MEANING OF SOIL BIOLOGICAL QUALITY AND METHODS OF CHARACTERIZING DEMONSTRATIONS

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The sustainability of the earth's land and water resources is dependent upon maintaining the health of living biota that provide critical inputs into the ecosystem services that support these resources. A vast assemblage of organisms naturally resides in the soil and performs a wide range of functions, which are essential for a normal healthy soil. Soil microorganisms for example decompose organic matter, release nutrients into plant-available forms, and degrade toxic residues. They also form symbiotic associations with roots (facilitating nitrogen fixation or phosphate uptake), act as antagonistic to pathogens, influence the weathering and solubilization of minerals, and contribute to the maintenance of soil structure. (Lee and Pinehurst, 1992; Pankhurst and Lynch, 1995). Larger soil organisms such as earthworms contribute to the soil health through bioturbation and communition of organic residues into the soil.

The role of soil organisms in mediating soil processes, together with their relatively high rate of turnover and sensitivity to perturbations, logically suggests that they have the potential to be utilized as sensitive indicators and early predicators of changing soil quality / health (Pankhurst *et al.,* 1997a; Gregorich *et al*., 1997). Measurable biological indices should therefore be considered as a component of any assessment of soil quality.

Main issues concerning the use of bio-indicators of soil quality

A large number of soil biological properties have been evaluated for their potential use as indicators of soil quality / health (Doran and Parkin, 1994; Pankhurst *et al.,* 1995; Gregorich *et al.,* 1997). Whilst all have their merits, it is simply not practicable to measure suggested indices. Interpretation of the data generated and the definition of standards and sampling protocols remain issues associated with the use of all potential biological indicators. This also to many of the chemical or physical indicators of soil quality. For example, virtually all proposed minimum data sets of soil quality indicators include a measure of soil organic matter (Gregorich *et al.,* 1994). However, soil vary widely in their organic C content and because it may take several decades before a changing in organic C level of a soil is detectable following a change in land management practice, it is very difficult to state (a) what is a 'normal' organic matter level, (b) what are the critical 'threshold' levels in organic C for a particular soil, (c) What level of organic C constitutes good or bad soil quality, and (d) what is an acceptable equilibrium level of organic C under a given land use. These issues need to be addressed before any kind of soil quality indicators can be used in a way that is meaningful for land managers.

An approach to assessing soil biological quality that is relevant to the National Land and Water Resources Audit

To be relevant to the National Land and Water Resources Audit, a quantitative approach to the assessment of soil biological quality is needed. One such approach has been advocated recently by Sparkling (1997) and Schipper and Sparling (1997). The approach is based on combining measures of organic matter, microbial biomass (a measures of living microbial weight (mass of a soil) and microbial activity (soil respiration). This provides a simple and convenient way of determining whether or not the soil is in balance with respect to its available resources (organic matter) and its microbial biomass.

Whilst soil organic C, microbial biomass and respiration are all recognized as important indicators of biological change in soil, there is as yet no absolute values on which to define quality over a range of soil types and ecosystems. However, by combining these parameters and making use of ratios rather than absolute values it is possible to make comparisons between soils of different types, and from different land use and geographical areas. Research carried out by Schipper and Sparling (1997) on a series of New Zealand soils has shown a strong relationship between the available carbon resources in the soil, depicted as the ratio of repairable carbon: total carbon, and the microbial biomass. This relationship, described as a soil biological quality scale, indicates that the biomass supported in a soil is dependent on the availability of carbon and the size of the total resource from which the available carbon is derived.

A limitation to this approach to quantification of soil biological quality is how and where to define the threshold points. The graphical display will differentiate soils into a 'low' or 'high' zone, but the issue of where to draw any dividing line remains. A soil in the 'low'zone is not necessarily of poor quality as this will depend on what the soil is being used for-a decision made by society. It is likely that some of the very nutrient-poor, low-productivity ecosystems (eg.sand dune communities, or an old stand of eucalyptus forest) would fall in the 'low' zone, and could be considered to have good soil quality for reserve or habitat conservation, but poor soil quality if the land use is changed to crop production. A major advantage of the approach is that it requires relatively little data; the methods for obtaining the data are relatively simple, and cost effective, and are recognized internationally. The method of expressing the data seems applicable to a wide range of ecosystems, soils, and land uses. The approach readily separates similar land uses and groups together similar land uses, even when they occur on different soil types.

Ecosystem Services:

An ecosystem is a community of animals and plants interacting with one another and with their physical environment. Ecosystems include physical and chemical components, such as soils, water, and nutrients that support the organisms living within them. These organisms may range from large animals and plants to microscopic bacteria. Ecosystems include the interaction among all organisms in a given habitat. People are part of ecosystems. The health and well being of human populations depends upon the services provided by ecosystems and their components-organisms, soil, water, and nutrients.

Ecosystem Services are the processes by which the environment produces resources that we often take for granted such as clean water, timber, and habitat for fisheries, and pollination of native and agricultural plants. Whether we find ourselves in the city or a rural area, the ecosystems in which humans live provide goods and services that are very familiar to us.

Ecosystems provide"services" that:

- Moderate weather extremes and their impacts
- Disperse seeds

- Mitigate drought and floods
- Protect people from the sun's harmful ultraviolet rays
- Cycle and move nutrients
- Protect stream and river channels and coastal shores from erosion
- Detoxify and decompose wastes
- Control agricultural pests
- Maintain biodiversity
- Generate and preserve soils and renew their fertility
- Contribute to climate stability
- Purify the air and water
- Regulate disease carrying organisms
- Pollinate crops and natural vegetation

Nutrient Cycling & Maintaining Soil Fertility:

Essential plant nutrients:

There are at least 16 essential chemical elements for plant growth. Carbon (C), hydrogen (H), and oxygen (O), obtained from air and water, frequently are not included as '*nutrient*' elements. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), and chlorine (Cl) are obtained from the soil and required by all plants. Sodium (Na), silicon (Si), and nickel (Ni) are essential elements for some plant species and, although not required, have positive or *beneficial* effects on the growth of other species. Cobalt (Co) is essential for nitrogen fixation by legumes. Additional elements, such as selenium (Se), arsenic (As), and iodine (I) are not required by plants, but can be important in plant nutrition since they are essential nutrients for humans and other animals that consume plants. All essential nutrients are equally important for healthy plant growth, but there are large differences in the amounts required. N, P, and K are *primary macronutrients* with crop requirements generally in the range of 50-150 lb. per acre. Ca, Mg, and S are *secondary macronutrients*, required in amounts of 10-50 lb. per acre. *Micronutrient* requirements (Fe, Mn, Zn, Cu, B, Mo, and Cl) are generally less than 1 lb. per acre.

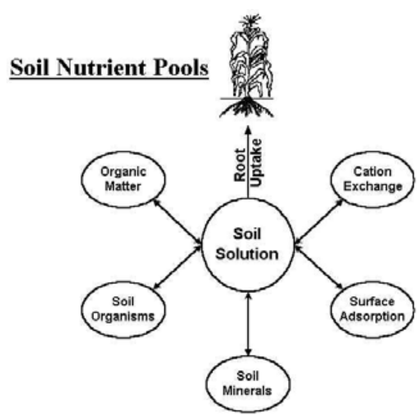
Nutrient Cycling:

Sources of plant nutrients in the soil: Plants through root uptake from the soil solution obtain mineral nutrients. Sources of these soluble nutrients in the soil include: 1) Weathering of soil minerals, 2) decomposition of plant residues, animal remains, and soil microorganisms, 3) application of fertilizers and liming materials, 4) application of manures, composts, biosolids (sewage sludge) and other organic amendments, 5) N-fixation by legumes, 6) ground rock powders or dusts including greensand, basalt, and rock phosphate, 7) inorganic industrial byproducts, 8) atmospheric deposition, such as N and S from acid rain or N-fixation by lightning discharges, and 9) deposition of nutrient-rich sediment from erosion and flooding.

Losses of plant nutrients from the soil: Mineral nutrients also can be lost from the soil system and become unavailable for plant uptake. Nutrient losses are not only costly and wasteful, but they can be a source of environmental contamination when they reach lakes, rivers, and groundwater. Nutrient losses occur through: 1) *Runoff* - loss of dissolved nutrients in water moving across the soil surface, 2) *Erosion* - loss of nutrients in or attached to soil particles that are removed from fields by wind or water movement, 3) *Leaching* - loss of dissolved nutrients in water that moves down through the soil to groundwater *or* out of the field through drain lines, 4) *Gaseous losses* to the atmosphere - primarily losses of different N forms through volatilization and identification, and 5) *Crop removal* - plant uptake and removal of nutrients from the field in harvested products.

Nutrient pools in the soil: In addition to the variety of inputs and outputs, plant nutrients exist in many different forms or 'nutrient pools' within the soil. These pools range from soluble, readily available forms, to weakly bound forms that are in rapid equilibrium with soluble pools, to strongly bound or precipitated forms that are very insoluble and become available only over long time periods. Plant roots can take up nutrients in solution immediately, but they also move with water and can easily leach below the plant root zone or be lost from farm fields. The ideal fertile soil has high nutrient concentrations in the soil solution when crop growth rates are high, but a large storage capacity to retain nutrients when crop needs are low or there is no growing crop.

Exchangeable cations are a short-term storage pool that can rapidly replenish nutrient ions in the soil solution. Soil organic matter releases nutrients slowly as it decomposes, but is an important supply of N, P, S, and micronutrients. Soil minerals and precipitates vary from fairly soluble types (carbonates, sulfates, chlorides) in equilibrium with the soil solution to rather insoluble forms (feldspars, apatite, mica) that release nutrients through reactions with chemical agents such as organic acids. Adsorbed anions, such as phosphate and iron oxides bound to clay and organic matter surfaces, are held strongly and released very slowly, but can contribute to the long-term supply of plant-available nutrients.



Cation exchange capacity (CEC): Clay particles and organic matter have negatively charged sites that hold positively charged ions on their surfaces. CEC protects soluble ions from leaching and loss from the plant root zone. These ions are rapidly exchangeable with other soluble ions, however, so when root uptake depletes the nutrient supply they replenish plant-available cations in the soil solution. Cation exchange is a major source of nutrients like K^+, Ca^{2+}, and Mg^{2+}, as well as NH_4^+ and micronutrient trace metals like Zn^{2+}, Mn^{2+}, and Cu^{2+}.

Organic matter: Soil organic matter is a very important factor in soil fertility. It is a reservoir of plant nutrients, has a high CEC, buffers the soil against pH changes, and chelates micronutrients. Organic matter exists in different forms in the soil, ranging from living soil organisms to fresh, readily decomposed plant residues to humus that is very stable and resistant to further degradation. The recycling of plant nutrients through soil organic matter supplies a significant portion of a growing crop's nutrient needs. Stable humus is the organic matter fraction that has a high CEC. Cation exchange helps soils resist changes in pH in addition to retaining plant nutrients. Chelation is the ability of soluble organic compounds to form complexes with micronutrient metals that keep them in solution and available for uptake.

Nutrient cycles: Soil fertility is maintained when nutrients are efficiently recycled through the soil food web and the soil-plant-animal system.

Basic Plant Nutrient Cycle: The basic nutrient cycle highlights the central role of soil organic matter. Cycling of many plant nutrients, especially N, P, S, and micronutrients, closely follows the Carbon Cycle. Plant residues and manure from animals that are fed forage, grain, and other plant-derived foods are returned to the soil. This organic matter pool of carbon compounds becomes food for bacteria, fungi, and other decomposers. As organic matter is broken down to simpler compounds, plant nutrients are released in available forms for root uptake and the cycle begins again. Plant-available nutrients such as K, Ca, Mg, P, and trace metal micronutrients are also released when soil minerals dissolve.

Nitrogen Cycle: The nitrogen cycle is the biogeochemical cycle that describes the transformations of nitrogen and nitrogen-containing compounds in nature. The nitrogen cycle is a much more complicated biogeochemical cycle but also cycles through living parts and nonliving parts including the water, land, and air. Nitrogen is a very important element in that it is part of both proteins, present in the composition of the amino acids that make up proteins, as well as nucleic acids such as DNA and RNA, present in nitrogenous bases. The largest reservoir of nitrogen is the atmosphere, in which about 78% of nitrogen is contained as nitrogen gas (N_2). Nitrogen gas is "fixed," in a process called nitrogen fixation. Nitrogen fixation combines nitrogen with oxygen to create nitrates (NO_3).

Nitrates can then be used by plants or animals (which eat plants or eat animals that have eaten plants). Nitrogen can be fixed either by lightning, industrial methods (such as for fertilizer), in free nitrogen-fixing bacteria in the soil, as well as in nitrogen-fixing bacteria present in roots of legumes (such as rhizobium). Nitrogen-fixing bacteria use certain enzymes that are capable of fixing nitrogen gas into nitrates and include free bacteria in soil, symbiotic bacteria in legumes, and also cyanobacteria, or blue-green algae, in water.

After being used by plants and animals, nitrogen is then disposed of in decay and wastes. Detritivores and decomposers decompose the detritius from plants and animals, nitrogen is changed into ammonia, or nitrogen with 3 hydrogen atoms (NH_3). Ammonia is toxic and cannot be used by plants or animals, but nitrite bacteria present in the soil can take ammonia and turn it into nitrite, nitrogen with two oxygen atoms (NO_2). Although nitrite is also unusable by most plants and animals, nitrate bacteria changes nitrites back into nitrates, usable by plants and animals. Some nitrates are also converted back into nitrogen gas through the process of denitrification, which is the opposite of nitrogen-fixing, also called nitrification. Certain denitrifying bacteria are responsible for this.

Phosphorus cycle: The phosphorus cycle is the biogeochemical cycle that describes the movement of phosphorus through the lithosphere, hydrosphere, and biosphere. Unlike many other biogeochemicals, the atmosphere does not play a significant role in the movements of phosphorus, because phosphorus and phosphorus-based compounds are usually solids at the typical ranges of temperature and pressure found on Earth. Phosphorus normally occurs in nature as part of a phosphate ion, consisting of a phosphorus atom and some number of oxygen atoms, the most abundant form (called ***orthophosphate***) having four oxygens: PO_4^{3-}. Most phosphates are found as salts in rocks. The plants may then be consumed by herbivores who in turn may be consumed by carnivores. After death, the animal or plant decays, and the phosphates are returned to the soil. Runoff may carry them back to the ocean or they may be reincorporated into rock. The primary biological importance of phosphates is as a component of nucleotides, which serve as energy storage within cells (ATP) or when linked together, form the nucleic acids DNA and RNA. Phosphorus is also found in bones, whose strength is derived from calcium phosphate, and in phospholipids (found in all biological membranes). Phosphates move quickly through plants and animals.

Sulfur cycle: Sulfur is one of the constituents of many proteins, vitamins and hormones. It recycles as in other biogeochemical cycles. The essential steps of the sulfur cycle are:

- Mineralization of organic sulfur to the inorganic form, hydrogen sulfide: (H_2S).
- Oxidation of sulfide and elemental sulfur (S) and related compounds to sulfate (SO_4^{2-}).
- Reduction of sulfate to sulfide.
- Microbial immobilization of the sulfur compounds and subsequent incorporation into the organic form of sulfur.

Human impact on the sulfur cycle is primarily in the production of sulfur dioxide (SO_2) from industry (e.g. burning coal) and the internal combustion engine. Sulfur dioxide can precipitate onto surfaces where it can be oxidized to sulfate in the soil (it is also toxic to some plants), reduced to sulfide in the atmosphere, or oxidized to sulfate in the atmosphere as sulfuric acid, a principal component of acid rain.

Maintaining Soil Fertility:

Management practices to maximize nutrient cycling & nutrient-use efficiency: Nutrient management is defined as the efficient use of all nutrient sources and the primary challenges in sustaining soil fertility are to: 1) Reduce nutrient losses, 2) Maintain or increase nutrient storage capacity, and 3) Promote the recycling of plant nutrients. In addition, cultural practices that support the development of healthy, vigorous root systems result in efficient uptake and use of available nutrients. Many management practices help accomplish these goals, including establishing diverse *crop rotations*, growing *cover crops*, reducing *tillage*, managing & maintaining *crop residue*, handling *manure* as a valuable nutrient source, *composting* & using all available wastes, *liming* to maintain soil pH, applying supplemental *fertilizers*, and routine *soil testing*. These beneficial cultural practices have multiple effects on the soil fertility factors described above, which makes it important to integrate their use and examine their effects on the complete soil-crop system rather than just a single component of that system.

Crop rotations: Growing a variety of crops in sequence has many positive effects. In a diverse rotation, deep-rooted crops alternate with shallower, fibrous-rooted species to bring up nutrients from deeper in the soil. This captures nutrients that might otherwise be lost from the system. Including sod crops in rotation with row crops decreases nutrient losses from runoff and erosion and increases soil organic matter. Growing legumes to fix atmospheric N reduces the need for purchased fertilizer and increases the supply of N stored in soil organic matter for future crops. Biologically fixed N is used most efficiently in rotations where legumes are followed by crops with high N requirements. Rotating crops also increases soil biodiversity by supplying different residue types and food sources, reduces the buildup and carryover of soil-borne disease organisms, and creates growing conditions for healthy, well-developed crop root systems.

Cover crops: Growing cover crops can be viewed as an extension of crop rotation and provides many of the same benefits. Growing legume cover crops adds biologically fixed N. The additional plant diversity with cover crops stimulates a greater variety of soil microorganisms, enhances carbon and nutrient cycling, and promotes root health. The soil surface is covered for a longer period of time during the year, so nutrient losses from runoff and erosion are reduced. This longer period of plant growth substantially increases the capture of solar energy and the amount of plant biomass produced, which in turn increases organic matter additions to the soil. This organic matter is a pool of stored energy in the soil, in addition to a nutrient storage pool, and is the food and energy source for soil organisms. If you look at a farming system as an '*ecosystem*', and measure the health or productivity of that ecosystem by its harvest of solar energy, then cover crops increase the health of farming systems by increasing the flow of energy and productive capacity through them.

The extended growth period obtained with cover crops also extends the duration of root activity and the ability of root-exuded compounds to release insoluble soil nutrients. A winter cover crop traps excess soluble nutrients not used by the previous crop, prevents them from leaching, and stores them for release during the next growing season. Cover crops can also suppress weeds which otherwise would compete with crops for nutrients.

Soil & water conservation practices: Soil erosion removes top soil, which is the richest layer of soil in both organic matter and nutrient value. Implementing soil & water conservation measures that restrict runoff and erosion reduces nutrient losses and sustains soil productivity. Tillage practices and crop residue cover, along with soil topography, structure, and drainage are major factors in soil erosion. Surface residue reduces erosion by restricting water movement across the soil and tillage practices determine the amount of crop residue left on the surface. Reduced tillage or no-till maximize residue coverage. Water moves rapidly and is more erosive on steep slopes, so reducing tillage, maintaining surface residue, and planting on contour strips across the slope are recommended conservation practices. As discussed above, rotations and cover crops also reduce erosion. Soils with stable aggregates are less erosive than those with poor structure and organic matter helps bind soil particles together into aggregates. Tillage breaks down soil aggregates and also increases soil aeration, which accelerates organic matter decomposition. Well-drained soils with rapid water infiltration are less subject to erosion, because water moves rapidly through them and does not build up to the point where it moves across the surface. Drainage improvements on poorly drained soils reduce erosion. Improving drainage also decreases N losses from dentrification, which can be substantial on waterlogged soils, by increasing aeration.

Manure management: Returning manure to crop fields recycles a large portion of the plant nutrients removed in harvested crops. On farms, where livestock is fed large amounts of off-farm purchased feeds, manure applied to crop fields is a substantial source of nutrient inputs to the whole farming system. However, just as nutrients can be lost from the soil, nutrient losses from manure during storage, handling, and application are both economically wasteful and a potential environmental problem. Soluble nutrients readily leach from manure, especially when it is unprotected from rainfall during storage. Nitrogen is also readily lost through volatilization of ammonia, both during storage and when manure is not incorporated soon after field application. Nutrient losses from manure also occur when it is applied at excessive rates. Analyze manure for its nutrient content and adjust application rates based on crop needs and soil tests. Following heavy manure applications with crops that have high nutrient requirements, especially for N and P, reduces losses and increases nutrient-use efficiency. In addition to nutrient value, manure adds organic matter to the soil and provides benefits such as increased CEC for nutrient retention.

Compost and other soil amendments: In addition to manure, organic amendments such as biosolids (sewage sludge), food processing wastes, animal byproducts, yard wastes, seaweed, and many types of composted materials are nutrient sources for farm fields. Biosolids contain most plant nutrients, and are much ‘cleaner’ than they were twenty years ago, but regulations for farm application must be followed to prevent excessive trace metal accumulation. Composting is a decomposition process similar to the natural organic matter breakdown that occurs in soil. Composting stabilizes organic wastes and the nutrients they contain, reduces their bulk, and makes transportation and field application of many waste products more feasible. On-farm composting of manure and other wastes also facilitates their handling. Most organic materials can be composted, nearly all-organic materials contain plant nutrient elements, and recycling all available wastes through soil-crop systems by either composting or direct field application should be encouraged. These practices build up soil organic matter and provide a long-term, slow-release nutrient source. Inorganic byproducts also can be recycled through the soil and supply plant nutrients. Available materials vary by region, but rock powder from quarries, gypsum from high-sulfur coal scrubbers, and waste lime from water treatment plants are among the waste products that have been beneficially used.

Soil acidity and liming: Soil pH has strong effects on the availability of most nutrients. This is because pH affects both the chemical forms and solubility of nutrient elements. Trace metals such as Fe, Zn, and Mn are more available at lower pH than most nutrients, whereas Mg and Mo are more available at higher pH than many other nutrients. The ideal soil pH for most crops is slightly acid, about 6.3-6.8, because in that range there is well-balanced availability for all nutrients. This pH range is also optimum for an active and diverse soil microbial population.

Some crops grow better at higher or lower soil pH than 6.3-6.8, usually because of specific nutrient requirements. Blueberries grow best around pH 4.5-4.8 and are Fe deficient when the pH is much over 5. Most crops suffer from Al, Fe, or Mn toxicity when soil pH is that low. Legumes do best at a higher pH than most other crops, due to the high requirement for Mo by N-fixing bacteria.

Limestone is the most commonly used material to increase soil pH. Liming also supplies Ca and diplomatic lime supplies Mg as well. Liming rates depend upon the buffering capacity of a soil in addition to the measured pH. Buffering capacity, or ability to maintain pH within a given range, is related to CEC and increases as clay and/or organic matter content of the soil increases. The lime requirement to raise soil pH the same amount is much larger for fine-textured, high organic matter soils than for coarse-textured, sandier soils. Low soil pH is a more common problem than a pH that is too high, but reducing pH may be necessary for acid-loving plants. Elemental S is the most commonly used material to lower soil pH.

Fertilizer applications: Many materials can be applied to soil as sources of plant nutrients, but the term '*fertilizer*' is usually used to refer to relatively soluble nutrient sources with a high-analysis or concentration. Commercially available fertilizers supply essential elements in a variety of chemical forms, but most are relatively simple inorganic salts. Advantages of commercial fertilizers are their high water solubility, immediate availability to plants, and the accuracy with which specific nutrient amounts can be applied. Because they are relatively homogeneous compounds of fixed and known composition, it is very easy to calculate precise application rates. This is in contrast to organic nutrient sources which have variable composition, variable nutrient availability, and patterns of nutrient release that are greatly affected by temperature, moisture, and other conditions that alter biological activity.

The solubility of commercial fertilizers can also be a problem, because soluble nutrients leach when applied in excess or when large rains occur soon after fertilizer application. Increasing soil action exchange capacity by increasing organic matter reduces the leaching potential of some nutrients. Management practices that synchronize nutrient availability with crop demand and uptake also minimize leaching. Both application timing and the amount of fertilizer are important. Splitting fertilizer applications into several smaller applications rather than a single, large application is especially important on sandy, well-drained soils. Excess nutrient applications can be eliminated or at least significantly reduced by soil testing on a regular basis, setting realistic yield goals and fertilizing accordingly, accounting for all nutrient sources such as manure, legumes, and other amendments, and using plant tissue analysis as a monitoring tool for the fertilizer program.

Biological & chemical approaches to soil fertility and nutrient management: The goals of effective nutrient management are to provide adequate plant nutrients for optimum growth and high-quality harvested products, while at the same time restricting nutrient movement out of the plant root zone and into the off-farm environment. Biological processes in the soil control nutrient cycling and influence many other aspects of soil fertility. Knowledge of these important processes helps farmers make informed management decisions about their crop and livestock systems. How these decisions affect soil biology, especially microbial activity, root growth, and soil organic matter are key factors in efficient nutrient management. Managing soil organic matter and biological nutrient flows is complex because crop residues, manures, composts, and other organic nutrient sources are variable in composition, release nutrients in different ways, and their nutrient cycling is strongly affected by environmental conditions.

Chemical processes in the soil, to a large extent, control mineral solubility, cation exchange, solution pH, and binding to soil particle surfaces. Knowledge of soil chemistry makes it possible to formulate fertilizers that supply readily available plant nutrients. Management of inorganic nutrient sources is simpler than organic nutrient sources, because of their known and uniform composition and the predictability of their chemical reactions. Chemical and biological processes and their effects on plant nutrients cannot be clearly separated, however, since inorganic nutrients can quickly be incorporated into biological cycles. Chemical fertilizers should also be used only after accounting for all organic nutrient sources to avoid overloading the system and losing soluble nutrients. When used to supplement biological nutrient sources, they can help make more efficient use of other available plant-growth resources, such as water and sunlight, and work together with biological processes for a productive agriculture and healthy environment.

Soil fertility can be effectively increased by understanding the functions of the plants and animals living in and on the soil. Not only can soil organisms generate mineral nutrients or make them available, but these same minerals can also be recycled several times in a growing season, if the soil ecosystem is healthy and plant cover is optimal. With good management, nutrients can cycle quickly with minimal losses to air and water. Less fertilizer will be required, and this means increased profitability for the entire farm. Three different groups of living organisms drive the nutrient cycle: soil organisms, pasture plants, and grazing livestock.

Soil Organisms and Nutrient Cycling:
The soil is alive with organisms, ranging from visible insects and earthworms to microscopic bacteria and fungi. Soil bacteria are the most numerous, with every gram of soil containing at least a million of these tiny one-celled organisms. There are many different species of bacteria, each with its own role in the soil environment. One of the major benefits bacteria provide for plants is to help them take up nutrients. One of the primary ways they do this is by releasing nutrients from organic matter and soil minerals. Certain species release nitrogen, sulfur, phosphorus, and trace elements from organic matter. Other species break down some soil minerals and release potassium, phosphorus, magnesium, calcium, and iron. Still other species make and release plant growth hormones, which stimulate root activity. Some bacteria, either living inside the roots of legumes or free-living in the soil, fix nitrogen. Other services provided to plants by various species of bacteria include improving soil structure, fighting root diseases, and detoxifying the soil.

Actinomycetes are thread-like bacteria that look like fungi. While not as numerous as other bacteria, they perform vital roles in the soil. Like other bacteria, they help decompose organic matter into humus, releasing nutrients. They also produce antibiotics to fight root diseases. And they are responsible for the sweet earthy smell of biologically active soil.

Fungi come in many different species, sizes, and shapes in soil. Some species appear as thread-like colonies, while others are one-celled yeasts. Slime molds and mushrooms are also fungi. Many fungi aid plants by breaking down organic matter or by releasing nutrients from soil minerals. Some produce hormones and antibiotics that enhance root growth and provide disease suppression. There are even species of fungi that trap harmful plant-parasitic nematodes. Mycorrhizae are fungi that live either on or in plant roots and act to extend the reach of root hairs into the soil. Mycorrhizae increase the uptake of water and nutrients, especially in soils with nutrient deficiencies. The fungi, in turn, benefit by taking nutrients and carbohydrates from the plant roots they live with.

Many species of algae also live in the soil. Unlike most other soil organisms, algae produce their own food through photosynthesis. They appear as a greenish film on the soil surface following a rain. Their primary role is to improve soil structure by producing sticky materials that glue soil particles together into water-stable aggregates. A soil aggregate looks like a miniature crumb of granola. In addition, some species of algae (the blue-greens) can fix nitrogen, some of which is later released to plant roots.

Protozoa are free-living animals that crawl or swim in the water between soil particles. Many soil protozoa species are predatory, eating other microbes. By consuming bacteria, protozoa speed up the release of nitrogen and other nutrients through their waste products.

Nematodes are abundant in most soils, and only a few species are harmful to plants. The harmless species eat decaying plant litter, bacteria, fungi, algae, protozoa, and other nematodes. Like the other soil predators, nematodes speed the rate of nutrient cycling.

Earthworms are good indicators of soil health. Earthworm burrows enhance water infiltration and soil aeration. Earthworms pass soil, organic matter, and soil microbes through their digestive systems as they move through the soil. This process increases the soil's soluble nutrient content considerably. Worms eat dead plant material left on top of the soil and redistribute the organic matter and plant nutrients throughout the soil horizon. Research shows that a thick layer of dead organic material remains on the surface in pastures without any worms. Earthworms also secrete a material that stimulates plant growth. Some increase in plant growth, as well as the improved soil quality, can be attributed to this substance.

In addition to earthworms, there are many other species of soil organisms visible to the naked eye. Among them are dung beetles, sow bugs, millipedes, centipedes, slugs, snails, and springtails. These are the primary decomposers. They start eating the large particles of plant residue. Some bury residue, bringing it in contact with other soil organisms, which further decompose it. The springtails eat mostly fungi, and their waste is rich in plant nutrients. All these organisms—from the tiny bacteria up to the large earthworms and snails—function together in a whole-soil ecosystem.

Organic Matter is Essential to Soil Health:

Organic matter is critical for storing water and nutrients in the soil. It holds nutrients in plant-available forms that don't easily wash away. It creates an open soil structure into which water, dissolved minerals, and oxygen can move, ready for plants to use. It provides further nutrient storage in the soil and can disable certain plant toxins. In addition, beneficial soil organisms depend upon organic matter as a source of food. These countless tiny plants and animals create an ecosystem that releases mineral nutrients, increases their availability to plants, and helps protect plant roots from disease.

Testing for soil organic matter (OM) is a simple way to make sure there is a functioning community of organisms in the soil. All the organisms mentioned above, except algae, depend on organic matter for their food. The primary decomposers start with raw plant residues and manure. Their by-products are eaten by other species whose wastes feed still other microbes. After moving through several species, these raw materials become soluble plant nutrients and humus. The humus contributes to well-structured soil, which in turn produces high-quality forage.

Maintaining or building organic matter is the first step to developing soil humus. Humus results from the final stages of organic matter decomposition. Favorable biological processes, which decompose the organic matter into humus, can be limited or even stopped by lack of nitrogen, lack of oxygen, unfavorable temperature, or unfavorable pH. Once stable humus has accumulated in the soil, it has a host of beneficial effects on plants. These positive effects are directly related to the presence and diversity of microbial life.

Different methods of characterizing demonstrations on composting process

There are different methods of composting. Basically the process is carried out either in pits or heaps. In the heap system, decomposition is carried out 1-2 m above ground. This consists of different configurations (Miller, 1993). The pile refers to a simple process caused by dumping of wastes into a cone or pyramidal shape on the ground. These may or may not be mechanically turned. The heap is same as piles but is a more indiscriminately dumped and of larger mass. Windrows are piles, turned using various machines. Large scale composting at outdoors involves windrow method. They vary in size depending on the type of turning equipment utilized. The height of the windrows ranges from 1.5 to 3.0 m, with a width ranging from 2 to 3 m. Composting process is continued in windrows for there months and later placed in curing pile for four to six weeks depending on the substrate. The product formed can be utilized by selling or distributed in the society. Different methods of composting have been proposed and used, altering the methodology for convenience and for faster degradation.

Bangalore method:
This method of composting was developed by Acharya (1939). This method is suitable in places where night soil and refuse are used for preparing the compost and in areas having scanty rain fall. Here composting is carried out in trenches: their size vary based on population: a population of more than 50 can have trenches dimension of 10m*2.5m*1m,length, breadth and depth respectively. The trenches should preferably have sloping walls and a floor of 90cm slope to prevent water logging.

A layer of refuse about 15 cm depth is spread at the bottom of trench, over this night soil is added at 5cm,similarly like alternative layers are made till about 30cm above the ground level. Finally the pit is covered with a 15-20cm thick layer of refuse. The materials are allowed to remain in the pit without turning and watering for 90days. During this duration, there is reduction in the volume of biomass and we can add additional layer of night soil and refuse in alternative layers on the top, and this is plastered with mud to prevent loss of moisture and breeding of flies. Intially, there is aerobic decomposition and the temperature rises to 60-70c,then this is taken over by anaerobic digestion occurring at a slower rate for a period of 180-240 days to obtain end product, which is odorless and has high manorial value.

Chinese method:

A. Another method of composting night soil is using heaps called as high temperature composting. Here the base material consists of stalks and roughages of crops and layering with night soil, urine, sewage, animal dung and chopped plant residues follows this. Here water is added at optimum levels. The heap is finally shaped and covered with mud plaster. Poles of bamboo are pierced vertically into the mud plaster and all the way to the bottom of the heap: this is kept for 24 hours and later removed, which act as holes for ventilation. The temperature of the heap rises to about 60-70^{0}C and at this state sealing with mud plaster closes the holes of aeration. This is left for a period of two months and the compost is ready and free from pathogens.

B. Generally, composting is carried out in a corner of a field and in a circular or rectangular pit. Rice straw, animal dung (usually pig), aquatic weeds or green manure crops are used and often silt pumped from riverbeds 15cm thick. Usually, the first layer is of a green manure crop or water hyacinth, the second layer are alternated until the pit is full, when a top layer of mud is added a water layer of about 4 cm depth is maintained on the surface to create anaerobic condition which help to reduce losses of nitrogen. Approximate quantities of the different residues in tones per pit are: river silt 7.5, rice straw 0.15animal dung 1.0, aquatic plants or green manure 0.75 and super phosphate, 0.02. Three turnings are given in all, the first one month after filling the pit and, at this time, super phosphate is added and thoroughly mixed in. Water is added as necessary. The material is allowed to decompose for three months and produces about eight tones of compost per pit.

Indore method:

This method is suitable when there is mellifluous plant residues, animal dung, urine, wood ash etc. The plant wastes include vegetable wastes, weeds, stalks, stems, fallen pruning, chaff, fodder remnants, green matter *etc.* Here the total composting period taken is about three months.

Pit method:

The site selected for pit method should be near cattle shed and at a high level so that no rainwater gets in during the monsoon season. Pits are dug at about 1m deep and 1.5-2.0 m wide and of any suitable length. The material got from cattle shed, like bedding material and other wastes are mixed and spread in the pit, each layer of the substrate is covered with slurry of dung made with 4.5 kg of inoculums taken from a 15 day-old compost pit. The pit is sufficiently moistened and care should be taken to avoid compaction of the substrate. The substrate in the pit is turned after 15, 30 and 60 days from the date of filling the pit. During each turning the substrate is properly mixed and sufficiently moistened.

Heap method:

Heap method is preferred in places where there is low rainfall. The site for heap preparation is selected at an elevation. The Indore pile should have a dimension of 2 m long, 1.5 m high, 2 m wide and the top of 0.5 m narrowed by tapering. A layer of carbonaceous materials such as leaves, hay straw, saw dust, wood chips, corn stalks etc, are spread to about 20 cm height, this is then covered by nitrogenous materials like grass, weeds, garbage, other plant residues, manure, digested sewage sludge. This layering is repeated similarly till the pile is 1.5m high and moistened. The heaps are turned at 6 and 12week interval.

NADEP method:

This method is in parallel with heap method of composting. The NADEP method employs a brick lined tank of size about 1*2*4m. Aeration is achieved by holes on all sides of the brick tank, helping air circulation.

Common substrates employed in this method are agro wastes *viz*,, cattle feed refuse, weeds, grasses, leaves, sugarcane trash, stalks, roots, plant clippings *etc*. Methodically the substrates consisting of organic wastes, cow dung slurry and soil are layered: at the bottom layer of 150 kg organic wastes are spread, on this cow dung slurry (6 kg cow dung in 100 l water) is spread, a third layer consisting of 60 to 80 kg cleaned sieved dry soil is spread and over it water is sprinkled. The layering is repeated similarly up to about 1m. Finally a layer of cow dung soil paste is added. Aerobic decomposition process takes about 90 to 120 days.

Japanese method of composting:
In this method instead of pits, vats of stone slabs are made which measures 5.5-9.0m in length and 0.9-12 m in width and have a height of 0,75-15 m. The stonewalls are laid in such a way that aeration can be made. The stones can also have holes. At the bottom of the vat, the stone slabs are laid and plastered with cement to prevent leaching of the nutrients. This method employs five different substrates *viz*.,

1. Cow dung and poultry wastes.
2. Grass, crop residues and weeds that include fresh and dry green leaves.
3. Wastes like agro-based industries like press mud, sericulture wastes, wastes from vegetable and fruit processing.
4. Naturally occurring nutrient source like rock phosphate.
5. Organic wastes form towns and cites like sewage and sludge.

In the bottom of the vats, a layer of highly lignaceous substrates like coconut leaves, coconut shells and other fibrous materials are layered up to 10-15cm height. The second layer is spread with dried leaves, grass, groundnut shells *etc*. up to 10-15 cm height. These layers absorb the moisture and nutrients loaded from the top. The layers after being laid are sprinkled with cow dung slurry or with biogas spent slurry. The third layer is made up of green leaves of pongamia, green grass, weeds and other crop residues rich in nitrogen. The fourth layer of contains organic waste rich in phosphorous like roots of legume crop, green manures and rock phosphate, along with these potassium rich substrates like calotropis, other weeds, tobacco residues, tomato crop residues, ash, poultry wastes are used. Over these 2-3 buckets of cattle dung slurry is sprinkled and covered with straw. This is finally covered with cattle dung and some old composted material or tank silt or ash, which acts as good casing material. The substrate is turned once in 15days.

Synthetic compost:
In the preparation of synthetic compost, nitrogen in the form of dung required by microorganisms could be completely substituted with inorganic nitrogenous compounds like ammonium sulphate or urea, which are utilized equally effectively for decomposition of carbonaceous materials into compost. This facilitates the utilization of large quantities of various organic waste materials, where supplies of dung are either short of the requirement or not available at all as on mechanized farms. In this method nitrogenous fertilizers are added to bring down the C/N ratio to favour the decomposition. The material to be composted is sprayed with fertilizer solution and then with lime. Super phosphate may be added to fortify the phosphorous content of the manure. The manure becomes ready for application in about 4 to 6 months.

Windrow method:
Turned windrows: The windrow method is a widely practiced method of composting in USA. In this process, the waste material like garbage received is dumped and is sorted for plastic, glass and rubber. The waste materials are piled in long rows of 2-3m width and 1.5-3m height on a hard surface and usually in the open area. Aeration of window is by periodic turning using equipment such as front-end loader or specially designed machinery like aero tillers. Occasionally forced aeration in conjunction with turning has been applied to the windrow process. The windrow method is also exploited by distillery and sugar industry for composting of press mud with distillery-spent wash.

Static pile method:

A. In this method a mixture of solid wastes is stock piled in the open and turned occasionally for aeration. This method is considered to waste both ammonia and energy. These disadvantages have been substantially mitigated by forcing air through perforated pipes at the bottom of the static pile, to keep the temperature below 60c.
B. Aerated static pile method: The aerated static pile makes use of pipes embedded in the piles for aeration. The raw material mixture is piled over a base of wood chips, chopped straw, or other porous material. This porous material contains a perforated pipe. The pipe is connected to a blower, which either pulls or pushes air through the pile.

Sheet method:
Spreading organic materials on the surface of the soil or untilled ground and allowing it to decompose naturally carry out sheet composting. Over time the material will decompose and filter into the soil. This method is ideally suited for forage land, no-till application, erosion control, roadside landscaping etc. The process does not favour the destruction of weed seeds, fly larvae, pathogens etc and composting materials should be limited to plant residue and manure. Decomposition time is governed by environmental conditions and can be quite lengthy.

Rapid composting using microorganisms to hasten/activate the process:
Basically, composting is catalyzed by a consortium of heterogeneous population of bacteria and fungi. These are contributed by the raw material, adjuvant; soil where pits/heaps for composting are created and periodic addition of water for retention of desired amount of moisture and environment. Besides, substrate-specific microbes for expediting composting are added. It generally takes about 4-6 months to get finished compost under normal conditions. Fungi with lingo- cellulololy6tic activity such as *Aspergillus niger*, *Penicullium sp*., *Trichoderma viride*, *Trichurous spiralis*, *Chaetomium sp*., *Phanerochaete chrysosporium* and *Paeciliomyces fuscisporus* are used to hasten the decomposition process (Bagyaraj & Radhakrishna, 2000) These cultures are added at the rate of 2 kg per ton of wastes.

Enrichment of compost with nutrient enhancing microorganisms:
Phospho-compost: India is producing 0.4% of world rock phosphate, which is of inferior quality and not used for fertilizer production. Nearly 95% of P fertilizer in the country is from imported rock phosphate. India has 260 million tones of low-grade rock phosphate, which can save a minimum of Rs.3000 foreign exchange for every tone of phosphatic fertilizer through composting has led to the process called phosphocompost. Rock phosphate can be added at the beginning of composting to get phosphorus enriched compost. The level of rock phosphate many be 12.5-25% depending on the required P enrichment. There is also a practice of additions of gypsum and some oil cakes, which are not used as cattle feed, during the last turning of the compost. Along with addition of rock phosphate, phosphate-solubilizing microorganisms like *Bacillus megaterium*, *Aspergillus awamori*, *Pseudomonas*, *Flavobacterium*, *Pencilluum*, *Fusarium etc*. are inoculated at the rate of 1-2 kg per tone of the substrate. The phosphocompost is used as the phosphatic manure, which is superior to super phosphate as it serves as a good source of P to crop plants and is less chemically fixed in soils.

Addition of rock phosphate to wood waste-glyricidia mixture with subsequent inoculation with a phosphate solubilizer *Pseudomonas striata* resulted in a biocompost rich in phosphorus. *Pseudomonas striata* solubilized the rock phosphate and released higher amounts of available P, hastened the composting process, besides increasing the P content in the biocompost (Sharath and Jagadeesh, 2004a)

Enrichment with plant growth promoting organisms: Nutrient status of the compost can be enhanced through inoculation with plant growth promoting organisms. Bacterial inoculants such as *Azotobacter* and *Azospirillum* are added to the decomposing materials at the rate of 2 kg/tone after the thermophilic phase *i.e*. after a period of 30-45 days of initial decomposition. These nitrogen-fixing bacteria increase in population and enhance the nitrogen content. The fungal cultures such as *Trichoderma sp*. or bacteria like *Bacillus sp.* are also inoculated after 30-45 days initial decomposition, which on increasing in population improve the quality of the final product. These organisms can also help in suppressing the root pathogens (Bagyaraj & Radhakrishna, 2000).

These are the number of methods for most scientific and quick method of composting. However, the method that is ideal to be practiced in the study site would be rapid composting using microorganisms to hasten/activate the process followed by enrichment with nutrient enhancing microorganisms.

Methods of characterizing inoculation studies in crops:

VA mycorrhizal fungi: Arbuscular mycorrhizal (AM) fungi are ubiquitous root-symbiotic fungi in the phylum Glomeromycota formerly Glomales within the Zygomycota (Schussler *et al*. 2001). They form mutualistic associations with roots of the majority of higher plants, including crop plants. They have a variety of important influences on ecological processes at several scales. At the individual plant host level, the AMF role in nutrient acquisition has historically been emphasized (Smith and Read, 1997) and they are also important in defense against soil-borne pathogens (Newsham *et al*. 1995). At the plant community level they have been shown to be important co-determinants of plant species diversity (van der Heijden *et al.*, 1998) and at the ecosystem level AM fungi are of recognized importance in processes such as nutrient cycling and play a role in the formation of stable soil aggregates, building up of macro porous structure of soil that allows penetration of air and water (Miller and Jastrow, 2000; Rilling, 2004). Improved plant growth due to inoculation of soil with AM fungi has been demonstrated especially under P deficient condition (Mosse, 1973). There is well-documented evidence that VA mycorrhiza have important effects on plant P uptake through soil exploration by mycorrhizal roots as a means of increasing phosphate uptake (Hayman, 1983). AM fungi can also enhance tolerance or resistance to root pathogens (Borowicz, 2001) and abiotic stresses such as drought and metal toxicity (Meharg and Cairney, 2000). AM fungi also play a role in the formation of stable soil aggregates, building up of macro porous structure of soil that allows penetration of water and air and prevents erosion (Miller and Jastrow, 1992). Glomalin, a soil protein produced by arbuscular mycorrhizal fungi play an important role in soil aggregation (Rilling *et al*., 2003; Rilling, 2004)

The increased growth of plants inoculated with AM fungi is not only attributed to improved phosphate uptake but also to better availability of other elements like Zn, Cu, K, Al, Mn, Fe *etc*. Many workers for the last three decades under controlled green house studies have demonstrated that AM fungi are associated with most crop plants and can improve crop growth and yield by several mechanisms: in cotton, cowpea and finger millet (Bagyaraj and Manjunath, 1980), Chilles (Brechelt, 1987; Srinivasa, 1992 and Srinivasa and Krishnaraj, 1992), Cluster beans (Rao and Tarfdar, 1993), Pearl millet (Champawat and Patak, 1993).

Such benefits have also been very well documented in forestry and Horticulture crops; In apple (Geddeda *et al*., 1984), banana (Lin and Chang, 1987), coffee (Cruz, 1989), troyer citrange and trifoliate orange (Vinayak and Bagyaraj, 1990 a, b), tomato (Dhinakaran and Savithri, 1997 and Iqbal and Mahmood, 1998).) and in forestry such as non-nodulating *Acacia melanoxylon, A. mangium, A. auriculiformis* (Mizogachi, *Ethiopian Acacias* (Michelson, 1992), mulberry beds (Das *et al*., 1995), *Leucaena leucocephala* (Koffa *et al*., 1995), cardamom (Sreeramulu and Bagyaraj, 1999).

Role of N-fixing *Azotobacte*r, P-solubilazing organisms and their interaction with AM fungi:- Mycorrhizal fungi also interact with a wide range of soil microorganisms in the rhizosphere. There have been many studies which have shown that mycorrhizal colonization allows introduced populations of beneficial soil organisms like N-fixing *Azotobacter*, *Azospirillum* and phosphate solubilising bacteria to maintain in higher numbers and exert synergistic effects on plant growth (Azcon *et al*., 1976; Bagyaraj and Menge, 1978; Secilia and Bagyaraj, 1987). Several worker have reported a positive interaction AM fungi and with other beneficial organisms like N-fixing microorganisms and P-solubilizing microorganisms. Brown and Carr (1984) reported that lettuce plants responded best to VAM fungi and *Azotobacter chroococcum* only in 'P' deficient soil. Similarly, *Azospirillum brasilense* has been reported to stimulate VAM root colonization and growth of pearl millet (Tilak and Singh, 1988). Nahid and Gomah (1991) reported that dual inoculation of *Azospirillum* and VAM increased shoot dry matter of wheat. In a study conducted by Veeraswamy *et al*. (1992) to understand the interaction effect of *Glomus intraradices* and *Azospirillum lipoferum* on growth of sorghum indicated a significant increase in plant growth, alkaline phosphatase activity and better uptake of N, P, Zn, Cu and Fe.Murumkar and Patil (1996) reported a significant increase in the growth and yield of *Capsicum annum* (Bell pepper).studied due to inoculation of *Glomus fasciculatum, Gigaspora margarita, Acaulospora* sp. and their combination with *Azotobacter chroococcum* or *Azospirillum lipoferum*

Chang and Young (1992) reported that the VAM fungi and phosphorus solubilizing bacteria enhanced the growth of tea cuttings grown in plastic bags. In a pot experiment carried out by Tarafdar and Marschner (1995) with duel inoculation of *Aspergillus fumigatus* and *Glomus mosseae* resulted in enhanced biomass production and nutrient uptake in wheat. Rao and Rao (1996) reported that the combined inoculation of *Glomus fasciculatum* and *Aspergillus niger* with rock phosphate as a source of 'P' resulted in better improvement of black gram and green gram. Similarly, rock phosphate fertilization and inoculation of *Glomus constrictum* with rock phosphate solubilizing fungi (*Aspergillus niger* and *Penicillium citrinum*) significantly increased dry matter production of wheat (Omar, 1998). Inoculation of *Rhizobium*, VAM and associative bacteria in different soils under field conditions stimulated the growth of legumes and a number of Graminae and Cruciferaceae (Hoeflich *et al*., 1994). Sekar *et al*. (1995) reported a significant increase in biomass, colonization, P uptake and acid phosphatase activity due to combined inoculation of *Azospirillum, Phosphobacteria* and VAM fungi (*Glomus mosseae* and *G. fasciculatum*) singly or in combinations on three *Syzygium* species. Alagawadi and Gaur (1992) reported that inoculation of soil with *Azospirillum brasilense* and phosphate solubilizing bacteria increased the dry matter yield and phosphate uptake in sorghum.

Legume *Rhizobium* symbiosis: There has been lot of work carried out on the inoculation effects of *Rhizobium* inoculants. Okan *et al*. (1979) studied the inoculation effects of *Bradyrhizobium japanicum* strains as peat granules and seed application in soybean and observed an increase in yield by 32 per cent with use of granular peat when applied at the rate of 1 kg/1000m^2 and by 11.2 per cent with seed inoculation at the rate of 5 g/kg of seed compared to that of uninoculated. Vaishya and Gajendragadkar (1982) studied seed inoculation with *Rhizobium* on Urd crop (*Vigna mungo*) and reported increase in nodule number and yield of the crop. Kucey and Toomsan (1988) observed increased seed yield and nitrogen uptake by peanut due to inoculation of *Bradyrhizobium* in field experiments. Tiwari *et al.* (1989) studied the effect of *Rhizobium* inoculation on black gram , bengal gram, peas and barseem in pot experiments and pigenpea and groundnut in field experiments. El-essawi and Adebi (1990) observed that seed inoculation with rhizobia markedly increased nodule development (number and weight) in soybean. Pandzou *et al.* (1990) noticed that inoculation of rhizobia increased seed yield by 21 to 42 per cent in soybean. Hume and Blair (1992) reported that soybean yield in land that had not grown soybean before were increased by an average of 24 % due to *Rhizobium* inoculation. Oad *et al.* (2002) reported that seed treatment of *R. japanicum* to soybean enhanced the growth and seed yield.

Therefore, these microorganisms will be multiplied in large numbers and introduced in the rhizosphere of plants. In the first phase around 67 species of AM fungi have been isolated. Of them, seven species have been most dominantly found in the study site area. The inoculums will be prepared by mass multiplying the selected in sterilized sand: soil mixture in pots. Guinea grass will be grown as the trap plant. Before sowing the grass, the inoculum developed already by using funnel technique will be inoculated to sterilized: soil mixture and the grass will be grown for 2-3 months before they are used. For this the shoot is harvested and the roots in the soil will be cut to small pieces, mixed with the soil and used as mycorrhizal inoculum. Each seedling grown in polythene bags will be inoculated with 10 g of inoculum containing 12, 500 infective propagules per gram of inoculum.

Similarly, two species of N-fixing *Azotobacter* and a few isolates of P-solubilizing microorganisms were isolated from different land use types of the study site area. There numbers were too small in these soils. Inoculating these organisms in the rhizosphere of chilies and coffee will increase the population of these microorganisms and thereby effecting enhanced plant growth. The organisms will be multiplied in large numbers on N-free medium and nutrient broth. Inoculants of these organisms in carrier materials will be prepared containing 5x10^8 cells/g of carrier based culture and inoculated to plants along with AM fungi.

References:

Acharaya, C.N. 1939. Comparison of different methods of composting waste materials. Ind. J. Agril.Sci 4: 135-149.

Alagawadi, A.R. and Gaur, A.C., 1992. Inoculation of *Azospirillum brasiliense* and phosphate solubilizing bacteria on yield of Sorghum (*Sorghum bicolor* L Moench) in dry land. *Tropic. Agric*., **69**: 347-350.

attributes of soil quality. In: Soil Quality for crop production and Ecosystem Health (E.G. Gregorich and M.R. Carter, eds). Elsevier, New york. Pp. 81-113.

Azcon, A., Barea, J.M. and Hayman, D.S., 1976. Interactions of endogone-phosphobacteria. *Soil Biol. Biochem*., **8**: 135-138.

Bagyaraj, D.J. and Manjunath, A., 1980. Selection of suitable host for mass productin of VA mycorrhizal inoculation. *Plant. Soil,* **55:** 495-498.

Bagyaraj, D.J. and Menge, J.A., 1977. Interaction of *Azotobacter* and VA mycorrhiza. *New Phytol*., **80**: 567-573.

Bagyaraj, D.J.& Radhakrishna, D. 2000. Recent advances in composting, in L.V.Gangawane, Ganju, Y. Thomas S. & Aggarwal S.L. (eds), Vistas in Mycology and plant pathology. Commanwealth pub., New Delhi. Pp. 88-100.

Borowicz, V.A., 2001. Do arbuscualar mycorrhizal fungi alter plant pathogen relations? *Ecology*, **82**: 3057-3068.

Brown, M.E. and Carr, G.R., 1984, Intractions between *Azotobacter chroococcum* and vesicular-arbuscular mycorrhiza and their effects on plant growth. *J. Appl. Basteriol*., **56**: 429-437.

Champavat, R.S. and Pothak, V.N., 1993, Effect of vesicular arbuscular mycorrhizal fungi on growth and nutrition uptake of pearl millet. *Indian J. Mycology Pl. Pathology*, **23**: 30-34.

Chung, F.P. and Young, C.C., 1992, Effects of VA mycorrhizal fungi and phosphorus-solubilizing bacteria inoculated in growth of tea cuttings in plastic bag. Taiwan Tea Research Bulletin, No. 11, pp. 79-89.

Cruz, S.J.C., 1989, Investigations of the VA mycorrhiza (VAM) symbiosis in a culture of coffee (*Coffea Arabica* L. var. *Caturra*). *Fitopatologia Colombiana*, **13**: 56-64.

Das, P.K., Katiyar, R.S., Hanumanthu Gowda, M., Fathima, P.S. and Choudhury, P.C., 1995, Effect of vesicular-Arbuscular mycorrhizal inoculation on growth and development of mulberry (*Horus* spp) saplings. *Indian J. Seric*., **34**: 15-17.

Dinakaran, R. and Savithri, P., 1997, Phosphorus and vesicular-arbuscular mycorrhizal (VAM) fungi inoculation. *J. Nuclear Agricl. Biol*., **26**: 142-146.

Doran, J.W. and parkin, T.B.(1994). Defining and assessing soil quality. In: Defining Soil Quality for a Sustainable Environment (J.W.Doran, D.C. Coleman, D.F. Bezdicek and B.A. Stewart, eds). SSSA, Madison, WI, USA. Pp. 3-21.

El-essawi, J.M. and Adebi, P., 1990. Quality and yield of Soybean seeds as affected by inoculation, NPK fertilizers. *Arid Soil Res. Reham.*, **4**: 43-51.

Geddeda, V.I., Trappe, J.M. and Stebbins, B.L., 1984, Effect of vesicular arbuscular mycorrhiza and phosphorus on apple seedlings. *J. Am. Soc. Hort. Sci*., **109**: 24-27.

Gregorich, E.G., Carter, M, R., Doran,, J.W,. Pankhurst, C.E. and Dwyer, L.M. (1997). Biological

Hayman, D.S., 1983. The physiology of vesicular arbuscular endomycorrhizal symbiosis. *Can. J. Bot*., **61** : 944-963.

Hoeflich, G., Wiche, W. and Kuchn, G., 1994, Plant growth stimulation by inoculation with symbiotic, associative rhizosphere microorganisms. *Experienta* (Basel), **50**: 897-905.

Hume D.J and Blair, D.H., 1992. Effect of number of *Bradyrhizobium* applied in commercial inoculants on soybean yield. *Canadian j. of microbiology*.38: 588-593.

Iqbal, J. and Mahamood, I., 1998, Effect of single and multiple VAM inoculants on the growth parameters of tomato. *Mycorrhiza News*, **10**: 13-15.

Koffa, S.N., Cruz, R.E. and De-la=Cruz, R.E., 1995, Green house performance of VAM-inoculated seedlings of Leucaena leucocephala (Lam.) Dewit. In a phosphorus deficient and auminium sulfate treated medium. *New Forests*, **9**: 273-279.

Kucey, R.M.N. and Toomsan, B., 1988. Peanut cultivar response to *Bradyrhizobium* inoculation in northeast Thialand. *Peanut sci.*, **15**:63-69.

Lee, K.E. and Pankhurst, C.E. (1992). Soil organisms and sustainable productivity. Australian Journal of Soil Reesarch 30, 855-892.

Lin, C.H. and Chang, D.C.N., 1987, Effect of three *Glomus* endomycorhizal fungi on the growth of micropropagated banana plantlets. *Trans. Mycol. Soc. Rep*. China, **2**: 37-45.

Michelson, A., 1992, Growth improvement of Etiopian-acacians by additions of vesicular arbuscular mycorrhizal fungi or roots of native plants to non sterile nursery soil. *For. Ecol. Manage*., **59**: 193-206.

Miller, R.M. and Jastrow, J.D., 1992, The application and reclamation. In: *Mycorrhizal functioning*. (Ed.) M.F. Allen, Chapman and Hall Ltd., London, England., pp.214-229

Miller, R.M. and Jastrow, J.D., 2000. Mycorrhizal fungi influence soil structure. In: *Arbuscular mycorrhizae: molecular biology and physiology*. (Eds.)Y.Kapulnik and D.D. Douds.. Kluwer Academic Press, Dordrecht, The Netherlands. pp. 3-18.

Miller,F.C. 1993. Composting as a process based on the control of ecologically selective factors. In F.D.metting (ed.), Soil Microbial Ecology.Pp. 514-544.

Mosse, B., 1973. Advances in the study of vesicular-arbuscular mycorrhiza. *Annu. Rev. Phytopathol.*, **11**: 171-196.

Murumkar, D.R. and Patil, P.L., 1996, VAM diazotrophs bell pepper symbiosis. *J. Maharastra Agric. Unvi.*, **2**: 394-397.

Nahid, S. and Gomah, A.H.M., 1991, Response of wheat to dual inoculation with VAM and *Azospirillum* fertilized with NPK and irrigated with sewage effluent, Arid. *Soil Re.s Rehabil*., **5**: 83-96.

Newsham, K.K., Fitter, A.H. and Watkinson, A.R. 1995. Arbuscular mycorrhiza protect an annual grass from root pathogenic fungi in the field. *J. Ecol.* **83**: 991-1000.

Oad. F.C, Kumar.L and Biswas J.K., 2002. Effect of *Rhizobium japonicum* inoculants doses (Liquid culture) on growth and seed yield of soybean crop., *Asian J. of Pl. sci.* 4 : 340-342.

Okan, Y., Volfovitch, M., Henis, Y. and Pinthus, M.S., 1979. Inoculation of soybean (G. max) in Isreal with *Rhizobium japanicum*. *Expt. Agriculture*, **15**: 261-272.

Omar, S.A., 1998, The role of rock phosphate solubilizing fungi and vesicular arbuscular mycorrhiza (VAM) in growth of wheat plant fertilized with rock phosphate. *World J. Microbiot, Biotech*, **14**: 211-218.

Pandozou, S., Beunard, P. and Saint, M.H., 1990. Inoculation of soil in cong. *Agronomic tropical*, **45**: 199-204.

Pankhurst, C.E. and Lynch, J.M.(1995). The role of soil microbiology in sustainable intensive agrilculture. Advances in Plant Pathology 11,229-247.

Pankhurst, C.E., Double, B.M. and Gupta, V.V.S.R.(1997a). (eds). Biological indicators of Soil Health. CAB International, Wallingford, UK.437 pp.

Rao, A.V. and Tarafdar, T.C., 1993, Role of VAM fungi in nutrient uptake and growth of cluster bean in an arid soil. *Arid Soil Research and Rehabilitation*, **7**: 275-280.

Rilling, M.C., 2004. Arbuscular mycorrhizae, glomalin and Soil aggregation. *J. Soil. Sci.,* **84:** 355-363.

Rilling, M.C., Ramsey, P.W., Morris, S. and Paul, E.A., 2003, Glomalin, an arbuscular mycorrhizal fungal soil protein, responds to land use changes, *Plant Soil*, **253**: 293-299.

Schipper, L. and sparling, G.P.(1997). A quantitative approach to assessing soil biological quality. New Zealand Soil News 45,59-66.

Schussler, A., Schwarzott, D. and Walker, C., 2001. A new fungal phylum, the Glomeromycota; Phylogeny and evolution. *Mycol. Res.* **105:** 1413-1421.

Secilia, J. and Bagyaraj, D.J., 1987, Bacteria and actinomycetes associated with pot cultures of mycorrhizas, *Can. J. Microbiol.,* **33**: 1069-1073.

Sekar, I., Vanagamudi, K. and Suresh, K.K., 1995, Effect of bio-fertilizers on the seedling biomass, VAM colonization, enzyme activity and phosphorus uptake in the shoal tree species. *My Forest*, **31**: 21-26.

Sharath, S. & Jagadeesh, K.S. 2004b. Composting of wood waste of a paper mill: optimiztion of parameters. Bill Agril. Sci. I: 9-18.

Smith, S.E. and Read, D.J. 1997. *Mycorrhizal symbiosis*. Academic press, San Diego. CA.

Sparling, G.P.(1997). Soil microbial biomass activity and nutrient cycling as indicators of soil health. In: Biological Indicators of soil Health,(C.E.. Pankhurst, B.M. Double and V.V.S.R. Gupta, eds). CAB International, Wallingford, UK. Pp. 97-119

Sreenivasa, M.N. 1992. Selection of an efficient vesicular arbuscular mycorrhizal fungus for chilli (*Capsicum annuum* L.). Scientia Horticulture 50: 53-58.

Sreenivasa, M.N. and Krishnaraj, P.V., 1992, Synergetic interaction between VA mycorrhizal fungi and phosphate solubilizing bacterium in chilli (*Capsicum annum* L.) *Zentrabl. Mikrobiol*., **147**: 126-130.

Tarafdar, J.C. and Marschner, H., 1995, Dual moculation with *Aspergillus fumigatus* and *Glomus mosseae* enhances biomass production and nutrient uptake in wheat (iTriticum aestivum *L.*) supplied with organic phosphorus as Na Phytate. *Plant Soil*, **173**: 97-102.

Tilak, K.V.B.R. and Singh, C.S., 1988, Response of pearl millet (*Pennisetum americanum*) to inoculation with vesicular arbuscular mycorrhizae and *Aozspirillum brasilense* with different sources of phosphorus. *Curr. Sci*., **57**: 43-44.

Tiwari, V.N., Lehari, L.K. and Pathak, A.N., 1989. Rhizobium inoculation of legumes as influenced by phosphate and molybdenum fertilization. *J. Ind. Soc. Soil Sci.,* **37**: 712-716.

Vaishya, V.K. and Gajendragadkar, G.R., 1982. Effect of rhizobial inoculation on nodulation and yield of different genotypes of urd (*Vigna mungo) Ind. J.Microbiol,* **22**: 132-134.

Veeraswamy, T., Padmavathi, T. and Venkateshwarly, K., 1992, Intraction effects of *Glomus intraradices* and *Azospirillum lipoferum* on sorghum. *Indian J. Microbiol*., **32**: 305-308.

Vinayaj, K. and Bagyaraj, D.J., 1990a, Selection of efficient VA mycorrhizal fungi for trifoliate orange. *Biol. Agri. Hort*., **6**: 305-311.

Vinayak, K. and Bagyaraj, D.J., 1990b, Vesicular arbuscular mycorrhizae screened for Troyer Citrange. *Biol. Fert. Soil*., **9**: 311-314.