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THE SOIL - A LIVING BODY

by
Adewale Adebayo

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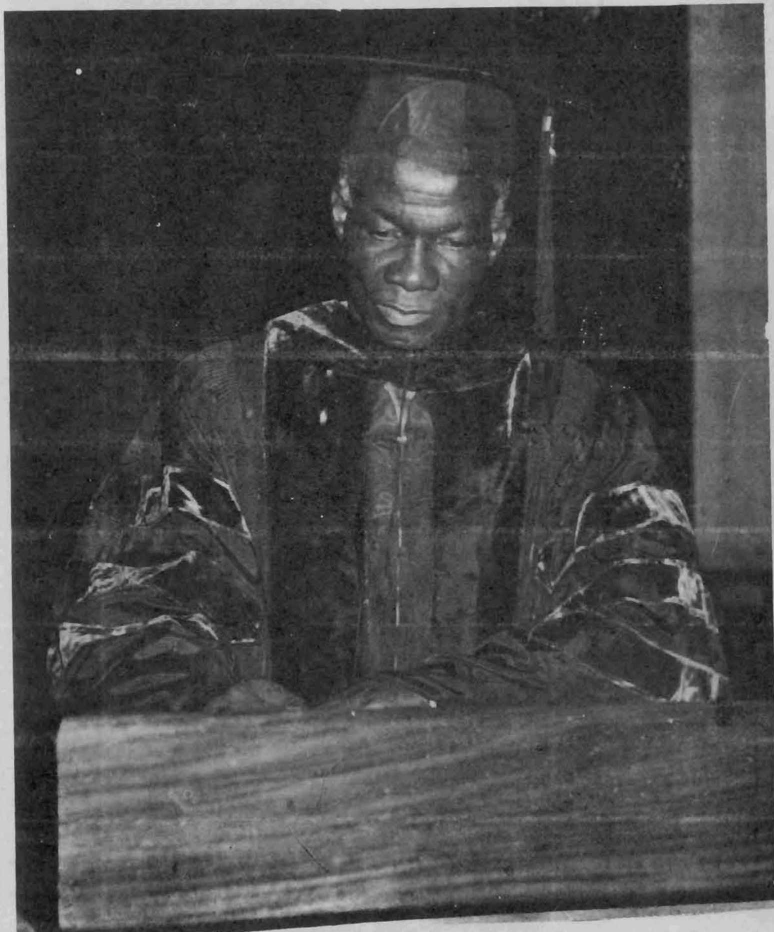

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INTRODUCTION

"Not by might nor by power, but by my spirit, says the Lord Almighty" Zechariah 4:6 of the Holy Bible. Therefore, all honour, power and glory to the Almighty Jesus for His love endures forever.

Different people have different concepts of the soil and the soil means different things to different people. To the Civil Engineer, the soil may be the firm foundation for erecting buildings, constructing roads and building bridges. The Forester sees the soil as a nutrient source for the trees. The Geologist is more interest in the soil from the viewpoint of its geological formations. The Mining Engineer sees the soil as a debris which must be removed to get into the reserve of the precious minerals he is interested in. The soil fertility expert is interested in the soil from the viewpoint of its nutrient content and availability. Mr. Vice-Chancellor Sir, as an Animal Scientist, probably your own interest in the soil is from the angle of a growth medium for grasses and pasture to feed your animals or as a receptacle for the wastes from your chicken and rabbits. However, as a Microbiologist, I am interested in the soil because the soil is the Universal Culture Medium which yields universal medium to all organisms. It is the 'Mother' medium. About ninety-nine (99%) percent of all bacteria known have their home in the soil or can live in there for an exaggerated period of time. Irrespective of your professional calling as a microbiologist in Pharmacy, in Medicine, in Agriculture or Food Science, the soil is the original medium for the culture of all the important microorganisms.

The soil has been able to play this excellent role because of its intrinsic properties. There is no soil in the world that does not contain micro-organisms in one form or the other; from the very cold Tundra regions to the extremely arid and hot Sahara and Kalahari deserts of the world, in acid mines and limestone deposits, micro-organisms are present. Some micro-organisms especially species of Aspergilli and Penicillia have been shown to grow at very low water potentials - as low as - 396 bars (0.75aw or 75% RH).

Characteristics of the Soil as a Culture Medium

One may ask - what are the properties of the soil that make it so unique as a culture medium? The synthetic culture media in the laboratory have certain characteristics that make them suitable for the growth of most micro-organisms. Let us examine these features vis-a-vis the soil.

(i) *Water requirement:* All micro-organisms move in water or film of water. Although micro-organisms do not and cannot grow in pure water, water is necessary as a solvent for microbial food and transport of waste products. The amount of water required is dependent on how concentrated the food is.

Water is a major environmental variable affecting microbial activities. For most micro-organisms, the soil, any where in the world has sufficient water for the micro-organisms that are adapted to the ecology. While most plants would not survive under extreme water stress, micro-organisms require only films of water to grow. As shown in our earlier studies on the response of micro-organisms to water stress (Adebayo *et al;* 1971; Adebayo and Harris; 1971), water that cannot be extracted by higher plants are available to micro-organisms. Micro-organisms in the soil or artificial cultures do not respond to water *per se,* but to the energy of the water. This is why we proposed in 1971 that water requirement from the microbial stand point should be looked at from the energy perspective rather than the water content. Applying the science of Physics to microbiology, I showed for the first time in literature in 1971 that fungi micro organisms grow under water stress because of the possession of a positive turgor pressure and the tendency for fungi and other micro-organisms to possess a significant positive turgor pressure under water stress is related to the ability of the micro-organisms to grow at low substrate water potentials and that a pre-requisite for positive turgor pressure is the existence of an internal osmotic water potential lower than that of the external environment. Therefore, as far as the water requirement of micro-organism is concerned, the soil more than meets the adequacy for water.

(ii) *Carbon: nitrogen balance:* No micro-organism can live in an environment devoid of carbon and nitrogen. Carbon is used entirely by micro-organisms for energy and for building the cell blocks. Nitrogen is used for building the body protoplasm; that is, indirectly for growth. One percent carbohydrate in a culture medium is the ordinary case. If the organism is a gum producer, the percentage may be cut down commensurately. Carbohydrates most in demand are the pentoses and hexoses. However, some micro-organisms use alcohols, celluloses, starch, aldehydes etc. and the ability to use any of these substrates is used as a basis for characterization. These sugars tend to be common and adequate in soils.

Nitrogen is utilized by micro-organisms in practically all forms. In general, an organism has a broad spectrum of nitrogen utilization. This is fortunate in terms of the soil as a culture medium because all forms of nitrogen can be found in the soil because the soil nitrogen undergoes a series of complex breakdown.

(iii) *Mineral sources:* The minerals commonly required by micro-organisms are carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus and potassium. These minerals help in cell wall synthesis, cell physiology and other enzymatic activities of the cell. The microbial requirement for minerals are easily satisfied by most soils as micro-organisms require only very minute quantities. For instance, working with fallow and cultivated soils taken from Awe in the transition vegetational zone, Ilora in the derived savanna and Ife in the forest region, it was shown by Adebayo (1973) that most soils become phosphorous limited for micro-organisms only when the solution phosphorous falls below 0.005ppm which is the detection limit of most of the equipment currently in use then for phosphorous determination. It was under this condition that the phosphorous repressible alkaline phosphatase enzymes could be expressed in most micro-organisms. I tried to use the production of phosphorous repressible alkaline phosphatase as an index of soil fertility, due to other complex reactions in the soil like enzyme adsorption and de-activation by clay and other colloidal materials, it was discovered that the use of alkaline phosphatase enzyme to measure phosphorous fertility of the soil was unreliable and therefore not advisable.

(iv) *Buffers:* Culture media in the laboratory are usually buffered against abrupt changes in pH by the use of other chemicals like phosphates. By the last count, there were over 17,000 different culture media in laboratories worldwide and in an average laboratory one should expect between 5,000 - 7,000 culture media (may be not in Nigeria's laboratories). Looking around the world, we have different types of soils which serve as culture media for different organisms and hold different microbial balance. The limestones, granites, sandstones, shale and other types of rocks which are the origin of the soils give the soil different minerals and composition.

(v) *The soil air:* The tendency of the soil particles to become compacted determines whether the soil is going to be anaerobic or aerobic. The soil structure determines the amount and movement of gases in the soil. The soil atmosphere is heterogenous consisting of gases from organic matter decomposition. Because the soil air varies, there are pockets in the soil where there are organisms quite different from those found uniformly in the soil. The soil can take care of both the aerobic and anaerobic requirements of all micro organisms. This is evident in the phenomena of nitrification (an obligate aerobic process) and denitrification (a facultatively anaerobic process) taking place simultaneously in the same soil.

There are other features of the soil which make it a 'mother' medium of all media for the culture of micro-organisms such as the varying temperatures and varying hydrogen ion concentrations. The soil solution can be easily equated to a nutrient broth commonly used in the laboratory for the growth of most fastidious organisms.

The Soil As a Living Body

A good soil is a living soil and any soil that does not contain micro-organisms is a dead soil. It is the natural habitat for myriads of micro-organisms and other living forms representing numerous genera and species. The numbers, the kinds and activities of these organisms are influenced by the food material available or the organic matter, temperature, aeration and other factors. They live according to the rule of the survival of the fittest. The forms flourishing in any particular micro-environment are the ones best adapted to the conditions present or represent the most successful competitor.

Although in some soils a few of the organisms may parasitize or injure plant roots, the vast majority performs beneficial functions which are important for the soil, the plant and for most living things upon the earth. An old Microbiologist, Thom, C. in an article published in the *Journal of Washington Academy of Science* in 1938 volume 28: 137-153 titled *A Microbiologist Digs in the Soil* wrote and I quote:

> . . . "Bacteria, molds, actinomycetes, myxomycetes, algae, protozoa and other more complex microorganisms fill a microbiological jungle in which friends and foes, saprophytes and parasites, symbionts and antagonists compete with each other and with crop plants for space and food. They are a challenge to our skill in culture, to our discrimination in interpretation and to our constructive imagination in devising means to control and direct these myriads to useful ends".

Mr. Vice-Chancellor Sir, this has been my challenge and focus as a Soil Microbiologist in my research endeavours that have now spanned about 28 years; that is, to direct these micro organisms to useful ends in Nigeria's agricultural development.

The microorganisms commonly encountered in a good agricultural soil are:-

Bacteria	-	$3 \times 10^6 - 5 \times 10^8$/g soil
Actinomycetes	-	$1 \times 10^6 - 2 \times 10^7$/g soil
Fungi	-	$5 \times 10^3 - 1 \times 10^6$/g soil
Yeast	-	$1 \times 10^3 - 1 \times 10^6$/g soil
Protozoa	-	$1 \times 10^3 - 5 \times 10^5$/g soil
Algae	-	$1 \times 10^3 - 5 \times 10^5$/g soil
Nematodes	-	$10 - 5 \times 10^3$/100g soil.

With the possible exception of the microbial viruses, the bacteria are the most numerous in most soils. Examples of some of the common members of the different groups are:

(i) slide - *Bacillus cereus* in soil - a bacterium

(ii) slide - *Pseudomonas fluorescens* from artificial culture-another bacterium.

(iii) slide - probably the most typical soil forms of the actinomycetes belong to the genus *Streptomyces*.

(iv) slide - mycelium and fruiting structures of *Curvularia* sp - a fungus.

(v) slide - a group of fungi called slime molds or myxomycetes are commonly noted in moist places or lawns where organic residues are present. During their growth phase they consist of single cells which feed on the bacteria and other microbes which are decomposing the dead residues.

(vi) slide - yeasts are similar to fungi but are usually oval in shape and most reproduce by budding.

(vii) slide - after rain or irrigation algae may quickly develop on the soil surface.

(viii) slide - the protozoa are the simplest animal forms in the soil. The soil types are generally smaller than the aquatic varieties and are represented by Amoeba, Mastigophora and ciliata. Most feed on soil bacteria but some utilize soluble organic substances.

(ix) slide - the soil nematodes are small, round worms which may be large enough to be visible to the eye.

(x) slide - other soil animals include mites, spiders, scorpions, centipedes, millipedes, springtails, crickets, beetle grubs, termites, slugs, ants and earthworms.

The live weights of these organisms may vary from 500 - 2,000kg/ha. There is no soil without life in it and the weight of life in the soil is about the weight of heart in man. In terms of biomass, the bacteria are the least important, but with respect to the overall microbiological activities and diversity in the soil, the bacteria become the most important of all the soil organisms.

Important Activities of Microorganisms in soil

The reason why microorganisms are important in the soil is mainly because of their activities. These activities include -

(i) Decomposition of organic residues with release of nutrient elemen constituents.
(ii) Formation of soil humus
(iii) Improvement of soil physical properties
(iv) Release of plant nutrients from insoluble inorganic soil minerals
(v) Nitrogen fixation
(vi) Improved plant nutrition through mycorrhizal relationships.
(vii) Antagonistic action against plant pathogens.

Mr. Vice-Chancellor sir, although I shall make a statement or two on these activities, my areas of research focus in the last few years, that is post Ph.D, concern numbers (i) and (v) which I shall discuss in details later on in this lecture.

Formation of soil humus: With few exceptions, the organic residue molecules are completely broken down into simple inorganic constituents. Some of the simple compounds are utilized for synthesis of biomass and other products and a small fraction is converted to the important soil humus. Some of the beneficial properties of soil humus are:

(i) slow release of nitrogen, phosphorous and sulphur fertilizer;
(ii) improves soil structure;
(iii) improves micronutrient nutrition of plants through chelation reactions;
(iv) solubilizes plant nutrients elements in soil minerals;
(v) has a high exchange capacity for plant nutrient cations;
(vi) improves the soil buffer capacity;
(vii) the dark colour favours heat absorption and early plant growth;
(viii) certain components may exert growth - promoting effects;
(ix) supports a higher and more varied microbial population which favours biological control;
(x) reduces toxicity of natural toxic substances and pesticides; and
(xi) increases soil water holding capacity.

Improvement of soil structure: A good soil is one in which the soil particles are bound into water-stable aggregates. The advantages of aggregation are that aggregation favours better water penetration which then reduces erosion and run off, promotes better aeration which favours healthier plant root growth, offers less resistance to root penetration and cultivation processes. In the best agricultural soils, organic soil binding substances are very important. Many organic substances formed during microbial decomposition of organic residues including fungal and algal filaments and other microbial cells help to bind the soil particles into aggregates. Long, linear polysaccharide molecules bind one soil particle to another and are held by hydrogen bonding or are linked through di - and trivalent metal ions to carboxylic acid groups on the polysaccharide and exchange sites on the clays and humic acids.

Mycorrhizal relationships: The mycorrhizal fungi are important in plant nutrition relationships especially in low phosphorous or low nutrient soils. Most plants have either ectotrophic or endotrophic mycorrhizal fungi associated with their roots. The ectotrophic type form a mantel around the roots and are prevalent in forest soils. The endotrophic mycorrhizae occur on most cultivated crops and on numerous non-cultivated crops including many herbaceous and woody species. The mycelium grows outside the root, penetrates the root and develops between the cortical cells. The plant nutrients obtained from the soil by the fungus are thereby transferred to the plant.

Antagonistic relationships: Most soil organisms are always hungry. Competition for available carbon and energy material is intense. Some microbes produce toxic substances which inhibit or kill other organisms. Some of these substances which are the waste products from the micro-organisms have been isolated and constitute the so called wonder-drugs - the antibiotics which have been exceptionally useful in the cure of major bacterial infections (except that there is no antibiotic yet against AIDS, it is not a bacterial infection). One form of organism may parasitize another or trap it and then consume it. Protozoa can feed on bacteria, but certain fungi destroy protozoa. The antagonistic relationships are important in helping to control or reduce the harmful activities of plant root parasites and in maintaining microbial balance.

Transformations of inorganic elements: After inorganic elements have been released from decomposing organic residues, or from insoluble soil minerals, they may still undergo various microbial transformations which may or may not be considered beneficial. If the element or compound is in a reduced state, autotrophic organisms may oxidize it. For instance, ammonia released from decomposition of organic nitrogen compounds is readily oxidized by specific autotrophic bacteria to nitrite and nitrate.

Organic Residue Decomposition and Release of Nutrients

Probably the most important function of the soil microflora is the decomposition of organic residue with the release of nutrient element constituents such as carbon, nitrogen and sulphur - to be utilized by new generations of living things. The microorganisms are not interested in breaking down organic matter so as to release nutrients to plant crops, but the organic residues are being broken down to provide the micro-organisms with a source of cell carbon and energy. It is the excess over and above their requirements that are available to higher plants. The breakdown of organic matter is also a process by which the limited supply of carbon dioxide in the atmosphere is replenished for photosynthesis which is the basis of human survival.

The organic matter that is subject to microbial decay in the soil comes from various sources; plant remains and forest litter, subterranean portions of the plant and the above-ground portions that are mechanically incorporated and animal tissues and their excretory products are subject to microbial decomposition. In fact, there is no known organic residue as at now including those synthesized by the Organic Chemist that cannot be broken down by microorganisms. Mr. Vice-Chancellor sir, all of us will one day be subject to microbial decomposition. When I was an undergraduate some 30 years ago, my Entomology lecturer now Prof. T. Ajibola Taylor told us in class that the last surviving organisms would be the insects. But we now know that even the insects (dead or alive) are all subject to microbial decay.

In the process of decomposing organic matter, micro-organisms affect human lives in two fundamental and tremendous ways namely:-

(i) decomposition of organic residues becomes important in environmental sanitation. The environment, on the long run, will be rid of undesirable waste products which constitute health hazard to humans and decrease the aesthetic value and life span of our urban centres which are presently overloaded with garbage. With proper execution and not just for the purpose of awarding contracts, the garbage dumps on the street of our major cities can be cleared by employing and promoting microbial growth and activities. Similar to this is the clearing of major water pollutants by micro-organisms. It is estimated that between 5-10m tonnes of crude oil and its refined products are discharged each year into the world's marine environment (NAS, 1975; Grossling, 1977) and most of these major oil spills have been cleared by the use of microorganisms. By a process tagged "stimulated biodegradation", "the polluted water is sprayed with pure cultures of bacteria which can degrade the oil and under favourable conditions of nutrients and temperature it is estimated that micro-organisms can degrade up to 40-80 per cent of crude oil. As reported by Ajisebutu (1984), up to 80-100 strains of oil degrading bacteria had been isolated and described. The beauty of the biological degradation of oil and other organic materials is that no deleterious residues are left in the environment which could affect aquatic and human lives.

(ii) As mentioned earlier on, although the purpose of micro-organisms in decomposing organic matter is not to release nutrients for crops so as to feed human beings, the direct consequence of their action is the release of essential nutrients for plant growth. Some of the most important plant nutrients like nitrogen, phosphorous, sulphur and some micronutrients are tied up majorly in the soil organic matter and their release requires the intervention of these heterotrophic organisms. In the under-developed agriculture of the underdeveloped and impoverished countries like Nigeria, the feeding of millions of the people still depend on the release of nutrients from organic matter by micro-organisms because most farmers do not have access to fertilizers either due to poverty or the nefarious activities of the Nigerian businessmen and women who divert fertilizers away from the genuine end users.

The advantage of organic matter as a source of nutrients for plants is that because the release of nutrients is steady, plants make use of the nutrients as soon as they are released thereby reducing the loss of the nutrients into the underground water; the reduction in loss minimizes environmental concerns unlike the use of fertilizers. However, the major problems with the use of organic matter in crop production concerns two aspects - the scientific bottleneck and the socio-economic problem. Scientifically, researchers have not been able to synchronize the time of release of nutrients from organic matter with plant uptake. At present, this

is an arduous task that is taxing the ingenuity of basic and applied researchers in this area of research and it calls for great research funding in terms of investments in modern, computer-based sophisticated equipment This is a task that must be done especially for the benefit of the resource poor farmers in the underdeveloped countries who depend on organic matter as a source of plant nutrients.

The socio-economic aspect of the problem is that it is now well-established that with increasing populations (the world population as at March 25, 1996 was estimated by FAO at 5.8 billion with the possibility of increasing to 9.0 billion by the year 2030), nutrients from organic mater cannot sustain crop production to feed the increasing population. For example, in the Philippines at the International Rice Research Institute, a plot of land had been set apart and cultivated since 1960 to grow two crops of rice per year without any external inputs of chemicals. The sources of nutrients are biological nitrogen fixation and organic matter decomposition. Up till 1990 which was the last information I have, the plot still produced about 2 tonnes per hectare of rice grain under irrigated conditions. In Nigeria, under the upland conditions, that could be a substantial harvest but the world rice research stations are now aiming at 15 tonnes per hectare/crop and even more to be able to feed the world population by the year 2010 (IRRI Strategic Plan. 1989). In essence, dependence on nutrients from organic matter alone cannot sustain crop production and the present research trend is an integrated approach towards the combined use of organic and inorganic fertilizers (this will be given a fair mention later in the course of this lecture).

Even, assuming that nutrients from organic matter can sustain crop production elsewhere, it cannot sustain production in the under-developed countries for two major reasons. The first major reason is related to the rate of decomposition which is tied up to the environmental factors which are not conducive to organic matter conservation in the tropics. Most of the underdeveloped countries of the world in Asia, Africa and Latin America fall into the tropical regions where rainfall and temperatures are very high and promote excessive decomposition of organic matter by the heterotrophic microorganisms. For instance, in our early studies on the decomposition of organic matter in Nigerian soils, we (Adebayo and Akaeze, 1976) found that under laboratory conditions, the overall rate of organic matter decomposition was 2.62% in 15 weeks and that the rate was higher in the savanna soils of the country (3.23%) than in the forest soils (2.15%). The rates of decomposition were clearly linked to the initial organic matter contents of the soils. In a comparative study of soils from Britain (a temperate country) and Nigeria (a tropical region), Ayanaba and Jenkinson, (1977) discovered that the rate of organic matter decomposition in the tropics could be very high. They found that the rate of decomposition of the same quantity and quality of organic matter in Nigeria soils under Nigeria's climatic conditions was two and a half times faster than the rate at Rothamstead Experimental Station in England. The import of this is that if it takes a certain quantity of organic matter 25 years to decompose under temperate conditions, it would take only 10 years for the same quantity in Nigeria. As at now, we do not have the technology either indigenous or imported to manipulate God. If we can control the rate of decomposition under laboratory conditions, we cannot do the same under field conditions; we therefore have to look for other ways of solving the problem of organic mater conservation.

Unfortunately, people in the underdeveloped countries, especially Nigeria are more interested in resource exploitation rather than conservation. The only resource Nigerians conserve is probably money and not the natural resources. And this goes with management of organic matter in tropical soils - which is the second major problem of underdeveloped agriculture. Young (1987), considering only topsoil carbon estimated the amount of plant residues needed to maintain soil organic matter in the humid tropics to be 8,000kg dry matter above-ground residues per hectare/year against 4,000 and 2000 kg required for sub-humid and semi-arid areas respectively. The import of this finding is that ways and means should be devised to conserve and possibly increase the organic matter content of tropical soils. In this regard, we (Olayinka and Adebayo, 1983, 1984, 1985, 1989) have done extensive studies on the use of sawdust (which is currently being burnt-off by sawmillers) to increase organic matter level in two soil series and promote plant growth. The results showed that not only was soil organic matter increased, but also soil chemical properties, plant nutrient uptake and growth were promoted by the use of appropriate loading rates of sawdust amended organically or inorganically if the amended sawdust were pre-incubated for a maximum of four weeks before planting.

The 'Slash and Burn' system of farming characteristic of underdeveloped agriculture does not favour organic matter conservation. It can be argued and I have observed under field conditions that the first crop after a plot of land is burnt usually does well especially for crops planted during the rainy season due to various reasons which are explicable, but so much biochemical and microbiological damage is usually done to the soil that subsequent crops never do well except with substantial application of fertilizers (organic and inorganic). Such a system is not sustainable.

From the physical, chemical and biological attributes of the soil organic matter on soil properties, replenishing soil organic matter should be a major concern of the farmers in both the modernized and underdeveloped systems of agriculture and cultural practices must take into account the need to maintain, and if possible, to increase the levels of organic matter in the soils. The nitrogen and organic matter balances in soils can be improved by replacing burning with ploughing under. In this regard, I am therefore recommending that the half-hearted government legislations against bush-burning should be enforced and made to work not minding whose ox (or cow) is gored.

Biofertilizers and Integrated Use of Inorganic and Organic fertilizers

What are biofertilizers? Rao (1982) defined biofertilizers as "all soil-enriching inputs for plant growth which are of biological origin". Essentially, such materials will include microbial materials such as live organisms and their products and organic materials which have manurial values such as green manure, azolla and blue green algae usually designated as manure. In essence, not all organic materials can be defined as biofertilizers although they may essentially perform the same functions of enriching the soil.

For centuries, farmers in the tropics have harvested low but consistent crop yields with little or no chemical nitrogen fertilizer inputs because the traditional shifting cultivation maintained environmental quality and soil productivity on a sustained basis. Until the 1960's several countries used a green manure crop as a biofertilizer. The use was discontinued however, in most countries thereafter due to the development of high yielding crop varieties which require high analysis and readily available sources of nutrients. In recent years, the world-wide concern for the sustainability of crop productivity as lands are called upon to produce higher yields from a single crop and higher total annual yields under intensive cropping systems called to question the continued reliance on chemical fertilizers as sole source of nutrients. Relying solely on chemical fertilizers as sources of plant nutrients leads not only to the waste of large amounts of natural resources and environmental pollution, but also to the depletion of soil organic matter. The single most important nutrient in most biofertilizers is nitrogen. Nitrogen is known worldwide as one of the most important factors governing plant productivity. For instance, to produce 100kg of rice grain requires 1.8 - 2.0kgN. But the production of inorganic fertilizers requires considerable energy. It is estimated that fertilizer production accounts for about 45% of the total energy used in agriculture worldwide and that 73% of that energy is used to manufacture N fertilizer (McCune, 1984) making fertilization an expensive item of crop production. Therefore, in the early 1930s, research began on biofertilizers including algal and bacterial inoculants, although a country like China has a 3,000 yr. history of using green manure to increase cereal crops and to maintain and increase soil fertility (Lizhe, 1988). From then until the 1960s several countries used a green manure crop as biofertilizer. During the last two decades, however, leguminous green manure crops have been over looked because of crop intensification and increased availability of chemical fertilizers (FAO, 1978).

Recently, interest in the use of biofertilizers has revived because of fertilizer prices in relation to crop prices, increased concern for environmental quality and maintenance of high and stable yields on a long term basis.

Legume green manure

Shifting cultivation, still the traditional type of farming in the non-irrigated agricultural areas of the humid tropics is a stable agricultural system provided that a sufficiently long fallow period can be applied (Greenland, 1975; Okigbo 1984) or a green manure crop can be included in the cropping system. Such an inclusion of green manure in the traditional cropping system has been shown to be the best alternative to attain sustained crop production in low input agriculture we have in Nigeria as far as the supply of nutrients is concerned.

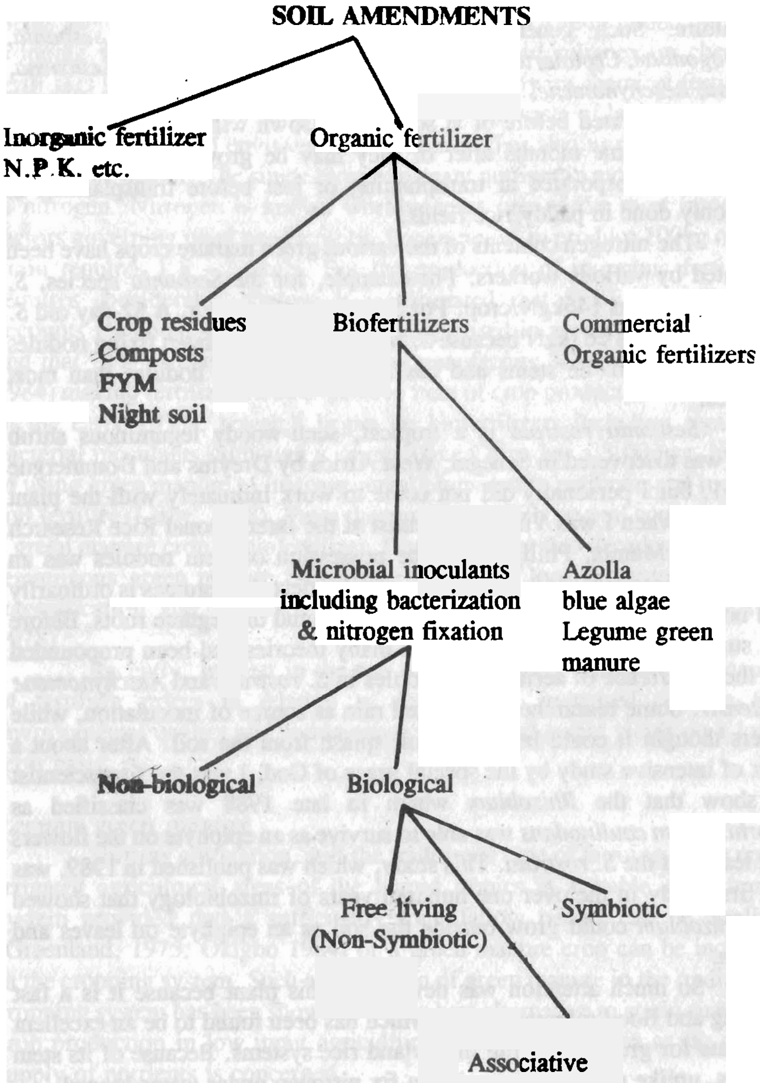
In recent years, many genera of green manure crops have been identified and put into use particularly under irrigated and low land rain-fed

agriculture. Such genera include the various species of *Sesbania, Calopogonium, Crotolaria, Centrosema, Stylosanthes, Gliricidia, Leucaena, Mimosa, Aeschynomene*, cowpea and a host of others. Such green manures can be incorporated before or at sowing, or sown with the crop and then incorporated some months after or they may be grown during a fallow period and incorporated at transplanting or just before transplanting as commonly done in paddy rice fields.

The nitrogen contents of the various green manure crops have been estimated by various workers. For example, for the *Sesbania* species, *S. sireceda* contains 146kgN/crop. For *S. sesban* it is 202kg. A 52-day old *S. rostrata* contains 267kgN because *S. rostrata* forms nitrogen fixing nodules on the roots and the stems and has 5-10 times more nodules than most legumes.

Sesbania rostrata is a tropical, semi-woody leguminous shrub which was discovered in Senegal, West Africa by Dreyfus and Dommergue in 1981, but I personally did not come to work intimately with the plant until 1987 when I was Visiting Scientist at the International Rice Research Institute in Manila, Philippines. The possession of stem nodules was an intriguing discovery since *Rhizobium* which infect the legumes is ordinarily and normally soil borne, found commonly around the legume roots. Before my studies which started in 1987, so many theories had been propounded for the occurrence of aerial stem nodules in *S. rostrata* and *Aeschynomene pratensis*. Some researchers suggested rain as source of inoculation, while others thought it could be due to soil splash from the soil. After about a year of intensive study by the special grace of God, I was the first scientist to show that the *Rhizobium* which in late 1988 was classified as *Azorhizobium caulinodans* was able to survive as an epiphyte on the flowers and leaves of the *S. rostrata*. This study, which was published in 1989, was the first study in the over one hundred years of rhizobiology that showed that *Rhizobium* could grow outside the soil as an epiphyte on leaves and flowers.

So much attention was devoted to this plant because it is a fast growing and flood tolerant legume which has been found to be an excellent candidate for green manuring in lowland rice systems. Because of its stem nodules, unlike most legumes, it can fix nitrogen under water-logged



conditions and when the N content of the medium is very high. Assuming that between 50 and 80% of N accumulated in legumes originates from biological nitrogen fixation, it appears that legume green manures could provide 50-80kg N to a crop and incorporating one legume crop is equivalent to applying 30 to 80kg fertilizer N.

In China, which has a long history of green manuring, Wen (1984) reported that on the average, applying 1 ton (fresh weight) of winter green manure to rice will increase yield by 30-80kg depending on soil fertility, rate of application and the rice cultivar. Pandy and Morris (1983) estimated legume potentialities to be 100kg grain yield increase per ton of green manure incorporated (winter, spring or summer green manures). *S. rostrata* incorporated 52 day old before transplanting increased rice yield by 3-7t/ha over the control (Rinaudo *et al.*, 1981). In contrast, applying 60kg N as $(NH4)_2SO_4$ increased yield by 1.7t/ha over the control In addition, legume green manure was reported to increase soil N and organic matter content, available Zn, hydraulic conductivity, WHC and aggregate stability of the soil. It also has a residual effect and could tie up mineralized soil N thus preventing its loss by denitrification, volatilization or leaching when land is fallow (Roger and Watanabe, 1986).

Despite their potential to increase yield, use of leguminous green manures has decreased in recent years. China is the only country where legumes are still widely used. Hectarage of green manure tends to increase where soil fertility is low and decreases where soil fertility is high (Roger and Watanabe, 1986). The non-acceptance or declining use of legume green manures has been attributed to a number of factors. In the temperate countries, some detrimental effects of green manuring has been reported. Decline of green manure in Japan was attributed by Watanabe (1984) to:

(i) possible plant growth reduction caused by anaerobic decomposition of green manure
(ii) lack of synchronization between N release and plant N needs which depresses growth at early stages and causes excessive growth detrimental to yield at later stages.
(iii) soil degradation.
(iv) unpredictability of the amount of N applied.

The bulkiness of legume green manures and resulting incorporation difficulties are great disadvantages to the use of green manures. The nitrogen content of most legumes varies from 0.2 to 0.6; therefore the fresh weight corresponding to 50kgN/ha varies from 10-26 tonnes. Large scale incorporation of such a large and more lignified biomass using animal draft power and traditional implements is difficult. In developed countries, high wage rates and lacking man power may be limiting.

Legume green manures are not appealing because they do not directly yield food or cash. Additionally, green manures are poorly competitive and not competitive where commercial N fertilizer is available. Furthermore, some governments have a fertilizer subsidy policy and make credit available for farmers to buy N fertilizers. The cost of green manure seed and necessary land preparation are unfavourable.

Although in terms of fixed N, legumes have tremendous potential and there is a large range of drought or sub-mergence adapted green manure species, green manuring is not wide-spread and even has declined in recent years. Green manuring has realistic potential where the subsistence component of the farm household complex is high. However, the availability of N from legume green manure depends on factors such as:

(i) green manure quality and quantity
(ii) time and method of application
(iii) soil fertility status
(iv) kinds of crops and cropping methods
(v) green manure species

In conclusion, I want to recommend that the decline in recent years of green manure use should evoke cautious and thoughtful research in an underdeveloped and impoverished economy like that of Nigeria.

1.3 Microbial Inoculation and Nitrogen Fixation

Despite high production and use of chemical N fertilizers in modern agriculture, soil N and biological N_2 fixation (BNF) remain primary sources for crop production in a vast area in the underdeveloped countries (Bouldin, 1986; Herdt and Stangel, 1984). For instances, for centuries, farmers in the tropics have harvested low but consistent rice yields with little or no chemical N fertilizer inputs because BNF occurs along with rice cropping (Koyana and App. 1979; Ladha 1986).

It is now over 100 years since Hellriegel and Wilforth published in 1886 their discovery, made two years previously that legume nodules fix nitrogen. Since then, a number of legume and non-legume crop species have

been screened for their potential to fix atmospheric nitrogen and the contribution of biological nitrogen fixation to crop production has been estimated variously by many workers. However, the contribution of biological nitrogen fixation to crop production could not be put in proper perspective because no precise, quantified data were available on the amount of nitrogen fixed by legumes. This was due to the fact that most of the work was carried out before the 1960s when N^{15} techniques were not readily available.

Legume species differ widely in N concentration and N yield. Because different authors measured N accumulation under diverse, cultural, climatic and edaphic conditions and for different durations, a valid comparison cannot be made. Published average and potential or highest estimates for nitrogen fixation by legumes obtained by N accumulation and fertilizer N equivalence methods indicate that the crops' N_2 - fixing potential is far from being totally exploited.

Apart from legumes, with the use of N^{15} isotope dilutions and N-balance methods, various grasses especially rice, sugar cane cultivars and *Panicum* sp have been shown to fix nitrogen in association with various microorganisms. Sugar cane cultivar cv 47-89 was shown to have obtained 40% of its N from fixation in the first 12 months of growth. A value of 30 kgN/year was reported for Kallar grass and *Panicum maximum* was shown to be capable of fixing 5-10kgN/ha/month during the rainy season (Graham *et al.*, 1988). Bacterization of wheat with *Azotobacter chroococcum* and *Azospirilum brasilense* enhanced the number of tillers, dry matter, grain yield and protein content in the grain depending on the initial fertility status of soil and the variety of crop planted (Zambre *et al.*, 1984).

In order to derive maximum benefit from nitrogen fixation, legume inoculants were produced late last century (Nutman, 1986). In the production of inoculants, pre-selected organisms were allowed to grow on and multiply in local carrier materials. After a period of maturation, the inoculants would be used to coat the seeds prior to sowing in the field. The success of legume inoculant production in any country depends on the use of suitable *Rhizobium* carriers. The most widely certified and used carrier in inoculant production is peat. But the importation of peat into a country like Nigeria where it is not available is an expensive undertaking involving huge foreign exchange transaction. Therefore, in 1989, we (Daramola and

Adebayo) set up studies to identify locally available carriers (soil and liquid) which could be adapted for use in inoculant production for grain legume cultivation in Nigeria. Using various antibiotic resistant strains of *Rhizobium* which were labelled with ampicillin, streptomycin and spectinomycin in our microbiology laboratory, we compared locally available materials such as Farm-yard manure, Baggasse (a waste product from sugar industry), sawdust and coconut water to peat as possible *Rhizobium* carriers. Our findings indicated that of all local materials tested, the survival and multiplication of the organism in Bagasse and Farm yard manure were not too significantly different from the survival in imported peat. Plant height, dry matter and nitrogen yields were comparable in respect of Farm yard manure and Bagasse, but gave significantly higher values of all variables when compared with sawdust. Our conclusion was that Farm yard manure and Bagasse can therefore be regarded as suitable alternative carriers to peat.

The greatest successes with inoculation have been achieved (a) where a cultivated legume is introduced into a site or region for the first time. (b) with annual legume crops for which the number of *Rhizobium* in the soil falls significantly between crops. But such successes are not universal, for instance, from our studies in Nigeria and other studies in Tanzania, cowpeas and some local tropical soybeans showed no response to inoculation whereas some introduced soybean cultivars did. Data from worldwide trials with crop legumes indicated that soybeans gave the most consistent response to inoculation (Davis *et al.*, 1984, Graham 1985).

One of the major problems of BNF application in agriculture is that inoculant rhizobia strains do not continue to nodulate plants in the field. Even when initially successful, they are commonly replaced within a year or two by indigenous strains, some of which can be as effective as the inoculants (Date and Roughley, 1977).

Integrated Use of Biofertilizers and Inorganic Fertilizers

Although there are constraints to the practical use of biofertilizers, their widespread use stemmed from the well-understood role they play in improving the physical, chemical and microbiological properties of the soil. Biofertilizers provide considerable amount of major and minor plant nutrients. There is a substantial fraction of N in green manures which

mineralizes rapidly during the first crop (Bouldin, 1988), and this nitrogen can supply a substantial portion of the N required by cereals (Ladha *et al.*, 1988, Singh, 1984). Green manure crops are reputed to have longer residual effects than fertilizer N. Although the residual effect of application of green manure on residual N may not be substantial in the first year, the residual effect can become important in the long run. Green manure crops do furnish an amount of N sufficient to replace 50 to over 100kg of fertilizer N to a succeeding non-legume crop. In some experiments, a green manure crop has been reported to have increased soil productivity and increased the effectiveness of fertilizer N. Although the residual effect of one green manure crop may be small, the cumulative effects of continued use of green manures are expected to be important not only on N supply but also on soil productivity.

On the other hand, chemical or inorganic fertilizers have higher nutrient content than organic fertilizers, hence, they are less difficult to handle and store. Chemical fertilizers are convenient to apply and the nutrients they contain are more readily available to plants. The ease of application and evenness of distribution for chemical fertilizers and the predictable amount of nitrogen available for crop growth have won them a place in production systems that will be difficult for green manure to fill.

However, increased and total dependence on chemical fertilizers have led to more serious problems. It has led not only to the waste of large amounts of natural resources and to environmental pollution, but also to the depletion of soil organic matter (Wen, 1984). Brown (1981) reported deterioration in the fertility of a considerable portion of American soils because of the continuous use of chemical fertilizers alone. The occurrence of zinc and sulphur deficiencies in many rice-growing areas was believed to have resulted from heavy applications of chemical fertilizers, (INSURF, 1988).

An integrated management of organic and inorganic fertilizers including legumes in cropping systems can contribute to the maintenance of a sustainable system while increasing farm income above subsistence level (Meelu and Morris, 1981). In an experiment (fig. 2) by Bhatti *et al.*, (1985), the yield of rice in a fallow-rice-wheat and green manure-rice-wheat rotations were evaluated and compared with added fertilizer N applications. It was shown that no amount of fertilizer N without green manure will give a yield equal to that obtained with green manure and fertilizer N combined. In a similar experiment by Islam *et al.*, (1984), rice was grown under greenhouse conditions and N uptake under Azolla and mineral N fertilizer was compared. Results showed that in the urea treated pots, the rice took up a smaller fraction of the mineral N than in the green manure pots. An hypothesis is that urea created NH_3 toxicity and decreased the root density/root activity.

In the experiment of Tiwari *et al.*, (1980) the yield of rice in fallow-rice-wheat and green manure-rice-wheat rotations were plotted against fertilizer N added, while the grain yield response per kg of fertilizers was 21 kg grain/kg N without green manure, it was 45kg grain/kg N with green manure (Fig. 3). Thus the green manure has increased the yield of grain from 1.5 to 2.5 mt/ha and the yield increase per kg of fertilizers was from 21 to 45kg grain/kg N.

From the above reports, it can be concluded that high yields may be obtained with biofertilizers, but as cropping intensity and use of high yield varieties increase, complete dependence on biofertilizers alone may not be advisable or truly economical. Biofertilizers cannot replace but can only supplement other mineral fertilizers.

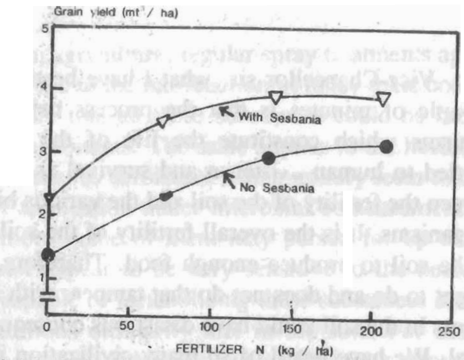


Figure 2: Yield of rice in fallow-rice-wheat and green manure-rice-wheat rotations plotted against fertilizer N added. Points are experimental observations, lines are arbitrarily drawn for reverence purposes. Average of 2 years. (Bhatti *et al.*, 1985).

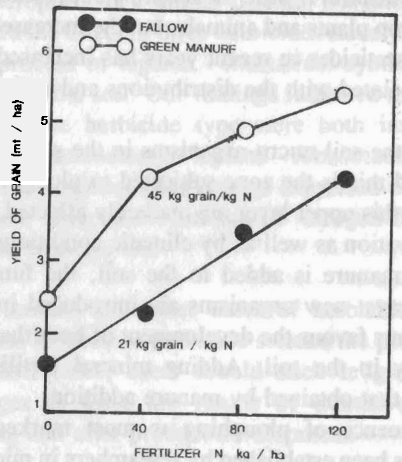


Figure 3: Yields of rice in fallow-rice-wheat and green manure-rice-wheat rotations plotted against fertilizer N added. Points are experimental observations, lines are arbitrarily drawn for reverence purposes. Average of 2 years (Tiwari *et al*, 1980).

Mr. Vice-Chancellor sir, what I have been trying to point out in the last couple of minutes is that the process being carried out by the microorganisms which constitute the life of the soil are so vital and intricately tied to human existence and survival as a delicate equilibrium exists between the fertility of the soil and the various biochemical activities of microorganisms. It is the overall fertility of the soil that determines the ability of the soil to produce enough food. Therefore, anything that man does or ought to do and does not do that tampers with life and activities of the organisms in the soil could have disastrous consequences on human life and survival. We have heard of so many civilization in the ancient world that have been destroyed because of the destruction of their soils.

Let me discuss very briefly then the influence of man on soil micro-organisms. Examination of cultivated soils shows that the activities of man greatly modify the normal distributions of soil micro-organisms. Most of this modification is brought about by cultivation of the soil and by the influence of crop plants and animals, but the increased use of fumigants, fungicides and insecticides in recent years has increased the complexity of the problems associated with the distributions and activity of organisms in the soil.

Most of the soil micro-organisms in the soil inhabit the upper 25 cm of the soil and this is the zone subjected to ploughing and cultivation. The organisms in this upper layer are markedly affected by the influence of crop and its cultivation as well as by climatic conditions. For instance, we know that when manure is added to the soil, the fungal flora could be affected in two ways: new organisms are introduced into the soil and the addition of nutrients favour the development of both the introduced species and those already in the soil. Adding mineral fertilizer would achieve similar results to that obtained by manure addition.

The influence of ploughing is most marked on the bacterial populations. It has been established by researchers in microbial ecology that immediately after ploughing, the numbers of bacteria increase in a few days to a value 20-30 times the original level. This high value is usually maintained for about two months and then falls fairly quickly to about twice the original level and then gradually falls off to the low level found at the end of the season. Actinomycetes and fungal counts were also found to

as that of bacteria.

In modern agriculture, regular spray treatments against pathogenic fungi and insects lead to the introduction of many toxic compounds into the soil. Indications are that all these substances could be broken down with time by the soil inhabitants. The same applies to the hormone weed killers commonly referred to as herbicides which usually seem to disappear within a few weeks of application under microbial bombardment although under very dry conditions some of them may persist for up to a year. Micro-organisms do not appear to be very sensitive to the herbicides and most organisms not capable of metabolizing these substances seem little affected by the concentrations ordinarily met in the soil. For instance, in 1979, Adebayo, Fadayomi and Salawu evaluated the effect of two corn herbicides in use in Nigeria then namely: cyanazine and atrazine on the process of nitrification - a very sensitive biological process in the soil. We found no evidence that the herbicides when used at recommended rates had any inhibitory effect on nitrification irrespective of whether the soils were cropped or uncropped. In a similar finding, Daramola and Adebayo (1981, 1982) evaluated the effect of three herbicides namely: Preforan, Dacthal and Dual on the process of legume - *Rhizobium* symbiosis with and without starter nitrogen in the soil. Our findings indicated that the rate of herbicide application and the herbicide type were both important factors which affected the vital parameters of legume - *Rhizobium* symbiosis in soil. For instance, Dual at recommended dosage depressed nodulation, reduced dry matter yield and reduced the amount of nitrogen fixed significantly. The import of these findings are:

(i) that farmers and other users of herbicide should be taught by experts in weed or herbicide science the proper way to handle and use herbicides; users should stick religiously to recommended dosages as these are results of extensive research and testing during and after product development.

(ii) the indiscriminate use of herbicides by farmers should be discouraged. Certain herbicides are recommended only for certain crops or combination of crops and the use of such herbicides for non-recommended crops could destroy the crops leading to disastrous consequences on human beings.

Another activity of man that can destroy the life in the soil is prolonged growth of one crop on a soil and this can lead to what has been termed "soil sickness". The sickness could be due to an accumulation of infective units of pathogens to a level where successful growth of the crop is uneconomic. This is a reason why credit has to be given to our forefathers who out of their experience devised the system of the traditional shifting cultivation and fallowing.

Therefore, Mr. Vice-Chancellor Sir, it is imperative for man to promote the growth and survival of life in the soil if he is not to destroy himself.

ACKNOWLEDGEMENT

Mr. Vice-Chancellor Sir, before I end this lecture, I want to give honour, praises and adoration to my Lord Jesus Christ for giving me the grace to reach the pinnacle of my academic career. I extend my profound and sincere appreciation to my immediate family members - my wife and children and all members of the extended family especially my mother who slept in the Lord on 9th February, 1996, for their understanding, cooperation, financial and emotional investments in my education. To all my teachers at all levels of my education, I say thank you. To Dr. Olupelu Jaiyebo of blessed memory and Prof. Supo Ladipo who allowed God to use them for my cause at a very critical period in my educational advancement, may Dr. Jaiyebo's soul continue to rest in perfect peace and may God grant you Prof. Supo Ladipo the grace to live a long and enjoyable life. I extend my sincere appreciation to all my friends in and outside the University who have made my life worth living. To my very exceptional and hard working first graduate students, Drs. Olayinka and Dramola, God bless you and may your own days of glory meet you in perfect peace of body and mind. And to all my colleagues in the Department, I say thank you very much.

Mr. Vice-Chancellor Sir, this is part story of my academic career so far. Thank you and God bless you all.

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