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THE AMAZING ROLES OF SOIL MICROBES IN SOIL FERTILITY MAINTENANCE

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ABSTRACT

During the early years of man's quest for food; farming was mainly biologically based. The practice brought with it quality and bountiful harvest. Subsequently, the discovery and application of chemical fertilizers in farming post world war 11 gradually decreased the overall dependence on organic fertilizers and on legume biological nitrogen fixation (BNF). Though the chemical approach revolutionized crop yields and food availability worldwide, the economic, ecological and environmental costs are progressively emerging. Global concern is now shifting to sustainable alternatives. Biological approaches offer alternatives that are agronomically, environmentally and economically sustainable. Renewed and emerging emphases are now on a combination of biological technologies like integrated nutrient management, composting, biological nitrogen fixation (BNF), biopesticides, biofertilizers and biocontrol etc.

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Keywords- Organic and chemical fertilizers, biofertilizers, ecological, economical, biopesticides.

INTRODUCTION

In the beginning, crop rotation and intercropping were the cornerstone of agriculture. During those years, our early farmers successfully managed their farming operations with optimum yield and quality with nitrogen-fixing plant species such as legumes and the addition of organic matter to the soils. Legumes by nature have the ability to recruit and nurture rhizobial bacteria in their roots and can utilize vast amount of atmospheric nitrogen by converting them to an organic form that the host plants can use. These legumes impregnated with fixed nitrogen uses the fixed nitrogen to make proteins that enter and pass through the food chain [1]. Apart from this, most plants in their natural environments, including more than 80% of all crop species form a root association with specialized fungi called mycorrizhae. Such a symbiotic association increases the effective surface absorbing area of roots thereby decreasing fertilizer inputs simply due to their network of tiny filaments. This discovery may perhaps lead to reduced dependence on synthetic nitrogen fertilizers in agriculture because arbuscular mycorrhizal (AM) fungi can access nitrogen in the form of organic amino acids stored in existing soils, manures, organic fertilizers and crop residues, thus reducing chemical fertilizer inputs [2]. But besides nitrogen; phosphorus acquisition is about mycorrhizal major role in plant fitness and productivity. Research studies unequivocally reports that beneficial soil microbes play significant roles in the conservation, mobilization and transportation of nutrients from soil into plants. Unfortunately, the late 1940s and the early years of 1950s marked the beginning of the end of most of the biological approaches that were responsible for maintaining plant health and productive soils. The switch from bomb making to manufacturing of chemical fertilizers in Musche Shaols, Alabama, USA marked a new beginning in the history of fertilizer production in North America. The then cheaply available synthetic fertilizer prompted farmers to jettison many of the 'biological practices' that kept soils alive and healthy at the expense of the soil and the environment [3]. The re-emergence of biological-based agricultural production in the year 2000 provided the needed platform for a result oriented-sustainable agricultural production. One major factor that drives the process is the beneficial plant/rhizobial symbiosis and mycorrhizae which can dramatically enhance plant health and productivity. But mycorrhizae are not new–they have been neglected for over 460 million years. Amaranthus and Simpson [3] argued that today's plants coevolved on land due to the marriage of convenience between mycorrhizal fungi and seaweeds. However, the astounding revelation of modern science in the past

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17 years have opened up new approaches and novel ideas of the potentials of mycorrizal/plant relationship in improving crops performance, health and productivity. Soil microbes are crucial to capturing and storing fertility in the ground [4]. Their absence causes nitrogen in the form of nitrates to be leached out easily into surface waters and aquifers causing eutrophication, while some of the added anhydrous ammonia as fertilizer volatilized into the air contributing to acid rain and global warming [3]. Fundamentally, soil structure is the product of microbial activity. Soil is probably the most complex ecosystem on the face of the earth [5]. It represents the source and origin of nearly all our food. Since the beginning of agricultural practice, the importance of plant-microbe interactions has been greatly underestimated. Agricultural practices have focused largely on the plant to the detriment of plant-microbe interactions. The over-application of fertilizer, pesticides and herbicides has seriously depleted the number of beneficial microbes on our agricultural soil leading to poor crop yields and quality. The disappearance of these beneficial microbes that conserve, preserve, cycle nutrients and water for plants and regulate our climate has greatly affected agricultural production globally. Amaranthus [6] contends that we have interfered with the natural process of carbon sequestration in arable lands and that agriculture has been implicated to be the biggest factor that elicits climate instability. Farmers are now gradually discovering the amazing benefits of some of the functions of these miniature microbes which include enhanced nutrient release, elevated nutrient uptake, improved moisture efficiencies, augmented soil tilt etc. Thus, by increasing yields and/or reducing costs, these "tiny microbes" render natural and powerful solutions to some of farmers' challenges [6]. Hence, the predicted increase in world population and the unavoidable global upsurge in demand for food necessitate a shift toward more sustainable, biological farming methods. We now discuss the two biological tools (N_2-fixing rhizobacteria and mycorrhizal fungi) that reduces the need for synthetic fertilizers in farming and their associated unique roles in plants fitness and productivity. The beneficial roles of microbial antagonists in agroecosystem will also be briefly discussed.

N_2–FIXING RHIZOBACTERIA: NODULATION AND THE EVOLVING PARADIGM SHIFT FROMSYNTHETIC N TO RENEWABLE SOURCES OF N

Biological utilization of nitrogen by plants through the activities of soil organisms such as *rhizobia* was the standard agricultural practice before the year 1909. These beneficial soil microbes also enjoyed support from the sun's energy in a symbiotic relationship with leguminous plants. Farmers' joy in planting legumes has been that after harvest, roots of legumes left in the soil decays and release organic nitrogen compounds for uptake by the next generation of plants [1]. Numerous research studies have corroborated that beneficial organisms play important roles in the conservation, mobilization and transportation of nutrients from soils into plants [7]. But nitrogen fixing efficiency varies with legumes. Grain legumes, such as soybean, are exceptionally good at fixing nitrogen and may fix up to 250 lbs of nitrogen per acre. Perennial and forage legumes such as alfalfa, are capable of fixing 250 to 500 lbs of nitrogen per acre [8]. Table 1 captures the estimates of N_2 fixation by legumes in farmers' fields and such on-farm data can be used to develop a picture of the relative importance of N_2 fixation to the N nutrition of crop legumes. Research has established some factors that influences the amount of nitrogen fixed to include; plant growth, the *rhizobia* strain infecting the legume and the amount of nitrogen in the soil. Drought and nutrient deficiency has also been implicated to reduce nitrogen fixation. Others are the efficiency of a particular strain of *rhizobia* and soil temperature. Also, optimum soil temperature range for nitrogen fixation has been determined to be between 55 to 80^0F [8].

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Table 1: Average values for % Ndfa for the major crop legumes in experiments and farmers'fields

Legume	Experiments[a]		Farmers fields[b]
	% Ndfa range	% Ndfa average	% Ndfa average
Common bean	0-73	40	36
Chickpea, lentil, pea, Cowpea, moungbean, pigeon pea etc.	8-97	63	65
Soybean, groundnut	0-95	68	58
Fababean, lupin	29-97	75	68

Source: [9] **%Ndfa: Proportion of nitrogen derived from the atmosphere.**

Rhizobia bacteria are soil dwelling organisms. They are free living and motile, feeding on the remains of dead organisms until legume plant roots are available to infect. Specifically, one *Rhizobium* strain can only infect certain species of legumes. For example, the pea is the host plant to *Rhizobium leguminasarum* biovar *viciae*, whereas clover acts as host to *R. leguminasarum* biovar *trifolii* [1]. The release of a variety of chemicals by a leguminous root cells into the soil initiates interaction between the plant and the available free-living rhizobia. To assist in the attraction of rhizobia to the legume, studies have demonstrated that volatile organic compounds, specifically dimethyl sulfide released by the legumes are used to attract nematodes that transport the rhizobia to the legume for the purpose of symbiosis [10]. This unique example is one among the multitrophic interactions that can exist in the rhizosphere as well as demonstrating the potential influence plants have in manipulating their environment. Through communication with compatible rhizobia and a legume, they multiply and attach to the root hairs of the plant [11]. Within 2 to 3 weeks of infection/after planting, nodules are visible to the naked eyes (Figs. 1A, B & C). Each root nodule is packed with thousands of living rhizobium bacteria, most of which are irregular in shape known as bacteroids. The nodules vary in size, shape and colour. Young nodules that are not yet fixing nitrogen are white or grey inside. As the nodules grow and mature, they turn pink in the center (Figs. 1D, E & F**)**, implying that nitrogen fixation has begun [8]. The pink or reddish colour is caused by leghemoglobin, which helps to regulate the oxygen within the nodule.

The enzyme nitrogenase catalyses the conversion of nitrogen gas to ammonia. This enzyme is highly sensitive to oxygen because one of its components the MoFe cofactor is irreversibly denatured by oxygen [12] but requires hydrogen as well as energy from ATP. To cope with this paradox, different strategies are used in different symbiotic interactions. But among the nitrogen-fixers, *Clostridium* is anaerobic and thus has no difficulties, but the free living aerobic bacteria such as *Azotobacter* and *Rhizobium* have a variety of different mechanisms for protecting the nitrogenase complex, which includes high rates of metabolism and physical barriers. *Azotobacter* circumvents this problem by having the highest rate of respiration of any organism, thus maintaining a low level of oxygen in its cells. By contrast *Rhizobium* controls oxygen levels in the nodule with leghemoglobin by providing enough oxygen for the metabolic functions of the bacteroids but prevents the accumulation of free oxygen that would destroy the activity of nitrogenase. Plants acquire N from two principal sources: (a) the soil, through synthetic fertilizer, manure, and/or mineralization of organic matter, and (b) the atmosphere through symbiotic nitrogen fixation. Non-N_2-fixing plants (for example cereals) absorb all the nitrogen they need from the soil while N_2-fixing plants (example legumes) take a part of the nitrogen they require from the atmosphere. Enhanced availability of N is fundamentally necessary for high quality, protein-rich food. A grain yield of 5 to 9 metric tons Ha^{-1} was reported to require the addition of 200 to 300 kg N Ha^{-1} [13, 14]. But the efficiency of N absorption by grain crops ranges from 35 to 75 % with an average close to 50% [15, 16]. For example, N absorption by maize was reported to be 39% for the first 100 kg of N fertilizer application and only 13 % for the second 100 kg [16]. Thus, the huge residual quantity of N left in the

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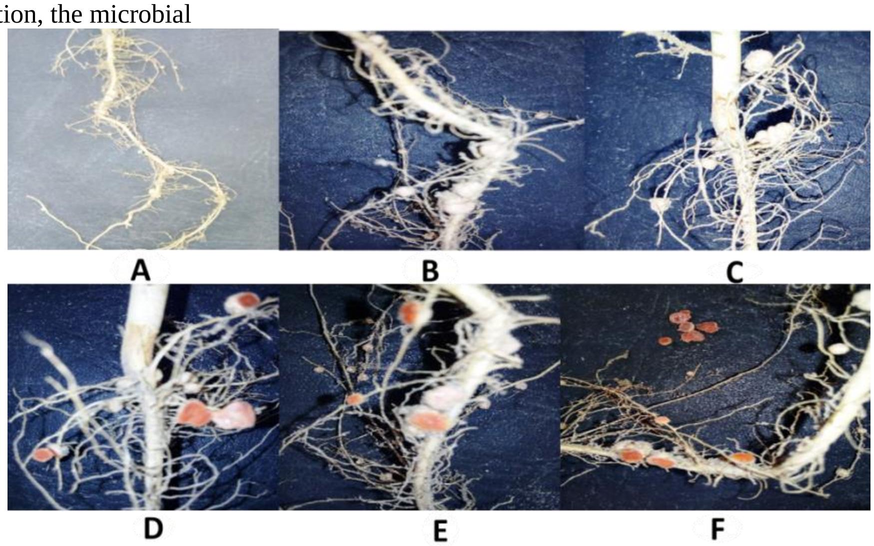
soil due to inefficient absorption by crops has been implicated in most of the environmental and health problems [17]. In addition, the microbial



Figs. 1A, B & C: Nodules on bean roots. 1D, E & F: Nodules on bean roots cut open to show the reddish-pink (due to leghemoglobin) colour that indicates active healthy nodulating roots.
Photo by Dr. Alfred O. Ubalua, NRCRI Umudike, Umuahia, Nigeria.

nitrification and denitrification of soil N are the major contributors to NOx and N_2O emissions from agricultural soils [16]. Socolow, [5] further argued that while N_2O acts as a greenhouse gas, stimulating global warming, NOx depletes stratospheric ozone and is also a toxic pollutant to plants. The unabsorbed fertilizer N (excess NO^-_3) in drinking water has been implicated in methemoglobin anemia in infants and young children when concentrations rise above 10 mg NO^-_3 NL^{-1} [17, 16] while run-offs in surface water is associated with eutrophication and hypoxia in aquatic ecosystems [17]. And on land, it is suggestive that excess N from intensive agriculture reduces biodiversity and ecosystem function [17, 18, 16, 19]. Table 2 summarizes the potential adverse impacts of excessive fertilizer N application. The challenge now is the unavailability of N fertilizer for subsistence farmers in the developing world due to high cost, poor transportation, and weak infrastructure. This leaves the subsistence farmers to source N from intercropping legumes and other renewable sources of N such as species capable of symbiotic nitrogen fixation as the only sources of N.

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Table 2: Potential adverse environmental and health impacts of excessive N use

Impact	Causative agents
Human health	
Methemoglobin anemia in infants	Excess NO_3 and NO_2 in waters and food
Cancer	Nitrosamine illness from NO_2, secondary amines
Respiratory illness	Peroxyacyl nitrates, alkyl nitrates, NO_3 aerosols, NO_2, HNO_3 vapour in urban atmospheres
Environmental health	
Environment	Excess NO_3 in feed and water
Eutrophication	Inorganic and organic N in surface waters
Materials and ecosystem damage	HNO_3 aerosols in rainfall
Plant toxicity	High levels of NO_2 in soils
Excessive plant growth	Excess available N
Stratospheric ozone depletion	Nitrous oxide from nitrification, denitrification, stack emissions

Source: [20]

Efforts in the last decades were geared towards other alternative approaches for improving the soil N status through biological N_2 fixation. Incorporating nitrogen–fixing plants into farm management practices also adds nitrogen and organic matter to soils in a less leachable form. By modest estimate a legume cover crop can add and store as much as 200 pounds of N_2 in an acre of soil [21] while AM fungi have been considered as a valuable tool to decrease fertilizer inputs because their dense mass of tiny fungal filaments reaches out into the surrounding soil, and dramatically enhancing the plants ability to absorb and acquire mineral nutrients, water and amino acid molecules, which contains nitrogen. Depending upon good management and cropping system, legumes green manures have the potential to replace more than 100 kg N Ha^{-1} for subsequent grain crops. This equates to a savings of between \$60 to \$90 Ha^{-1} in N fertilizer, implying an enhanced yield due to rotation effect and savings in fertilizer expenses [22]. Apart from effective savings due to the use of legumes and other N_2-fixing associations accompanied by good agronomic practices, incorporation of the legume residue results in higher soil organic matter content and increased P and N availability. There is a consensual agreement that BNF is one of the most sustainable approaches to meeting crop N demands. To buttress this assertion, Lassaletta [23] reported that NUE increases exponentially with increasing levels of biologically fixed N_2 in soils while NUE decreases linearly with increasing levels of applied synthetic N fertilizers. Therefore, in addition to providing an immediate source of dietary N, the incorporated legume residues after seed harvest makes P and N more available to subsequent crops [22]. Thus, responsible and qualitative management of N is necessary for maximizing crop quality and yield with minimal impact on the environment and natural resources.

According to Tilman [24], an estimated 137 million metric tons of chemical fertilizers was used globally in 1998. By modest estimate crops actually absorb only one-third to one-half of the nitrogen applied to farmland as fertilizers. Thus nitrogen that runs off croplands into rivers causes eutrophication and the excess nitrogen in soil can lead to less diversity of plant species, as well as reduced production of biomass [25]. In addition, chemical fertilizers can gradually increase the acidity of the soil until it begins to impede plant growth [26] as well as less biological activity compared to plots fertilized organically with manure or with beneficial microbes [27]. Pimentel *et al.*, [28] reported that each year the world uses about 3 million tons of pesticides (comprising herbicides, insecticides and fungicides) formulated from about 1,600 different chemicals. Though complete toxicity data are lacking, however its use is steadily increasing making crops to be more vulnerable to pests. They argued that the high-volume use reflects the imprecise nature of pesticide application, estimating that only 0.1% of applied pesticides reach the target pests, leaving the bulk of the pesticides (99.9%) to impact the environment. Pesticide run-off and airborne pesticide “drift” pollute surface waters and ground water. Other negative effects include reduced number of honeybee colonies [29, 30, 31]; developmental abnormalities in amphibians [32, 33, 34]

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compromised immune function in dolphins, seals and whales [35]. Furthermore, its widespread nature has induced resistance in most of its target species (in both plants and insects). For instance, as at 1990, more than five hundred insect species developed pesticide resistance as against less than twenty in 1950. Similarly, 273 plant species were so reported to have exhibited herbicide resistance [36, 37]. However, by radically changing the management of soil, water, nutrients, it is possible to create a growing environment in which plants develop better, become stronger and healthier, and produce often more than the best conventional system [38].

THE VERSATILITY OF MYCORRHIZAE IN AGROECOSYSTEMS

The symbiosis between arbuscular mycorrhizal fungi (AMF) and the majority of land plants is one of the most ancient and abundant mutualisms on Earth [39]. AMF is pervasive by nature and forms massive hyphal network in soil that helps plants roots to scour for nutrients in exchange for photosynthates [40]. The ubiquity of AMF underscores its ability in establishing intimate relationships with root tissues of their plants hosts, by penetrating the cortical cells of roots. But beyond nutrient acquisition and soil structure, AMF can influence plant diversity and invasion success. Appreciable levels of drought tolerance far exceeding those found in agricultural areas are achievable partly due to the extensive network of mycorrhizal hyphae and specialized storage cells. These are the reasons why plant communities in natural vegetations enjoy luxuriant abundant growth. In addition, mycorrhizal hyphae measuring about 1/25th the diameter of a human hair with a spread of up to 18-24 inches in length can penetrate into the smallest openings in soil to access microscopic sources of water that are inaccessible to the much thicker roots [41].

As a soil dwelling microbe, mycorrhizal fungi belongs to the beneficial group of rhizosphere microbes with multiple ecosystem functions and may have the single largest effect on plant performance of any rhizosphere-associated microbe, functioning as an extension of the root system of the plant and increasing absorptive area [42, 43, 44]. The coverage of the hyphal web implies that a single plant is linked in a network with many other mycorrhizal plants, with more resources shared within the existing mycelia network [45]. AMF forms both clusters of finely divided hyphae known as arbuscules (Fig. 2) and also a membrane–bound organelles of varying shapes known as vesicles (Fig. 2) in the cortex. While arbuscles are sites for exchange of water, nutrients and sugars, vesicles generally serve as storage and reproductive structures when they are old. These two distinct structures together with a large spore are the major diagonistic features of the arbuscular mycorrhizal associations [41].

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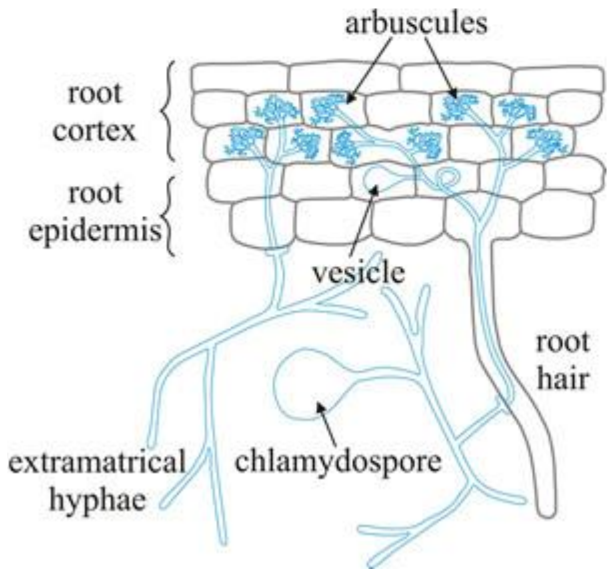

Fig. 2: AMF arbuscules & vesicles
Source: [46]

Enhanced access and acquisition of phosphorus is about the major mycorrhizal sole contribution to a crop plant. The importance of this mineral nutrient to essential plant functions, include: energy transfer, photosynthesis, transformation of carbohydrates, systemic nutrient mobilization and genetic transfers [3]. This mineral (phosphorus) is a critical component in crop fertilizers because its deficiency in a crop is correlated with poor yield. However, most naturally-occurring phosphorus is totally bound with elements such as iron or aluminum in the form of recalcitrant compounds. Similarly, phosphorus inputs derived from synthetic fertilizers often react with ambient soil cations to form insoluble salts. But plant communities in natural ecosystems depend on mycorrhizal fungi to access these forms of phosphorus. Mycorrhizal hypha produces and secretes enzymes, including phosphatase to convert this tightly-bound phosphorus into soluble plant-usable forms. Thus, increasing the availability of natural phosphorus and also improving the efficient uptake of phosphorus derived from chemical fertilizers. With increased phosphorus uptake, farming costs will be dramatically reduced with the concomitant increase in yield as well. To further enhance crop productivity, mycorrhizal spongy network of hyphae typically extends beyond the roots thus increasing the absorptive surface area of the colonized roots hundreds to thousands of times ensuring optimum uptake of the available nitrogen and other nutrients [41]. Another crop enhancing benefit offered by these amazing fungi is water management. The expanded and enormous absorptive surface area connected to plants roots ensures that almost all moisture in a plant's surrounding soil is accessed. During drought, mycorrhizae survives with the help of surplus nutrients and water stored in its vesicles (Fig. 2) in the root cell to avoid stress for extended periods ranging from weeks or even months. But when nutrients or moisture becomes available, the plant returns to normal, healthy respiration and growth without shock or other negative symptoms [3]. One more significant contribution of mycorrhizae to soil and agricultural practice is glomalin secretion. AMF hyphal filaments are coated with a sticky glycol-protein called glomalin. Endomycorrhizal fungi *Glomales* secrets glomalin; a carbon-rich natural superglue that binds organic matter to mineral particles in soil. This natural sticky glue binds individual soil particles in water-stable aggregates that encourage the flow of both moisture and CO_2 through the root zone. Such a soil is said to have a good tilt because its well aggregated, influences the ease of tillage, root penetration and seedling emergence. These aggregates hold moisture and improve tilt, making soil loamier, nutrient-rich and less subject to erosion

[47]. Thus, as glomalin production increases, soil defenses against degradation and erosion also increases with a corresponding boost in soil-crop productivity.

But beyond glomalin secretion, nutrient and mineral acquisition, mycorrhizal fungi are also implicated in plant natural defense against fungal root diseases such as *Phytophthora, Fusarium, Pythium* and *Rhizoctonia*. They produce and release suppressive exudates such as antibiotics that prevent infection by these organisms and other fungal root pathogens. Furthermore, they also form a physical barrier made of chitin to deter invasion by soil pathogens. **C**hemical fertilizers, some pesticides, tillage, compaction, organic matter loss, erosion, fallow periods, and high rates of available phosphorus are inimical to growth and establishment of mycorrhizae. However, to restore depleted mycorrhizal populations, the most efficient approach is the application of commercial mycorrhizal inoculants to seeds when planting. Seed treatment or in-furrow applications produces the best result because the mycorrhizal fungus colonizes the roots early in the plants life. Technically, mycorrhizal inoculation encourages reduced total fertilizer inputs because the increased root network captures more of the applied fertilizer and in the case of phosphorus, before it becomes insoluble or in the case of nitrogen before it volatizes and/or leaches out into the water table as nitrous acid [21]. AM fungi, therefore, are an important component of nutrient management programmes that aim to reduce environmental pollution [41]. In Nigeria, one obvious target crop for the application of AMF is cassava (*Manihot esculenta* (Crantz)), being a major food crop in the country. The reported increase of 10-20 times associated with AMF fertilized-cassava field compared to those established in natural undisturbed soil is a significant breakthrough for a country like Nigeria that is thickly populated with over 200 million people on a land mass of 983,213 km^2. In addition, in Colombia, yield increases of up to 5 tons ha^{-1} have been recorded suggesting minimal phosphate fertilizer application and a reduction in environmental pollution [48, 49, 50]. Such a breakthrough recommends the economic and ecological importance of AMF research on tropical crop like cassava and could as well reduce our long aged reliance on external N and P fertilizers to enhance plant growth and productivity.

BENEFICIAL ROLES OF MICROBIAL ANTAGONISTS IN AGROECOSYSTEMS

Since the inception of modern agriculture, the increasing applications of chemical fertilizers and arrays of biocides have largely depleted a good number of beneficial microbes in agroecosystems. Their increases in production and application post-second world war may have necessitated the shift from microbe management to intensive agricultural practices. According to Tilman, [51], microbe management, either through selection and inoculation of specific microbial strains or by simply promoting naturally existing microbes, holds great promise for sustainable agriculture. First, microbes are multi-functional with effects ranging from pathogen protection to improved nutrient uptake. Secondly, microbes can reproduce and may be self-sustaining. Current agricultural systems are impoverished in terms of biodiversity, genetic and functional diversity. Fertile soils contain a wide array of microbes which include different species of bacteria, fungi, protozoa, algae and viruses. These microbes are mostly found in the rhizosphere where they decompose organic matter into humus. *Streptomycetes*, *Pseudomonas* and *Bacillus*, *Aspergillus*, *Penicillium*, and *Rhizopus* are among the important microorganisms that releases elemental phosphorus from different phosphorus containing compounds present in the organic matter. They achieve this feat through the production and release of phosphatases. Sidhu, [52] argued that soil organic matter contains more than 95% of soil nitrogen, 5-60% of total phosphorus and about 30% of soil sulfur. But for these nutrients to be available to plants, the organic matter has to be decomposed by microorganisms. Thus, lack of microorganisms may result in the accumulation of organic matter which can adversely affect the soil fertility by clogging the soil texture.

Generally, all plants in all environments depend on microbes. Suppression of diseases and deterring of pathogens and predators are among the multiple roles that microbes play in plants fitness. These protections from pathogens have evolved over time in the partnerships that plants have made with microbes of many different kinds [53]. Specifically, diverse bacteria and fungi, especially of the genera *Pseudomonas*, *Bacillus,* and *Trichoderma* produce a range of metabolites against other phytopathogenic fungi [54, 55, 56]. Hart and Treyors, [57] contends that the application of biological solution for sustainable agriculture may hold the expected promise for quality and

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increased agricultural production. They opined that one possible means to achieve this goal has been hidden in the rhizosphere for decades in the form of plant growth-promoting microorganisms (PGPR). In the rhizosphere, plant roots are possibly involved in attracting PGPR through the release of cues (root exudates) in which carbohydrates and amino acids predominantly act as chemoattractants. There are two broad based groups of beneficial rhizospheric organisms namely: microorganisms with direct effects on plant growth promotion (plant growth promoting microorganisms (PGPM) and biological control agents (BCA) that indirectly assist with plant productivity through the control of plant pathogens. *Pseudomonas fluorescence*, nitrogen fixing bacteria, like *Rhizobium*, *Azotobacter*, *Azospirilllum* are typical examples of PGPR. They exist in virtually all soil conditions associated with roots, soil and plant debris or organic matter. Their mode of action includes rhizosphere competition and antibiosis. They also protect crops against several soil borne and foliar plant pathogenic fungi and bacteria. Other functions include enhanced germination, root and shoot growths, plant survival and stimulation of plant growth. Among the biological agents are *Trichoderma* species which is an established biological agent against several soils borne and foliar plant pathogens [58]. They occur in almost all agro ecosystems, including roots, soil and soil organic matter. Their biocontrol action includes mycoparasitism, antibiosis, rhizosphere competition, and resistance against biotic and abiotic stress in treated plants, stimulation of plant growth and enhanced nutrient uptake and germination.

CONCLUSIONS

Microbe's unique nature, adaptions and capabilities were briefly explored and described in this paper. Their ability in multiple benefits in various areas such as plant health and protection, enhanced nutrient release, improved moisture efficiencies, augmented soil tilt for improved plant growth and suppression of diseases and rendering, deterring of pathogens and predators are among the catalogue of functions attributed to their innate versatility in soil fertility maintenance. In addition, their intricate roles in plant/rhizobial symbiosis and mycorrhizal functions can dramatically enhance plant health, performance and productivity.

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