practices and other anthropogenic activities in the process of reclamation would impose distinct impacts on the soil micro-environments in which microbes exist and that the variation in edaphic environmental conditions would be the most crucial factor affecting the soil microbial community. There are spatial and temporal variation in type of microbes and its community involved in land restoration. Figure 3 showed different type of microbes involved in the soil restoration.

Soil microbes

Micro-fauna (mites, collembolan and nematodes) recycle organic matter that is trapped in bacteria, fungi and protozoa. They create more surface area for fungi and bacteria to act upon by breaking down organic matter. It makes nutrients in more stable form and therefore the nutrients are easily available for plant uptake. Degraded lands when added with bacterial and fungal feeding nematodes can be restored in less period of time than the soil without the nematodes. The feeding material for fungi and bacteria are the dead cells from the plant roots as well as sugars, amino acids and organic acids that leaks from roots. To keep the plant roots healthy and aid them to grow faster on degraded lands, some of the microorganisms produce antibiotic compounds and hormones to recycle nutrients more rapidly. In legumes, VAM fungi supply the phosphorus required by rhizobium bacteria to fix nitrogen efficiently. Soil microbe populations are one of the important soil components.

It plays a major role in aggregate stabilization which consequently maintains suitable structural conditions for cultivation and porosity for crop growth [18]. Their activity declines when soil layers are disrupted and is slow to resume independently. Soil microbes include several bacterial species active in decomposition of plant material as well as fungal species whose symbiotic relationship with many plants facilitates uptake of nitrogen and phosphorus in exchange of carbon. They produce polysaccharides that improve soil aggregation and positively affect plant growth [19]. Sites with an active soil microbe community exhibit stable soil aggregation, whereas sites with decreased microbial activity have compacted soil and poor aggregation [20].

Bacteria

Bacteria play an important role in decomposition of organic materials, especially in the early stages of decomposition when moisture levels are high. In the later stages of decomposition fungi tend to dominate. Rhizobia are single celled bacteria, belongs to family of bacteria Rhizobiacea, form a mutually beneficial association, or symbiosis with legume plants. These bacteria take nitrogen from air (which plant cannot use) and convert it into a form of nitrogen called ammonia (NH_4^+) used by plants [21]. Free living as well as symbiotic plant growth promoting rhizo-bacteria can enhance plant growth directly by providing bioavailable P for plant uptake, fixing N for plant use, sequestering trace elements like iron for plants by siderophores, producing plant hormone like auxins, cytokinins and gibberlins, and lowering of plant ethylene levels [22-23]. When soil layers are removed and stockpiled, the bacteria inhabiting the original upper layers end up on the bottom of the pile under compacted soil. A flush of activity occurs in the new upper layer during the first year as bacteria are exposed to atmospheric oxygen. After two years of storage there is little change in the bacterial numbers at the surface, but less than one half the initial populations persist at depths below 50 cm [19].

Arbuscular Mycorrhizal Fungi

Arbuscular Mycorrhizal (AM) fungi stabilize the soil and enhance plant growth by alleviating nutrient and drought stress. Their contributions to agriculture are well-known. Usually, an evaluation of the mycorrhizal status of degraded land is recommended as a first step in rehabilitation and restoration. It contributed the restoration process by stabilizing windborne soil that settles under dense plant canopies and enhancing establishment of colonizer plants in bare soils of disturbed areas [24]. Mycorrhizal fungi strengthen soil structure in both physical and chemical manner. Physically, the hyphal network of these fungi link soil particles to each other and to plant roots. Chemically, AM fungi produce glomalin, a sticky substance that is important in soil aggregation [25]. Glomalin naturally binds soil aggregates together while still allowing water, nutrients, roots and soil fauna to move within the soil [26]. Some experiments were conducted to evaluate the importance of AM fungal inoculum for the establishment of six species of cactus under native mesquite (*P. articulata*) trees. The results suggested that AM fungal inoculum potential in these hot desert soils and it was also concluded that AM fungal inoculum density is not the primary factor for the establishment of cactus seedlings and that favorable edaphic factors probably play a more important role [27].

AM fungi are common in harsh and limiting environments because they mitigate plant stress. Their hyphae permeate large volumes of soil, interconnect the root systems of adjacent plants to facilitate exchange of nutrients between them, and contribute to soil structure. AM fungi are an essential component of plant–soil systems of deserts and have been detected worldwide. Mycorrhizal colonization apparently enhances water and nutrient uptake in dry environments for the succulent *Agave deserti* and the cacti *Ferocactus acanthodes* and *Opuntia ficus-indica*. Artificial inoculation of these plants with field-collected AM fungi increased the phosphorus content of roots and shoots compared with uninoculated plants. Lateral root hydraulic conductivity in *A. deserti* was significantly higher for inoculated plants [28].

The destruction of mycorrhizal fungal network in soil system is the vital event of soil disturbance, and its reinstallation is an essential approach of habitat restoration. Successful revegetation of severely disturbed mine lands can be achieved by using “biological tools” mycorrhizal fungi inoculated tree seedlings, shrubs, and grasses.

Rhizobacteria

In the process of land rehabilitation plant growth promoting bacteria deserve special attention as they are actively involved in plant and soil interactions. Generally, the bacteria that are plant-associated migrate from the bulk soil to the rhizosphere of living plant and aggressively colonize the rhizosphere and roots of plants (Kloepper *et al*. 1980). Rhizobacteria such as *Achromobacter, Arthrobacter, Azotobacter, Azospirillum, Bacillus, Enterobacter, Pseudomonas* and *Serratia* [29], as well as *Streptomyces* sp. have been found to have beneficial effects on various soil [30-32].

Other compounds produced by rhizobacteria that are beneficial include enzymes, osmolytes, biosurfactants, siderophores, nitric oxide, organic acids and antibiotics. These may be responsible for suppression of pathogenic and deleterious organisms [33-34], improved mineral uptake, associative nitrogen fixation [35] tolerance to abiotic stresses [36-37] or production of phytohormones [38]. Therefore, for knowing the status of rehabilitation of degraded lands, for promoting plant growth and health, extensive research efforts are to be made to explore microbial diversity, their distribution, as well as function in soils of degraded lands.

ROLE OF SOIL MICROBIAL BIOMASS IN RESTORATION OF DEGRADED LANDS

The mineral content and its physical structure are important for balanced condition of soil. In native soil the soil biota includes vast numbers of microorganisms that naturally reside in soil and perform a wide range of functions which are essential for a normal and healthy soil, whereas in a disturbed soil the micro-organism decreases in number shown in figure 4. Main role of soil microbes is to decompose organic matter and release nutrients into plant available forms. It also regulates the production and destruction of pollutant like nitrous oxides, methane, nitrates and other biologically toxic compounds [39]. It influences the weathering and solubilization of minerals and contributes to soil structure and aggregation. They also form the symbiotic associations with roots. All organisms in the biosphere depend on microbial activity because it leads to the degradation of organic materials and provide food [40]. Many anthropogenic activities like city development, agriculture, mining, use of pesticides and pollution can potentially affect soil microbial diversity.

Microbial biomass is one of the components to measure the restoration progress of the degraded areas. To assess soil development, the microbial properties such as the amount of soil microbial biomass, soil respiration rate and metabolic quotient have been used [41-43]. For various chronosequences of restored degraded soils a gradual increase of organic carbon and microbial biomass has been reported [44]. With increase in soil organic carbon and microbial biomass the functional diversity of soil microbial communities may increase that consequently increases the functionality and stability of soil ecosystems [45-47]. Role of soil microbes in the establishment of biogeochemical cycles, for energy transfer and formation of soil is well known, but standard quantitative information is lacking for optimum level of soil microbial biomass which is requisite for the soil development in the degraded areas.

The soil microbial population consisting of bacteria, fungi and microfauna (Micro means microscopic that one can’t see with naked eyes and fauna means animals) are termed as soil microbial biomass (SMB) and it is closely related to the soil organic matter (SOM) [7]. It is measured as the amount of C and N in the SMB thus the terms SMB-C and SMB-N. During decomposition the SMB assimilates complex organic substrates for energy and biomass carbon with excess inorganic nutrients being released to the soil.

Ecosystem would remain in degraded condition without the natural processes of soil development. At the early stages of ecosystem development soil act as a critical controlling component. Soils are made up of four basic components minerals, air, water and organic matter. It is a natural medium in which microbes live, multiply and die. Organic matter, mineral nutrients and microbial nutrients decrease in disturbed soil [48-50]. During restoration of degraded lands, it is necessary to establish and maintain a vegetation cover without the use of top soils or other bulky amendments [51]. To recover the fundamental functionality of the soil ecosystem it is requisite to make an effective strategy to catalyze the natural return of some of the basis for further restoration processes. The cycling of nutrients regulates the sustainability of any plant community. Without cycling, nutrients will be lost or immobilized and plant community will not be capable of regeneration. Destruction of soil properties causes reduced soil productivity. Mine spoil present very rigorous condition for both plants as well as microbial growth because of low nutrient contents, either coarse texture or compact structure [52]. A comparative study of effect of various plantations was done in coal mine spoil and was observed that microbial biomass C, N and P were highest in the plot of *Grevellia pteridifolia* as compared to *Cassia siamea* [52]. Soil functionality greatly depends on the microbial structure. But there is little known about the dynamics of microbial biomass in mine spoils and overburden dumps. An interesting and important fact is that very little is known about the functional diversity and metabolic abilities of microbial communities is spontaneously developing mine spoil [53]. Ross et al. [54] suggested that in the initial stage of the soil restoration, rate of mineralization of soil organic matter is dependent on substrate supply and the size of microbial population. The ratios of microbial biomass C: total C [55] and respiration: microbial C [56] has been proposed as measures of the success of reclamation efforts [54]. Smith and Paul [57] concluded that monitoring of changes in ratios of fungi to bacteria and in species diversity, biomass estimation could be a powerful method of prediction. Moussa et al. [58] suggested that low vegetation abundance and the poor condition (degradation) was the prime determinant of the low soil microbial biomass. Same thing was concluded by Barbhuiya *et al*. [59] that the soil microbial biomass and its activities are dependent on the quality, quantity and turnover of detrital organic matter in the forest floor. Soil microbial biomass is a potential source of plant nutrients, and higher level of soil microbial biomass is an indicator of soil fertility.

MEASUREMENT OF RESTORATION SUCCESS

The measurement of ecological processes is not so easy it is evaluated by the presence of mycorrhizae or nutrient pools. Mycorrhizae colonization can significantly affect plant growth and patterns of succession after a disturbance [60]. The evaluation of restoration studies will be improved by measuring mycorrhizae and nutrient cycling (e.g., decomposition, mineralization, immobilization, or soil organic matter turnover). The main objective of restoration is to create a self-supporting ecosystem that is flexible to any perturbation [1]. By measuring the soil microbial community, the degradation process and restoration success can be assessed. The size, composition and activity of the soil microbial community convincingly distinguish between systems, and between the impacts of management strategies. Measurements of the soil microbial community may certainly be used to determine biodiversity, ecological processes and structures [61]. For determining the success of a restoration scheme, there are two main approaches first one is return to conditions that approximate a target or reference ecosystem and second one is maximization of efficiency of the ecosystem with respect to its function.

For measuring restoration success, the Society of Ecological Restoration International [1] produced a primer that provides a list of nine ecosystem attributes as a guideline. A restored ecosystem should have the following attributes: (1) similar diversity and community structure in comparison with reference sites (2) presence of indigenous species (3) presence of functional groups necessary for long-term stability (4) capacity of the physical environment to sustain reproducing populations (5) normal functioning (6) integration with the landscape (7) elimination of potential threats (8) resilience to natural disturbances and (9) self-sustainability. An excellent assessment of restoration success could be done by measuring these attributes.

Soil organic carbon is simultaneously a source and sinks for nutrients and plays a vital role in soil fertility maintenance. Soil microbial biomass can be a useful indicator of soil quality and could possibly serve as assessment criteria of successful rehabilitation of ecologically disturbed areas.

For example, the study site Maldeota, is located in Doon valley was 26 year old restored mined area having plantation of *Acacia catechu* and *Dalbergia sissoo* while adjacent natural forest area contains dominant tree species of *Cassia fistula*, *Bauhinia vareigata* and *Flacourtia cataphracta* respectively. Results indicated the recovery of soil quality after restoration as the microbial biomass in the restored area was found to be greater as compared to the natural forest.

Vance and Entry [62] sought appropriate soil measurements to track the success of restoration on barren land and adjacent Shasta red fir forest in the Siskyou Mountains, Oregon. They found that enzyme activity was a better indicator than microbial biomass in this respect, and that it reflected the accumulation of organic matter well.

An interesting technique for combining activity with diversity measurement has been devised and employed by Yin et al. [63]. The authors took soil samples along a transect on the Jamari tin mine site in the Jamari National Forest, Brazil, from bare minespoil through restored and recovering land to undisturbed forest. They then amended subsamples with individual carbon substrates (L-serine, L-threonine, sodium citrate, and lactose hydrate) in the presence of bromodeoxyuridine (BrdU), which would become incorporated into bacterial DNA as a result of metabolizing the added carbon.

This enabled them to identify what proportion of the bacterial biomass had been actively involved in the metabolism of the added substrates, and therefore to obtain an index of functional redundancy. They demonstrated clearly that bacterial functional redundancy increased as they went from disturbed to undisturbed land, and that this increase could be related to the re-establishment of plant species. Microbial community composition can also be analysed by estimating Phospholipid fatty acid (PLFA). The types and amounts of different PLFAs extracted from samples reflect both taxonomic and functional diversity. Peacock et al. [64] used PLFA analysis on five sites: light disturbance (infantry training); moderate disturbance (areas adjacent to tracked vehicle training); heavy disturbance (tracked vehicle training); remediated (previously heavily used, now planted with trees, and unused); and an unused reference area to show the effects of disturbance due to military vehicles at Fort Benning, Georgia, It was concluded that amount of PFLA was significantly smaller for the heavily disturbed area than the remediated area. There was great variation in the value of PFLAs for disturbed and remediated areas compared with the reference area. Peacock and co-workers further show that increased disturbance caused decreases in those PLFAs associated with Gram negative bacteria and micro-eukaryotes, but increases in relative proportions of Gram-positive bacterial and actinomycete biomarkers.

Figure 1. **Effect of different degree of disturbance on soil ecosystem [65]**

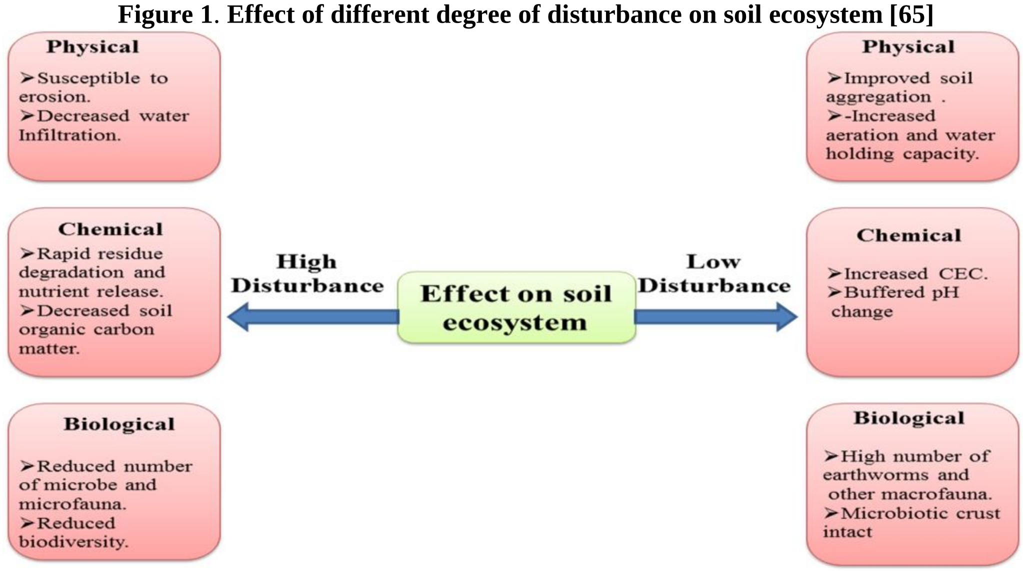


Figure 2. Schematic diagram to show the processes involved in soil restoration.

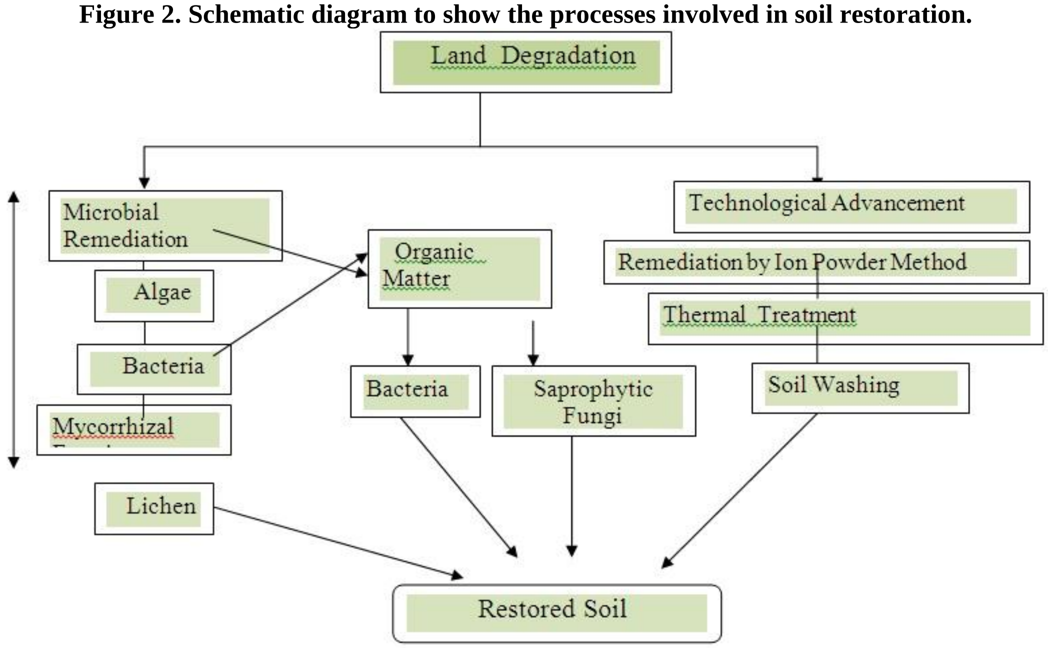
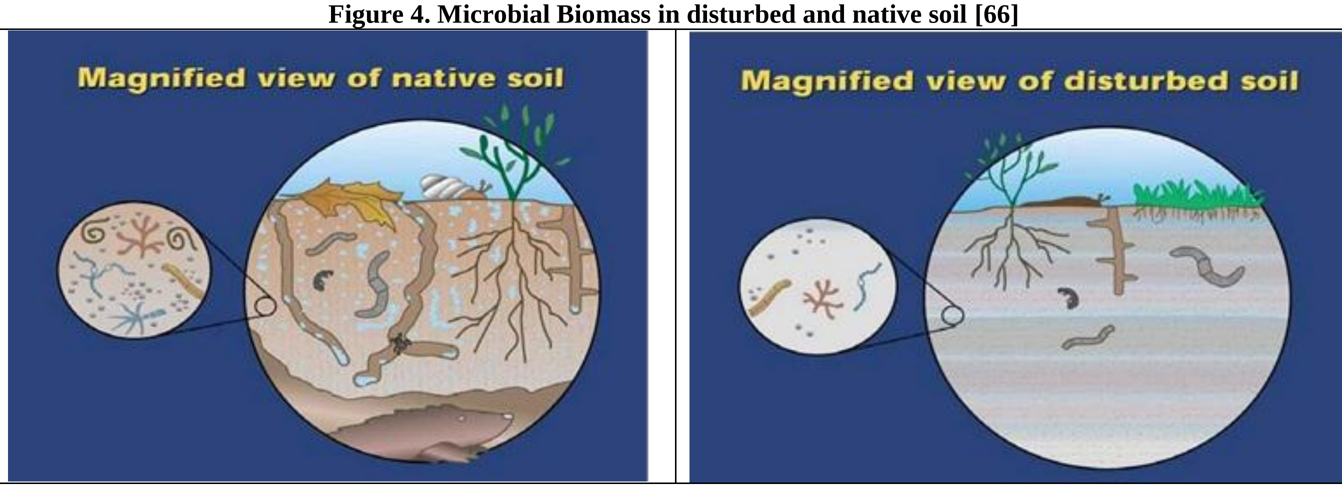


Figure 3. Different Microorganism involved in soil restoration.(AM: Arbuscular miccorrhiza.: PGPB: Plant growth Promoting Bacteria: PGPR: Plant growth promoting rhizzobacteria)

Figure 4. Microbial Biomass in disturbed and native soil [66]



CONCLUSION

Soil microbes play an important role in many critical ecosystem processes, but little is known about the effects of land reclamation. A fundamental shift is taking place worldwide in agricultural practices and food production. In the past, the principal driving force was to increase the yield potential of food crops and their productivity. Today, the drive for productivity is increasingly combined with the desire and even the demand for sustainability. Sustainable agriculture involves successful management of agricultural resources to satisfy human needs while maintaining environmental quality and conserving natural resources for future. Improvement in agricultural sustainability requires the optimal use and management of soil fertility and its physico-chemical properties. Both rely on soil biological process and soil biodiversity. This implies management practices that enhance soil biological activity and thereby buildup long term soil productivity and crop health. Such practices are of major concern in marginal lands to avoid degradation and in restoration of degraded lands at regions, where high external input agriculture is not feasible.

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