

**Review Article**

Micro and Macro (Organisms) and Their Contributions to Soil Fertility

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Abstract: Soil chemical properties and microbial populations were always determined in soil in order to compare the contributions of microorganisms to soil fertility and to sustain agricultural plant growth. The ability to supply essential plant nutrients (phosphorus (P), potassium (K), nitrogen (N), sulphur (S) etc.) and soil water in adequate amounts and proportions for plant growth and reproduction; and the absence of toxic substances which may inhibit plant growth. This research work therefore aimed at understanding the different types of microbes present in soil and their various contributions to soil fertility. Sample collection normally ranges from 0-20 cm depth in the soil. These samples were air dried, passed through a 2-mm sieve before soil properties were determined following standard methods. Fresh soil samples were used to determine the number of soil microorganisms via the dilution spread plate technique using the nutrient agar for bacteria and potato dextrose agar for fungi. Research showed that the forest and fallow lands had significantly lower pH value, available P, exchangeable K and Na, but significantly higher exchangeable H and bacteria population than the cultivated land. The mean exchangeable Ca was significantly higher in the cultivated land than in the fallow land but similar to that from the forestland. The fungi population was also higher in the forestland than in others which are similar statistically. The mean soil organic matter, total N, exchangeable Mg, exchangeable Al and CEC were similar in all the land use types. Contributions of microorganisms to soil fertility were generally more in the uncultivated lands, an indication that tillage operations may have affected the microbial populations. Also the relationship between some soil chemical properties and microbial densities signify important roles microorganism play in soil nutrient build up.

Keywords: Microorganisms, Soil Fertility, Soil Nutrients, Fallow Land, Cultivated Land

1. Introduction

Microorganisms are responsible for most biological transformations that result to the development of nutrients in the soil [1]. They influence several soil functions and are key indicators of soil quality. These organisms ensure the continued existence of nutrients in the soil. Management of these nutrients through sustainable use of soil resources is a requisite for successful agriculture [2]. Identifying and quantifying soil microorganisms may be one way of determining soil nutrient status [3]. This could help in the maintenance of soil nutrients for improved crop productivity.

Several factors including the physical and chemical properties of soils can influence the type of species, number and activities of microorganisms in a soil [4]. Studies have shown that in addition to environmental factors such as temperature, moisture and CO₂ levels, soil physical disturbance (structure), soil pH and other chemical properties are major determinants of soil microbial community structure [5-8]. Land use and soil management practices can influence soil nutrients through processes such as mineralization, oxidation, leaching and erosion [9, 10]. This may affect the presence and activities of soil microorganisms and hence soil fertility. For instance, intensive tillage operations common in continuously

cultivated soils may lead to increased decomposition/mineralization of available nutrients which may result to loss of nutrients from these soils.

Studies examining how different land use types influence the contributions of soil microorganisms to soil fertility are uncommon in tropical soil studies. Thus, the main objective of this research was to examine the contribution of microorganisms to soil fertility.

1.1. Soil Fertility

Soil fertility is ability of soil to provide all essential plant nutrients in available forms and in a suitable balance, it support luxuriant growth of plants with very little human effort [1]. It contains sufficient minerals, soil organic matters that improve soil structure, soil moisture retention, also nutrient retention and a pH between 5.5 and 7 [2]. The ability to supply essential plant nutrients and soil water in adequate proportion for plant growth and reproduction; and the absence of toxic substances which may inhibit plant growth. A fertile soil contains all the major nutrients for basic plant nutrition (e.g., nitrogen, phosphorus, and potassium), as well as other nutrients needed in smaller quantities (e.g., calcium, magnesium, sulfur, iron, zinc, copper, boron, molybdenum, nickel). Unfortunately, many soils do not have adequate levels of all the necessary plant nutrients, or conditions in the soil are unfavorable for plant uptake of certain nutrients [2]. Soil formation is the result of a complex network of biological as well as chemical and physical processes. The role of soil microbes is of high interest, since they are responsible for most biological transformations and drive the development of stable and labile pools of carbon (C), nitrogen (N) and other nutrients, which facilitate the subsequent establishment of plant communities. In this review we give insights into the role of microbes for soil development. Special attention is given to the development of nutrient cycles on the formation of biological soil crusts (BSCs) and on the establishment of plant-microbe interactions [4, 5]. The biological soil quality is determined by rooting, organic matter and underground biodiversity. Water and oxygen are critical factors for the balance and quality of soil life because they are needed for chemical reactions to occur [5].

1.2. Soil Microbiology

Soil microbiology is the study of organisms in soil, their functions, and how they affect soil properties. It is believed that between two and four billion years ago, the first ancient bacteria and microorganisms came about in Earth's oceans. These bacteria could fix nitrogen, in time multiplied and as a result released oxygen into the atmosphere. This led to more advanced microorganisms. Microorganisms in soil are important because they affect soil structure and fertility. Soil microorganisms can be classified as bacteria, actinomycetes, fungi, algae and protozoa. Each of these groups has characteristics that define them and their functions in soil [1]. Up to 10 billion bacterial cells inhabit each gram of soil in and around plant roots, a region known as the rhizosphere. In 2011,

a team detected more than 33,000 bacterial and archaeal species on sugar beet roots. The composition of the rhizobium can change rapidly in response to changes in the surrounding environment [2].

Micro-organisms

These are the smallest organisms (<0.1 mm in diameter) and are extremely abundant and diverse. They include algae, bacteria, cyanobacteria, fungi, yeasts, myxomycetes and actinomycetes that are able to decompose almost any existing natural material. Micro-organisms transform organic matter into plant nutrients that are assimilated by plants. Two main groups are normally found in agricultural soils: bacteria and mycorrhizal fungi.

(i) Bacteria

Bacteria are important in agricultural soils because they contribute to the carbon cycle by fixation (photosynthesis) and decomposition [1]. Some bacteria are important decomposers and others such as actinomycetes are particularly effective at breaking down tough substances such as cellulose (which makes up the cell walls of plants) and chitin (which makes up the cell walls of fungi). Land management has an influence on the structure of bacterial communities as it affects nutrient levels and hence can shift the dominance of decomposers from bacterial to fungal.

One group of bacteria is particularly important in nitrogen cycling. Free-living bacteria fix atmospheric N, adding it to the soil nitrogen pool; this is called biological nitrogen fixation and it is a natural process highly beneficial in agriculture. Other N-fixing bacteria form associations (in the form of nodules) with the roots of leguminous plants. The nodule is the place where the atmospheric N is fixed by bacteria and converted into ammonium that can be readily assimilated by the plant. The process is rather complicated but, in general, the bacteria multiply near the root and then adhere to it. Next, small hairs on the root surface curl around the bacteria and they enter the root. Alternatively, the bacteria may enter directly through points on the root surface. Once inside the root, the bacteria multiply within thin threads. Signals stimulate cell multiplication of both the plant cells and the bacteria. This repeated division results in a mass of root cells containing many bacterial cells. Some of these bacteria then change into a form that is able to convert gaseous N into ammonium nitrogen (they can "fix" N). These bacteria are then called bacteroids and present different properties from those of free cells. Most plants need very specific kinds of rhizobia to form nodules. A specific Rhizobium species will form a nodule on a specific plant root, and not on others. The shapes that the nodules form are controlled by the plant and nodules can vary considerably in size and shape.

Bacteria produce (exude) a sticky substance in the form of polysaccharides (a type of sugar) that helps bind soil particles into small aggregates, conferring structural stability to soils. Thus, bacteria are important as they help improve soil aggregate stability, water infiltration, and water holding capacity. However, in general their effect is less marked than that originated by large invertebrates such as earthworms.

Biochemical processes

One of the most distinguished features of bacteria is their biochemical versatility. A bacterial genus called *Pseudomonas* can metabolize a wide range of chemicals and fertilizers. In contrast, Bacteria are responsible for the process of nitrogen fixation, which is the conversion of atmospheric nitrogen into nitrogen-containing compounds (such as ammonia) that can be used by plants, this is achieved by another genus known as *Nitrobacter* can only derive its energy by turning nitrite into nitrate, which is also known as oxidation. The genus *Clostridium* is an example of bacterial versatility because it, unlike most species, can grow in the absence of oxygen, respiring anaerobically. Several species of *Pseudomonas*, such as *Pseudomonas aeruginosa* are able to respire both aerobically and anaerobically, using nitrate as the terminal electron acceptor [3].

(ii) Actinomycetes

Actinomycetes are soil microorganisms. They are a type of bacteria, but they share some characteristics with fungi that are most likely a result of convergent evolution due to a common habitat and lifestyle [4]. Although, they are members of the Bacteria kingdom, many actinomycetes share characteristics with fungi, including shape and branching properties, spore formation and secondary metabolite production. a. The mycelium branches in a manner similar to that of fungi, b. They form aerial mycelium as well as conidia. c. Their growth in liquid culture occurs as distinct clumps or pellets, rather than as a uniform turbid suspension as in bacteria.

Actinomycetes form thread-like filaments in the soil. The distinctive scent of freshly exposed, moist soil is attributed to these organisms, especially to the nutrients they release as a result of their metabolic processes. Actinomycetes form associations with some non-leguminous plants and fix N, which is then available to both the host and other plants in the near vicinity.

(iii) Fungi

Fungi are abundant in soil, but bacteria are more abundant. Fungi are important in the soil as food sources for other, larger organisms, pathogens, beneficial symbiotic relationships with plants or other organisms and soil health. Fungi can be split into species based primarily on the size, shape and color of their reproductive spores, which are used to reproduce. Most of the environmental factors that influence the growth and distribution of bacteria and actinomycetes also influence fungi. The quality as well as quantity of organic matter in the soil has a direct correlation to the growth of fungi, because most fungi consume organic matter for nutrition. Fungi thrive in acidic environments, while bacteria and actinomycetes cannot survive in acid, which results in an abundance of fungi in acidic areas. Fungi also grow well in dry, arid soils because fungi are aerobic, or dependent on oxygen, and the higher the moisture content in the soil, the less oxygen is present for them. These organisms are responsible for the important process of decomposition in terrestrial ecosystems as they degrade and assimilate cellulose, the component of plant cell walls. Fungi are constituted by microscopic cells that usually grow as long threads or strands called hyphae of only a few

micrometres in diameter but with the ability to span a length from a few cells to many metres. Soil fungi can be grouped into three general functional groups based on how they source their energy:

Decomposers - saprophytic fungi - convert dead organic material into fungal biomass, CO₂, and small molecules, such as organic acids. These fungi generally use complex substrates, such as the cellulose and lignin, in wood. They are essential for decomposing the carbon ring structures in some pollutants [34]. Like bacteria, fungi are important for immobilizing or retaining nutrients in the soil.

Mutualists - mycorrhizal fungi - colonize plant roots through a symbiotic relationship. The definition of symbiosis is a close, prolonged association between two or more different organisms of different species that may benefit each member. Mycorrhizae increase the surface area associated with the plant root, which allows the plant to reach nutrients and water that otherwise might not be available. Mycorrhizae essentially extend plant reach to water and nutrients, allowing plants to utilize more of the resources available in the soil. Mycorrhizae source their carbohydrates (energy) from the plant root they are living in/on and they usually help the plants by transferring phosphorus (P) from the soil into the root. Two major groups are identified: (i) ectomycorrhizae, that grow on the surface layers of the roots and are commonly associated with trees; and (ii) endomycorrhizae, such as arbuscular mycorrhizal fungi and vesicular mycorrhizal fungi, that grow within the root cells and are commonly associated with grasses, row crops, vegetables and shrubs. Arbuscular mycorrhizal fungi can also benefit the physical characteristics of the soil because their hyphae form a mesh to help stabilize soil aggregates. Vesicular-arbuscular mycorrhizae are the most widespread mycorrhizal fungi. Mycorrhizae are particularly important for phosphate uptake because P does not move towards plant roots easily. These organisms do not harm the plant, and in return, the plant provides energy to the fungus in the form of sugars. The fungus is actually a network of filaments that grows in and around the plant root cells, forming a mass that extends considerably beyond the root system of the plant.

Pathogens or parasites cause reduced production or death when they colonize roots and other organisms. Root-pathogenic fungi, such as *Verticillium*, *Pythium* and *Rhizoctonia*, cause major economic losses in agriculture each year. Many fungi help control diseases, e.g. nematode-trapping fungi that parasitize disease-causing nematodes and fungi that feed on insects may be useful as biocontrol agents.

(iv) Algae

Algae can make their own nutrients through photosynthesis. Photosynthesis converts light energy to chemical energy that can be stored as nutrients. For algae to grow, they must be exposed to light because photosynthesis requires light, so algae are typically distributed evenly wherever sunlight and moderate moisture is available. Algae do not have to be directly exposed to the Sun, but can live below the soil surface given uniform temperature and moisture conditions. Algae are

also capable of performing nitrogen fixation [1].

Types

Algae can be split up into three main groups: the Cyanophyceae, the Chlorophyceae and the Bacillariaceae. The Cyanophyceae contain chlorophyll, which is the molecule that absorbs sunlight and uses that energy to make carbohydrates from carbon dioxide and water and also pigments that make it blue-green to violet in color. The Chlorophyceae usually only have chlorophyll in them which makes them green, and the Bacillariaceae contain chlorophyll as well as pigments that make the algae brown in color [1].

a. Blue-green algae and nitrogen fixation

Blue-green algae, or Cyanophyceae, are responsible for nitrogen fixation. The amount of nitrogen they fix depends more on physiological and environmental factors rather than the organism's abilities. These factors include intensity of sunlight, concentration of inorganic and organic nitrogen sources and ambient temperature and stability [4].

(v) Protozoa

Protozoa are eukaryotic organisms that were some of the first microorganisms to reproduce sexually, a significant evolutionary step from duplication of spores, like those that many other soil microorganisms depend on. Protozoa can be split up into three categories: flagellates, amoebae and ciliates [4].

a. Flagellates

Flagellates are the smallest members of the protozoa group, and can be divided further based on whether they can participate in photosynthesis. Non-chlorophyll-containing flagellates are not capable of photosynthesis because chlorophyll is the green pigment that absorbs sunlight. These flagellates are found mostly in soil. Flagellates that contain chlorophyll typically occur in aquatic conditions. Flagellates can be distinguished by their flagella, which is their means of movement. Some have several flagella, while other species only have one that resembles a long branch or appendage [4].

b. Amoebae

Amoebae are larger than flagellates and move in a different way. Amoebae can be distinguished from other protozoa by their slug-like properties and pseudopodia. A pseudopodium or "false foot" is a temporary protrusion from the body of the amoeba that helps pull it along surfaces for movement or helps to pull in food. The amoeba does not have permanent appendages and the pseudopodium is more of a slime-like consistency than a flagellum [4].

c. Ciliates

Ciliates are the largest of the protozoa group, and move by means of short, numerous cilia that produce beating movements. Cilia resemble small, short hairs. They can move in different directions to move the organism, giving it more mobility than flagellates or amoebae [4].

Composition regulation

Plant hormones salicylic acid, jasmonic acid and ethylene are key regulators of innate immunity in plant leaves. Mutants impaired in salicylic acid synthesis and signaling are hypersusceptible to microbes that colonize the host plant to obtain nutrients, whereas mutants impaired in jasmonic acid

and ethylene synthesis and signaling are hypersusceptible to herbivorous insects and microbes that kill host cells to extract nutrients. The challenge of modulating a community of diverse microbes in plant roots is more involved than that of clearing a few pathogens from inside a plant leaf. Consequently, regulating root microbiome composition may require immune mechanisms other than those that control foliar microbes [5].

A 2015 study analyzed a panel of *Arabidopsis* hormone mutants impaired in synthesis or signaling of individual or combinations of plant hormones, the microbial community in the soil adjacent to the root and in bacteria living within root tissue. Changes in salicylic acid signaling stimulated a reproducible shift in the relative abundance of bacterial phyla in the endophytic compartment. These changes were consistent across many families within the affected phyla, indicating that salicylic acid may be a key regulator of microbiome community structure [5]. Classical plant defense hormones also function in plant growth, metabolism and abiotic stress responses, obscuring the precise mechanism by which salicylic acid regulates this microbiome [5]. During plant domestication, humans selected for traits related to plant improvement, but not for plant associations with a beneficial microbiome. Even minor changes in abundance of certain bacteria can have a major effect on plant defenses and physiology, with only minimal effects on overall microbiome structure. [5]

(vi) Microfauna

The microfauna (<0.1 mm in diameter) includes *inter alia* small collembola and mites, nematodes and protozoa that generally live in the soil water films and feed on microflora, plant roots, other microfauna and sometimes larger organisms (e.g. entomopathogenic nematodes feed on insects and other larger invertebrates). They are important to release nutrients immobilized by soil microorganisms.

Nematodes

Nematodes are tiny filiform roundworms that are common in soils everywhere. They may be free-living in soil water films; beneficial for agriculture or phytoparasitic and live at the surface or within the living roots (parasites). Free-living nematodes graze on bacteria and fungi, thus they control the populations of harmful micro-organisms. These nematodes are 0.15-5 mm long and 2-100 µm wide; an exception are Mermithidae nematodes, which may be 20 cm long and are very common in tropical soils, being parasites of some arthropods such as locusts. Nematodes can only move through the soil where a film of moisture surrounds the soil particles. They live in the water (they are hydrobionts) that fills spaces between soil particles and covers roots. In hot and dry conditions, they enter into a dormant stage, and as soon as water becomes available, they spring back to activity. Nematodes are recognized as a major consumer group in soils, generally grouped into four to five trophic categories based on the nature of their food, the structure of the stoma (mouth) and oesophagus, and the method of feeding [6]: bacterial feeders, fungal feeders, predatory feeders, omnivores, and plant feeders. The bacterial feeders prey on bacteria (bacterivores)

and may ingest up to 5 000 cells/minute, or 6.5 times their own weight daily. This helps disperse both the organic matter and the decomposers in the soil. Bacterial- and fungal-feeding nematodes release a large percent of N when feeding on their prey groups and are thus responsible for much of the plant available N in the majority of soils [10]. The annual overall consumption may be as much as 800 kg of bacteria per hectare and the amount of N turned over in the range of 20-130 kg [6]. Phytophages or plant-feeding nematodes damage plant roots, with important economic consequences for farmers. They possess stylets with a wide diversity of size and structure, and they are the most extensively studied group of soil nematodes because of their ability to cause plant disease and reduce crop yield.

2. Methods

2.1. Applications of Microbes to Soil

2.1.1. Agriculture

Microbes can make nutrients and minerals in the soil available to plants, produce hormones that spur growth, stimulate the plant immune system and trigger or dampen stress responses. In general a more diverse soil microbiome results in fewer plant diseases and higher yield. Farming can destroy soil's rhizobiome (microbial ecosystem) by using soil amendments such as fertilizer and pesticide without compensating for their effects. By contrast, healthy soil can increase fertility in multiple ways, including supplying nutrients such as nitrogen and protecting against pests and disease, while reducing the need for water and other inputs. Some approaches may even allow agriculture in soils that were never considered viable [2]. The groups of bacteria called rhizobia live inside the roots of legumes and fix nitrogen from the air into a biologically useful form. Mycorrhizae or root fungi form a dense network of thin filaments that reach far into the soil, acting as extensions of the plant roots they live on or in. These fungi facilitate the uptake of water and a wide range of nutrients. Up to 30% of the carbon fixed by plants is excreted from the roots as so-called exudates—including sugars, amino acids, flavonoids, aliphatic acids, and fatty acids—that attract and feed beneficial microbial species while repelling and killing harmful ones [2]. *Stenotrophomonas rhizophila* increases drought tolerance in crops such as sugar beets and maize. The microbe excretes molecules that help plants withstand stress, including osmoprotectants, which prevent the catastrophic outflux of water from plants in salty environments [2]. Microbes can affect the flavor of food plants: A bacterium called *Methylobacterium extorquens* increases the production of furanones, a group of molecules that gives strawberries their characteristic flavor [2]. One approach is to apply microbes to plant seeds before planting instead of directly into soil [2].

2.1.2. Commercial Activity

Almost all registered microbes are biopesticides, producing some \$1 billion annually, less than 1% of the chemical

amendment market, estimated at \$110 billion. Some microbes have been marketed for decades, such as *Trichoderma* fungi that suppress other, pathogenic fungi, and the caterpillar killer *Bacillus thuringiensis*. Serenade is a biopesticide containing a *Bacillus subtilis* strain that has antifungal and antibacterial properties and promotes plant growth. It can be applied in a liquid form on plants and to soil to fight a range of pathogens. It has found acceptance in both conventional and organic agriculture. Agrochemical companies such as Bayer have begun investing in the technology. In 2012, Bayer bought AgraQuest for \$425 million. Its €10 million annual research budget funds field-tests of dozens of new fungi and bacteria to replace chemical pesticides or to serve as biostimulants to promote crop health and growth. Novozymes, a company developing microbial fertilizers and pesticides, forged an alliance with Monsanto. Novozymes invested in a biofertilizer containing the soil fungus *Penicillium bilaiae* and a bioinsecticide that contains the fungus *Metarhizium anisopliae*. In 2014 Syngenta and BASF acquired companies developing microbial products, as did Dupont in 2015 [2].

A 2007 study showed that a complex symbiosis with fungi and viruses makes it possible for a grass called *Dichanthelium lanuginosum* to thrive in geothermal soils in Yellowstone National Park, where temperatures reach 60°C (140 °F). Introduced in the US market in 2014 for corn and rice, they trigger an adaptive stress response [2, 3]. In both the US and Europe, companies have to provide regulatory authorities with evidence that both the individual strains and the product as a whole are safe, leading many existing products to label themselves "biostimulants" instead of "biopesticides" [2].

Unhelpful microbes

A funguslike unicellular organism named *Phytophthora infestans*, responsible for potato blight and other crop diseases, has caused famines throughout history. Other fungi and bacteria cause the decay of roots and leaves. [2] Many strains that seemed promising in the lab often failed to prove effective in the field, because of soil, climate and ecosystem effects, leading companies to skip the lab phase and emphasize field tests [8].

Fade

Populations of beneficial microbes can diminish over time. Serenade stimulates a high initial *B. subtilis* density, but levels decrease because the bacteria lacks a defensible niche. One way to compensate is to use multiple collaborating strains. Fertilizers deplete soil of organic matter and trace elements, cause salination and suppress mycorrhizae; they can also turn symbiotic bacteria into competitors [5-7].

Pilot project

A pilot project in Europe used a plow to slightly loosen and ridge the soil. They planted oats and vetch, which attracts nitrogen-fixing bacteria. They planted small olive trees to boost microbial diversity. They split an unirrigated 100-hectare field into three zones, one treated with chemical fertilizer and pesticides; and the other two with different amounts of an organic biofertilizer, consisting of fermented grape leftovers and a variety of bacteria and fungi, along with four types of mycorrhiza spores [2].

The crops that had received the most organic fertilizer had reached nearly twice the height of those in zone A and were inches taller than zone C. The yield of that section equaled that of irrigated crops, whereas the yield of the conventional technique was negligible. The mycorrhiza had penetrated the rock by excreting acids, allowing plant roots to reach almost 2 meters into the rocky soil and reach groundwater [11].

2.2. Soil Organisms

Soil organisms are responsible, to a varying degree depending on the system, for performing vital functions in the soil. Soil organisms make up the diversity of life in the soil. This soil biodiversity is an important but poorly understood component of terrestrial ecosystems. Soil biodiversity is comprised of the organisms that spend all or a portion of their life cycles within the soil or on its immediate surface (including surface litter and decaying logs). Soil organisms represent a large fraction of global terrestrial biodiversity. They carry out a range of processes important for soil health and fertility in soils of both natural ecosystems and agricultural systems. This annex provides brief descriptions of organisms that are commonly found in the soil and their main biological and ecological attributes [6].

The community of organisms living all or part of their lives in the soil constitute the soil food web. The activities of soil organisms interact in a complex food web with some subsisting on living plants and animals (herbivores and

predators), others on dead plant debris (detritivores), on fungi or on bacteria, and others living off but not consuming their hosts (parasites). Plants, mosses and some algae are autotrophs, they play the role of primary producers by using solar energy, water and carbon (C) from atmospheric carbon dioxide (CO₂) to make organic compounds and living tissues. Other autotrophs obtain energy from the breakdown of soil minerals, through the oxidation of nitrogen (N), sulphur (S), iron (Fe) and C from carbonate minerals. Soil fauna and most fungi, bacteria and actinomycetes are heterotrophs, they rely on organic materials either directly (primary consumers) or through intermediaries (secondary or tertiary consumers) for C and energy needs [36].

The “structure” of a food web is the composition and relative numbers of organisms in each group within the soil. The living component of soil, the food web, is complex and has different compositions in different ecosystems. In a healthy soil, there are a large number of bacteria and bacterial feeding organisms. Where the soil has received heavy treatments of pesticides, chemical fertilizers, soil fungicides or fumigants that kill these organisms, the beneficial soil organisms may die (impeding the performance of their activities), or the balance between the pathogens and beneficial organisms may be upset, allowing those called opportunists (disease-causing organisms) to become problems.

Table 1. Categories and characteristics of soil organisms.

Category	Characteristics	Organisms
Permanent	Whole life cycle in the soil	Mites, collembola, earthworms
Temporal	Part of life cycle in the soil	Insect larvae
Periodical	Frequently enter into the soil	Some insect larvae
Transitory	An inactive phase in the soil (e.g. eggs, pupae, hibernation) but the active period not in the soil	Some insects
Accidental	Organisms fall down or they are drawn along	Insect larvae

The easiest and most widely used system for classifying soil organisms is by using body size and dividing them into three main groups: macrobiota, mesobiota and microbiota [9, 10]. The ranges that determine each size group are not exact for all members of each group.

2.2.1. MESOFAUNA

Mesofauna (0.1-2 mm in diameter) includes mainly microarthropods, such as pseudoscorpions, springtails, mites, and the worm-like enchytraeids. Mesofauna have limited burrowing ability and generally live within soil pores, feeding on organic materials, microflora, microfauna and other invertebrates [12].

(i) Collembola

Collembola or “springtails” are microarthropods that live in the litter or in the pore space of the upper 10-15 cm of soil. They are saprophagous and feed mainly on fungi, bacteria and algae growing on decomposing plant litter [14]. They are important as epigeic decomposers. Unlike most insects, they have no wings at any stage. They measure a few millimetres in length and elongate with a characteristic salutory organ, a

forked “tail” which enables them to spring when in danger. Springtails are probably the most abundant group of insects on Earth.

(ii) Pseudoscorpions

Pseudoscorpions are tiny arachnids rarely longer than 8 mm. They live in litter, decaying vegetation, and the soil. Pseudoscorpions superficially resemble true scorpions, bearing relatively large chelae on the pedipalps, but they do not have a telson or stinger. Pseudoscorpions feed on very small arthropods such as springtails and mites.

2.2.2. MACROFAUNA

Members of species classed as macrofauna are visible to the naked eye (generally > 2 mm in diameter). Macrofauna includes vertebrates (snakes, lizards, mice, rabbits, moles, etc.) that primarily dig within the soil for food or shelter, and invertebrates (snails, earthworms and soil arthropods such as ants, termites, millipedes, centipedes, caterpillars, beetle larvae and adults, fly and wasp larvae, spiders, scorpions, crickets and cockroaches) that live in and feed in or upon the soil, the surface litter and their components. In both natural

and agricultural systems, soil macrofauna are important regulators of decomposition, nutrient cycling, soil organic matter dynamics, and pathways of water movement as a consequence of their feeding and burrowing activities. Here the focus is on soil invertebrates.

(i) *Earthworms*

The effects of earthworms in the soil differ according to the ecological category of the species involved:

- 1) Epigeic: they live in the litter layers, a very changing environment, subject to drought, high temperatures and predator presence. These earthworms are generally small and pigmented (green or reddish) with rapid movements.
- 2) Endogeic: these are unpigmented (with no colour) worms that live and feed in the soil. This group is further divided into three subgroups: oligohumic, mesohumic and polyhumic, depending on the organic matter content of the soil ingested.
- 3) Anecic: these earthworms feed on the surface litter that they generally mix with soil, but they spend most of their time in the soil. They are large, with dark anterodorsal pigmentation, and they dig subvertical burrows.

As a result of this wide range of adaptations, earthworms have diverse functions in the soil. Epigeic worms can be used as compost makers with no impact on soil structure. Anecics and endogeics do have an impact on soil structure owing to their mixing and burrowing activities, and on soil organic matter [16, 25].

Earthworms generally exert beneficial effects on plant growth. However, negative effects may be induced under particular situations. The effect on grain yields is also proportional to the earthworm biomass; significant effects start to appear at biomass values > 30 g fresh weight [7], although very high biomasses of single species of earthworms, (e.g. *Pontoscolex corethrurus*) may inhibit production under particular situations. Many mechanisms are involved in the growth stimulation. These vary from large-scale effects on soil structure and nutrient availability, to the enhancement of mycorrhizal infection or control of plant-parasitic nematodes. Once the earthworms are established, a dynamic cropping system - involving crop rotations with long cycle crops or perennials with good organic matter additions - contributes to securing long-lasting benefits from earthworm activities. [17].

(ii) *Termites*

Termites are important members of soil macrofauna in various regions of the world. They are social insects, living in organized colonies with a number of castes (different individuals) with a set of morphological and physiological specializations. The main castes are: queen (the termite that founds the colony), worker and soldier.

Neither individual termites nor colonies normally travel long distances as they are constrained to live within their territorial border or within their food materials. A number of species feed on living plants and some may become serious pests in agricultural systems where dead residues are scarce [15]. Most species feed on dead-plant materials above and below the soil surface. Their food sources include

plant-decaying materials, dead foliage, woody materials, roots, seeds and the faeces of higher animals [25]. There are also soil-wood feeders and soil feeders, which means that they ingest a high proportion of mineral material. Their nutrition derives mainly from well-decayed wood and partly humified soil organic matter. Another group of termites grow fungi in their nests (fungus-growing termites).

Termites may be classified by their feeding habits:

- 1) grass harvesters,
- 2) surface litter feeders,
- 3) wood feeders,
- 4) soil-wood feeders,
- 5) soil feeders (humivores).

The nests formed by termites may occur in different locations, e.g. within the wood of living or dead trees, in subterranean locations, in other nests formed by other termite species, and by forming epigeal nests (above the soil surface) and arboreal nests.

(iii) *Ants*

Ants build a large variety of structures in the soil. However, because of their feeding habits, they are of less importance in regulating processes in the soil than termites or earthworms.

(iv) *Beetles*

Beetles (Coleoptera) are diverse taxonomically and differ widely in size and in the ecological role they perform in soil and litter. They are either saprophagous, phytophagous or predators. Two groups are of particular relevance in agricultural soils: larvae from the family Scarabaeidae (dung-beetles), crucial to burying cowdung in natural savannahs and grasslands used for cattle grazing (e.g. in Africa); and Melolonthinae beetles, whose larvae may be abundant in grasslands and affect crop production by feeding on living roots [21].

Dung beetles dig subvertical galleries 10-15 mm wide down to a depth of 50-70 cm with a variable number of chambers, which are further filled with large pellets of dung. The adult beetle lays one egg in each chamber and then the larva feeds on the pellet to complete the cycle [25]. They generally give rise to small mounds a few centimetres high on the soil surface [18].

2.3. *Biogenic Structures*

Biogenic structures are those structures created biologically by a living organism. Three main groups of biogenic structures are commonly found in agricultural systems: earthworm casts and burrows, termite mounds and ant heaps. The biogenic structures can be deposited in the soil surface and in the soil, and generally they have different physical and chemical properties from the surrounding soil. The colour, size, shape and general aspect of the structures produced by large soil organisms can be described for each species that produces it. The form of the biogenic structure can be likened to simple geometric forms in order to facilitate evaluation of the volume of soil moved through each type of structure on the soil surface.

2.3.1. Earthworm Casts

Earthworm casts vary in size depending on the size of the earthworm that produces them. They range from a few millimetres to several centimetres in diameter, weighing from only a few grams to more than 400 g.

Granular casts are very small and formed by isolated faecal pellets [22]. These casts can be found on the soil surface or within the soil, and are generally produced by epigeic earthworms.

Globular casts are larger and formed by large aggregates [22]. These are normally produced by endogeic and anecic earthworms. The casts produced by anecic earthworms comprise an accumulation of somewhat isolated round or oval-shaped pellets (one to several millimetres in diameter) which may coalesce into “paste-like slurries” that form large structures. Hence, casts are large in size, towerlike, and made of superposed layers of different ages, the older (i.e. dry and hard) located at the base and the younger (i.e. fresh and soft) on the top. Casts produced by anecic earthworms have a higher proportion of organic matter, especially large particles of plant material, and a larger proportion of small mineral components than in the surrounding soil.

2.3.2. Earthworm Burrows

Earthworms construct burrows or galleries through their movement in the soil matrix. The type and size of the galleries depends on the ecological category of earthworm that is producing it.

Anecic earthworms create semi-permanent subvertical galleries, while endogeic worms dig rather horizontal burrows. These galleries may be filled with casts, which can be split into smaller aggregates by other smaller earthworms or soil organisms. Galleries are cylindrical and their wall area coated with cutaneous mucus each time the worm passes through.

Soil micro-organisms (bacteria) are markedly concentrated at the surface of the gallery walls and within the adjacent 2 mm of the surrounding soil. This microenvironment comprises less than 3 percent of the total soil volume but contains 5-25 percent of the whole soil microflora and is where some functional groups of bacteria predominate [25].

2.3.3. Termite Mounds

Termite mounds are among the most conspicuous structures in savannah landscapes. Termite mounds are of diverse types and are the epigeal part of a termite nest that originates from subterranean beginnings. In Africa, termites build up half of the biomass of the plains.

Termites process high quantities of material in their building activities, thus influencing the soil properties as compared with surrounding soils [21]. Soil texture and structure are modified strongly in termite mounds. In general, the soil of the termite mounds exhibits a higher proportion of fine particles (clay), which termites transport from the deeper to upper soil horizons.

2.3.4. Ant Heaps

The tropical American genera *Acromyrmex* and *Atta* leaf-cutting ants make subterranean nests and their leaf

harvesting may lead to enormous incorporations of organic matter and, hence, nutrients into the soil.

2.4. Roots

Although not generally considered soil organisms, roots grow mostly within the soil and have wide-ranging, long-lasting effects on both plant and animal populations aboveground and belowground, and thus they are included among soil biota.

Rhizosphere

The rhizosphere is the region of soil immediately adjacent to and affected by plant roots. It is a very dynamic environment where plants, soil, micro-organisms, nutrients and water meet and interact. The rhizosphere differs from the bulk soil because of the activities of plant roots and their effect on soil organisms.

The root exudates can be used to increase the availability of nutrients and they provide a food source for micro-organisms. This causes the number of microorganisms to be greater in the rhizosphere than in the bulk soil. Their presence attracts larger soil organisms that feed on micro-organisms and the concentration of organisms in the rhizosphere can be up to 500 times higher than in the bulk soil. An important feature of the rhizosphere is the uptake of water and nutrients by plants. Plants take up water and nutrients into their roots. This draws water from the surrounding soil towards the roots and rhizosphere.

The soil organisms near the rhizosphere influence plant roots because:

- 1) They alter the movement of C compounds from roots to shoots (translocation).
- 2) Earthworm galleries (burrows) provide an easy pathway for roots to take as they grow through the soil.
- 3) Micorrhizal associations can increase nutrient uptake by plants.
- 4) Some of them are pathogenic and can attack plant roots.

3. Results Beneficial vs. Harmful Organisms in Agricultural Soils

Agricultural practices can have either positive or negative impacts on soil organisms. Land management and agricultural practices alter the composition of soil biota communities at all levels, with important consequences in terms of soil fertility and plant productivity. There are examples of both positive and negative effects of some groups of soil organisms, particularly micro-organisms, phytoparasites/pathogens or rhyzophages, plant roots, and macrofauna on plant production.

The different agricultural practices used by farmers also exert an important influence on soil biota, their activities and diversity. Clearing forested or grassland for cultivation has a drastic effect on the soil environment and, hence, on the numbers and kinds of soil organisms. In general, such activity reduces the quantity and quality of plant residues and the number of plant species considerably. Thus, the range of habitats and foods for soil organisms is reduced significantly.

Through changing the physical and chemical environment, agricultural practices alter the ratio of different organisms and their interactions significantly, for example, through adding lime, fertilizers and manures, or through tillage practices and pesticide use.

The beneficial effects of soil organisms on agricultural productivity that may be affected include:

- 1) organic matter decomposition and soil aggregation;
- 2) breakdown of toxic compounds, both metabolic by-products of organisms and agrochemicals;
- 3) inorganic transformations that make available nitrates, sulphates and phosphates as well as essential elements such as Fe and Mn;
- 4) N fixation into forms usable by higher plants.

However, other soil organisms are detrimental or harmful to plant production. For example ants, aphids and phytophagous nematodes can be serious pests, and some micro-organisms, bacteria and actinomycetes cause also plant diseases. However, most damage is caused by fungi, which account for most soil-borne crop diseases [19].

Humans generally begin their influence on soil biodiversity with naturally present communities at a particular site (resulting essentially from ecological and evolutionary forces). However, they also have the ability to introduce new organisms and, through imposition of different management practices, put selective pressures on the naturally present or introduced soil biota. This provides the opportunity to manage soil organisms and their activities in order to enhance soil fertility and crop growth. Although probably enough is known in theory to manage these communities, considerable basic and applied research is required in order to achieve appropriate levels of biological husbandry and optimal management of these biological resources [19].

Effects of organic matter on soil properties

Organic matter affects both the chemical and physical properties of the soil and its overall health. Properties influenced by organic matter include: soil structure; moisture holding capacity; diversity and activity of soil organisms, both those that are beneficial and harmful to crop production; and nutrient availability. It also influences the effects of chemical amendments, fertilizers, pesticides and herbicides.

Soil organic matter consists of a continuum of components ranging from labile compounds that mineralize rapidly during the first stage of decomposition to more recalcitrant residues (difficult to degrade) that accumulate as they are deposited during advanced stages of decomposition as microbial by-products [21-24].

Freshly added or partially decomposed plant residues and their non-humic decomposition products constitute the labile organic matter pool. The more stable humic substances tend to be more resistant to further decomposition. The labile soil organic matter pool regulates the nutrient supplying power of the soil, particularly of nitrogen (N), whereas both the labile and stable pools affect soil physical properties, such as aggregate formation and structural stability. When crops are harvested or residues burned, organic matter is removed from the system. However, the loss can be minimized by retaining

plant roots in the soil and leaving crop residues on the surface. Organic matter can also be restored to the soil through growing green manures, cuttings from agroforestry species and the addition of manures and compost. Soil organic matter is the key to soil life and the diverse functions provided by the range of soil organisms.

3.1. Biological Properties

Soil micro-organisms are of great importance for plant nutrition as they interact directly in the biogeochemical cycles of the nutrients.

Increased production of green manure or crop biomass aboveground and belowground increases the food source for the microbial population in the soil. Agricultural production systems in which residues are left on the soil surface and roots left in the soil, e.g. through direct seeding and the use of cover crops, therefore stimulate the development and activity of soil micro-organisms. In one 19-year experiment in Brazil, such practices resulted in a 129- percent increase in microbial carbon biomass and a 48-percent increase in microbial N biomass. The roots of most plants are infected with mycorrhizae, fungi that form a network of mycelia or threads on the roots and extend the surface area of the roots. [23-25].

In undisturbed soil ecosystems, e.g. in conservation agriculture, colonization with mycorrhizal fungi increases strongly with time compared with colonization under natural vegetation. Fine roots are the primary sites of mycorrhizal development as they are the most active site for nutrient uptake. This partly explains the increase in mycorrhizal colonization under undisturbed situations as rooting conditions are far better than under conventional tillage. Other factors that might stimulate mycorrhizal development are the increase in organic carbon (C) and the rotation of crops with cover crop/green manure species.

Another consequence of increased organic matter content is an increase in the earthworm population. Earthworms rarely come to the soil surface because of their characteristics: photophobia, lack of pigmentation and tolerance to periods of submergence and anaerobic conditions during rainfall. Soil moisture is one of the most important factors that determine the presence of earthworms in the soil. Through cover crops and crop residues, evaporation is reduced and organic matter in the soil is increased, which in turn can hold more water.

Residues on the soil surface induce earthworms to come to the surface in order to incorporate the residues in the soil. The burrowing activity of earthworms creates channels for air and water; this has an important effect on oxygen diffusion in the root zone, and the drainage of water from it. Furthermore, nutrients and amendments can be distributed easily and the root system can develop, especially in acid subsoil in the existing casts [26]. The shallow-dwelling earthworms create numerous channels throughout the topsoil, which increases overall porosity, and thus bulk density. The large vertical channels created by deep-burrowing earthworms increase water infiltration under very intense rainfall conditions.

3.2. Chemical Properties

Many important chemical properties of soil organic matter result from the weak acid nature of humus. The ability of organic matter to retain cations for plant use while protecting them from leaching, i.e. the cation exchange capacity (CEC) of the organic matter, is due to the negative charges created as hydrogen (H) is removed from weak acids during neutralization. Many acid-forming reactions occur continually in soils. Some of these acids are produced as a result of organic matter decomposition by microorganisms, secretion by roots, or oxidation of inorganic substances. Commonly used N fertilizers through microbial conversion of NH_4^+ to NO_3^- . In particular, ammonium fertilizers, such as urea, and ammonium phosphates, such as monoammonium and diammonium phosphate, are converted rapidly into nitrate through a nitrification process, releasing acids in the process and thus increasing the acidity of the topsoil [20].

When acids or bases are added to the soil, organic matter reduces or buffers the change in pH. This is why it takes tonnes of limestone to increase the pH of a soil significantly compared with what would be needed to simply neutralize the free H present in the soil solution. All of the free hydrogen ions in the water in a very strongly acid soil (pH 4) could be neutralized with less than 6 kg of limestone per hectare. However, from 5 to more than 24 tonnes of limestone per hectare would be needed to neutralize enough acidity in that soil to enable acid sensitive crops to grow. Almost all of the acid that must be neutralized to increase soil pH is in organic acids, or associated with aluminium (Al) where the pH is very low [31].

However, with large values of soil organic matter, the pH will decrease less rapidly and the field will have to be limed less frequently. A lime application of 1-2 tonnes/ha every 2-3 years might be sufficient to regulate the acidity [31].

Organic matter may provide nearly all of the CEC and pH buffering in soils low in clay or containing clays with low CEC. In comparing conventional and conservation tillage in Brazil, the highest values of soil CEC and exchangeable calcium (Ca) and magnesium (Mg) were found in legume-based rotation systems with the highest organic matter content. In particular, systems with pigeon peas and lablab resulted in a 70-percent increase in CEC compared with a fallow/maize system.

Organic matter releases many plant nutrients as it is broken down in the soil, including N, phosphorus (P) and sulphur (S). Leguminous species are very important as part of a cereal crop rotation in view of their capacity to fix N from the atmosphere through symbiotic associations with root dwelling bacteria. Again in Brazil, five years after starting an intensive system in which oats and clover were rotated with maize and cowpea, there was 490 kg/ha more total soil N in the 0-17.5-cm soil layer than under the traditional oats/maize system with conventional tillage [20]. After nine years, no tillage in combination with the intensive cropping system had resulted in a 24-percent increase in soil N compared with conventional tillage. Although N uptake by plants was less in no-tillage

systems, probably because of N immobilization and organic matter building, the maize yields under the different tillage systems did not differ. As the no-tillage system was more efficient in storing soil N from legume cover crops in the topsoil, in the long term this system can increase soil N available for maize production [27-29].

The P content (both inorganic P and total P) of the surface layer (0-5 cm) was higher in the plots with cover crops after nine years. Cover crops were shown to have an important P-recycling capacity, especially when the residues were left on the surface. This was especially clear in the fallow plots, where the conventional tillage plots had a P content 25 percent lower than the no-tillage plots. Depending on the cover crop, the increase was between 2 and almost 30 percent. Even more important is the effect of land preparation on the increase of P availability in the soil [29].

3.3. Physical Properties

Organic matter influences the physical conditions of a soil in several ways. Plant residues that cover the soil surface protect the soil from sealing and crusting by raindrop impact, thereby enhancing rainwater infiltration and reducing runoff. Increased organic matter also contributes indirectly to soil porosity (via increased soil faunal activity) [13].

Fresh organic matter stimulates the activity of macrofauna such as earthworms, which create burrows lined with the glue-like secretion from their bodies and intermittently filled with worm cast material. Surface infiltration depends on a number of factors including aggregation and stability, pore continuity and stability, the existence of cracks, and the soil surface condition.

Organic matter also contributes to the stability of soil aggregates and pores through the bonding or adhesion properties of organic materials, such as bacterial waste products, organic gels, fungal hyphae and worm secretions and casts. Moreover, organic matter intimately mixed with mineral soil materials has a considerable influence in increasing moisture holding capacity. The quality of the crop residues, in particular its chemical composition, determines the effect on soil structure and aggregation. [28].

3.4. Benefits of Soil Organic Matter

As noted above, the benefits of a soil that is rich in organic matter and hence rich in living organisms are many. Direct organic matter amendments include:

- 1) compost;
- 2) animal manure;
- 3) use of vermicompost;
- 4) use of waste sludge.

Crop management practices that contribute to organic matter include:

- 1) improved cropping systems and rotations;
- 2) plant cover crops;
- 3) maximizing crop residues and their management;
- 4) improved rooting systems.

The effects of the management practices depend largely on

the agroclimatic situation as temperature and moisture influence speed of decomposition and general cycling of organic matter and nutrients.

Benefits of soil organic matter for farmers include:

- 1) Reduced input costs: reduced fertilizer needs owing to improved nutrient cycling and reduced leaching from the rootzone; reduced pesticide needs owing to pest-predator interactions among organisms and natural biocontrol; reduced tillage costs owing to reliance on biotillage by macrofauna under conservation agriculture approaches.
- 2) Improved yield and crop quality: soil organic matter and soil biodiversity contribute to improved soil structure, root growth and mycorrhizal development, access to water and nutrients and hence improved root and tuber development and aboveground plant production. Improved soil and crop health reduce impacts of disease-causing organisms (pathogens and viruses and harmful bacteria).
- 3) Pollution prevention: soil organic matter enhances biological activity of soil organisms that detoxify and absorb excess nutrients that would otherwise become pollutants to groundwater and surface water supplies. Soil organic matter is an important means of C sequestration, and organic matter management practices contribute to C storage (up to 0.5 tonnes/ha/year) and reduced greenhouse gas emissions.

3.5. Soil Organic Matter and Decomposition

Soil organic matter consists of living parts of plants (principally roots), dead forms of organic material (principally dead plant parts), and soil organisms (micro-organisms and soil animals) in various stages of decomposition. It has great impact upon the chemical, physical and biological properties of the soil [36]. Organic matter in the soil gives the soil good structure, and enables the soil to absorb water and retain nutrients. It also facilitates the growth and life of the soil biota by providing energy from carbon compounds, N for protein formation, and other nutrients. Some of the nutrients in the soil are held in the organic matter, comprising almost all the N, a large amount of P and some S. When organic matter decomposes, the nutrients are released into the soil for plant use. Therefore, the amount and type of organic matter in the soil determines the quantity and availability of these nutrients in the soil. It also affects the colour of the soil.

Dead matter constitutes about 85 percent of all organic matter in soils. Living roots make up about another 10 percent, and microbes and soil animals make up the remainder.

Organic matter that has fully undergone decomposition is called humus. The origins of the materials after formation of humus cannot be recognized. Humus is dark in colour and very rich in plant nutrients. It is usually found in the top layers of a soil profile. The dark colour of humus absorbs heat from the sun, thereby improving soil temperature for plant growth and microbial activity under cooler climatic conditions.

Some of the most important functions of organic matter in the soil are:

- 1) It increases soil fertility as it retains cations and

conserves nutrients in organic forms and slowly releases required nutrients for plant uptake and growth.

- 2) It binds soil particles together; the cementing and aggregation functions improving soil structure and aeration.
- 3) It acts as a sponge in the soil, retaining soil moisture. Soils with high organic matter content can hold more water than those low in organic matter.
- 4) It provides food for micro-organisms living in the soil.

Decomposition is the general process whereby dead organic materials are transformed into simpler states with the concurrent release of energy and their contained biological nutrient and other elements in inorganic forms. Such forms are directly assimilable by micro-organisms and plants, and the remaining soil organic matter may be stabilized through physical and chemical processes or further decomposed [25]. These transformations of dead organic materials into assimilable forms involve the simultaneous and complementary processes of mineralization and humification:

- 1) Mineralization is the process through which the elements contained in organic form within biological tissues are converted to inorganic forms such as nitrate, phosphate and sulphate ions.
- 2) Humification is an anabolic process where organic molecules are condensed into degradation-resistant organic polymers, which may persist almost unaltered for decades or even centuries.

Decomposition is essentially a biological process. Nutrients taken up by plants are derived largely from the decomposition process. Micro-organisms are by far the major contributors to soil respiration and are responsible for 80-95 percent of the total carbon dioxide (CO₂) respired and, consequently, of the organic C respired [30, 32]. Therefore, decomposition is a process determined by the interactions of three factors: organisms, environmental conditions (climate and minerals present in the soil); and the quality of the decomposing resources [30, 32]. These factors operate at different spatial and temporal scales [29, 30].

4. Discussion

Living organisms are made up of thousands of different compounds [35]. Thus, when organisms die, there are thousands of compounds in the soil to be decomposed. As these compounds are decomposed, the organic matter in soil is gradually transformed until it is no longer recognizable as part of the original plant. The stages in this process are:

1. Breakdown of compounds that are easy to decompose, e.g. sugars, starches and proteins.
2. Breakdown of compounds that take several years to decompose, e.g. cellulose (an insoluble carbohydrate found in plants) and lignin (a very complicated structure that is part of wood).
3. Breakdown of compounds that can take up to ten years to decompose, e.g. some waxes and the phenols. This stage also includes compounds that have formed stable combinations and are located deep inside soil aggregates

and are therefore not accessible to soil organisms.

4. Breakdown of compounds that take tens, hundreds or thousands of years to decompose. These include humus-like substances that are the result of integration of compounds from breakdown products of plants and those generated by microorganisms [36].

The easily decomposable sugars, starches and proteins are quick and easy for fungi and bacteria to decompose, hence the C and energy they provide is readily available. Most of the microbes living in the soil can secrete the enzymes needed to break up these simple chemical compounds. The larger mites and small soil animals often help in this first stage of degradation by breaking up the organic matter into smaller pieces, thereby exposing more of the material to colonization by bacteria and fungi.

Some of the energy or nutrients released by the breakdown of molecules by enzymes can be used by the bacteria and fungi for their own growth. For example, when an enzyme stimulates the breakdown of a protein, a microbe may be able to use the C, N and S for its own physiological processes and cell structure. If there are nutrients that the microbes do not use, they will be available for other soil organisms or plants to take up and use [9]. When microbes die, their cells are degraded and the nutrients contained within them become available to plants and other soil organisms.

The second stage of decomposition involves the breakdown of more complicated compounds by many fungal and bacteria species. These compounds take longer to decompose because they are larger and are made up of more complicated units. Specific enzymes, not commonly produced by most micro-organisms, are required to break down these compounds [33].

Decomposition only takes place where conditions are suitable. Abiotic conditions have a considerable effect on the rate of breakdown. There must be some moisture available, soil temperatures must be suitable (usually between 10 and 35°C) and the soil must not be too acidic or alkaline. Decomposition also occurs at higher temperatures, as in composts, or under waterlogged conditions through anaerobic processes. Thus, the types of organisms involved in breaking down the organic matter also depend on the conditions.

The type of organic matter, the way it is applied or incorporated into soil and the way it is decomposed influence the physical, chemical and biological balances in the soil and determine the various impacts. It can change:

- 1) the amount of N available to plants;
- 2) the amount of other nutrients available;
- 3) how the soil binds together (soil aggregation);
- 4) the number and type of organisms present in the soil.

Micro-organisms can access N in the soil more easily than plants. This means that where there is not enough N for all the soil organisms, the plants will probably be N deficient. When soils are low in organic matter content, application of organic matter will increase the amount of N (and other nutrients) available to plants through enhanced microbial activity. The number of microbes in the soil will also multiply, as they can use the organic matter as a source of energy. Where the

number of fungi and bacteria associated with the breakdown of organic matter increases, there may be some improvements to the soil structure. [37] Adding organic matter can also increase the activity of earthworms, which in turn can also improve soil aggregation.

5. Conclusion

Contributions of microorganisms to soil fertility were generally more in the uncultivated lands, an indication that tillage operations may have affected the microbial populations. Also the relationship between some soil chemical properties and microbial densities signify important roles microorganism play in soil nutrient build up. Micro and macro (organisms) contributes in increasing plant growth by providing essential elements, minerals that plant cannot utilize by their own. They decompose organic matter to simple form that can be easily taken up by plants.

Thus have microorganisms made possible the soil and its crops essential to man for its food, clothing and shelter. Ultimately, the metabolic activity of micro and macro (organisms) in the soil controls the destinies of man.

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