OBAFEMI AWOLOWO UNIVERSITY, ILE-IFE, NIGERIA.

Inaugural Lecture Series 222

SOIL MICROORGANISMS, WASTES AND NATIONAL FOOD SECURITY

BY

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OBAFEMI AWOLOWO UNIVERSITY PRESS LIMITED.

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An Inaugural Lecture Delivered at Oduduwa Hall, Obafemi Awolowo University, Ile-Ife Nigeria. On Tuesday, May 26, 2009.

Inaugural lecture Series 222

Obafemi Awolowo University Press Limited, Ile-Ife.

ISSN 0189-7848

Printed by
Obafemi Awolowo University Press Limited
Ile-Ife, Nigeria.

INTRODUCTION

The Vice Chancellor, Sir, distinguished guests, colleagues, ladies and gentlemen. The Scriptures say, "Not unto us, O Lord, not unto us, but to Your name give glory, because of Your mercy, because of Your truth"(Psalm 115:1). I am grateful to God for this priviledge to deliver the 222nd Inaugural Lecture of the Obafemi Awolowo University, Ile-Ife, Nigeria. This is the sixth from the Department of Soil Science, Faculty of Agriculture and the second in the sub-discipline, Soil Microbiology and Biochemistry.

The sub-disciplines in Soil Science are Pedology, Soil Chemistry, Soil Fertility and Plant Nutrition, Soil Physics and Conservation, and Soil Microbiology and Biochemistry. Professor Emmet Schulte of the University of Wisconsin, Michigan, U.S.A, a Lecturer in the Department of Soil Science under the auspices of the United States Agency for International Development (USAID), who supervised my undergraduate Project in 1974, fired my interest in Soil Microbiology and Biochemistry. Providence charted my academic career in this sub-discipline when Professor 'Wale Adebayo became my teacher, supervisor and mentor at the postgraduate level. He delivered the first Inaugural Lecture in this sub-discipline titled, "The soil - a living body".

This lecture, is titled, "Soil Microorganisms, Wastes and National Food Security". I have directed my research effort at the transformations of wastes by soil microorganisms in order to improve soil properties, plant growth and crop production. The Vice Chancellor, Sir, I intend to explain concepts and terms that will enable the audience understand better the subject of this lecture

The Concept of Soil

The concept of soil differs as there are different end-users. It is the collection of natural bodies occupying portions of the earth's surface that supports plants and have properties due to the integrated effects of climate and living matter, acting on parent material as conditioned by relief, over periods of time (US Soil Survey Staff, 1998). From the soil microbiologist's point of view, the soil is the naturally-occurring unconsolidated mineral and organic material at the earth's surface that provides an environment for living organisms (Paul, 2007). Simply defined, it is the medium on the earth's surface in which plants grow. A typical mineral soil consists of 45% mineral matter, 5% organic matter (OM), 25% moisture, 25% air, and microorganisms. A productive soil has these constituents in proportions that are conductive to microbial activity and plant growth.

Soil Microorganisms

The microbial world was discovered by a merchant, Antony van Leeuwenhoek of Delft, Holland in 1676 using a simple light microscope. A controversy developed after this landmark discovery of microorganisms. Citing the emergence of maggots from rotting meat, some subscribed to the theory of abiogenesis or spontaneous generation meaning that microorganisms arise from non-living matter. Others who subscribed correctly to the theory of biogenesis maintained that microorganisms are produced from living matter. The theory of spontaneous generation was disproved by Francesco Redi, an Italian biologist and physician, Louis Pasteur, a French chemist and John Tyndall, an English physicist in 1665, 1861 and 1876, respectively.

Microorganisms are found everywhere including within and on the bodies of man and animals, air, water and the soil. Those inhabiting the soil are termed soil microorganisms. Apart from the soil being a medium for plant growth, it is also a natural habitat for microorganisms. It is estimated that 98% of all known microorganisms are true residents of the soil or are transients that pass through the soil (Brady and Weil, 1999). The populations of the microorganisms found per gramme of fertile agricultural soil are:-

Bacteria	-	$3 \times 10^6 - 5 \times 10^8$
Actinomycetes	-	$1 \times 10^6 - 2 \times 10^6$
Fungi	-	$5 \times 10^3 - 1 \times 10^6$
Yeast	-	$1 \times 10^3 - 1 \times 10^6$
Protozoa	-	$1 \times 10^3 - 5 \times 10^5$
Algae	-	$1 \times 10^3 - 5 \times 10^5$
Nematodes	-	$1 \times 10 — 5 \times 10^3$

Beneficial Activities of Soil Microorganisms

Microorganisms carry out activities in the soil which may either be beneficial or detrimental to man, plants and the environment. Some of the beneficial activities of soil microorganisms are:-

(i) Formation of soil organic matter (SOM) through decomposition of organic materials added to the soil.

(ii) Plant nutrients are released e.g. nitrogen (N), phosphorus (P) and sulfur (S) through decomposition of the SOM.

(iii) Improvement of soil structure as soil particles are bound together by actinomycetes and fungal filaments, and microbial mucopolysaccharides

(iv) Fixation of atmospheric nitrogen (N_2) thereby increasing the budget of the soil.

(v) Improved plant nutrition through symbiotic mycorrhizal relationships with the roots of about 85% of vascular plants e.g. citrus, coffee, tea, cacao, rubber, papaya, oil palm, cowpea and maize. The plants are able to absorb more water and such nutrients as P,N, potassium (K), S, manganese (Mn), zinc (Zn) and copper (Cu).

(vi) Some microorganisms produce factors that help the plant fight against pathogens e.g. novobiocine and tyrothricine are antibiotics produced by some actinomycetes in this regard.

(vii) Release of plant nutrients from insoluble inorganic soil minerals.

Classification of Soil Microorganisms

Soil microorganisms can be classified on the basis of the following:

(i) **Ecological** – The microorganisms that are always actively carrying out biochemical processes in the soil are the autochthonous flora. Examples are the decomposers of SOM. Those that exist for short periods are the allochthonous or zymogenous flora.

(ii) **Biochemical capability** – Soil microorganisms that require free oxygen (O_2) for respiration are aerobes while those existing in its absence are anaerobes. Facultative anaerobes carry out their biochemical activities either in the presence or absence of O_2. Microearophiles exist in the presence of low concentrations of O_2. In normal agricultural soils, the aerobes predominate.

(iii) **Optimum temperature for growth** - On the basis of optimum temperature ranges for growth and development, soil microorganisms are classified as psychrophiles (<20 °C), mesophiles (25 – 35 °C) and thermophiles (45 – 65 °C). Most soil microorganisms are mesophiles.

(iv) **Sources of energy and cell carbon** - Soil microorganisms require energy for growth and carbon (C) for cell formation. The ones that need preformed organic substrates as sources of both energy and cell C are termed chemoheterotrophs. They are the most numerous in the soil and are important in the formation and mineralization of SOM. Examples of chemoheterotrophic bacteria and fungi isolated in our soils include *Chromobacterium* sp, *Anicetobacter* sp, *Actinomyces* sp, *Brevibacterium* sp, and *Klebsiella* sp, and *Aspergillus* sp, *Penicillium* sp, *Paecilomyces* sp, *Pullularia* sp, *Fusarium* sp, *Rhizopus* sp, and *Cladosporium* sp, respectively (Oduekun, 2002; Faborode, 2008). The chemoautotrophs obtain energy through oxidation of inorganic nutrients and cell C from carbon dioxide (CO_2). The nitrifying microorganisms, viz, *Nitrosomonas* sp and *Nitrobacter* sp, oxidize ammonium (NH_4^+) and nitrite (NO_2^-), respectively, to nitrite and nitrate (NO_3^-) as the endproducts.

Factors Affecting Microbial Activities in the Soil

The mere presence of microorganisms in the soil is of little importance. It is the activities they carry out that are of great significance. The biochemical activities they carry out in the soil are affected by the following primary factors:

i) **Moisture**- This is the major component (~70%) of microbial protoplasm. It is the medium through which nutrients and food are transported into the cells and metabolic wastes excreted. Maximum activity of the aerobes is in the range of 50 – 75% of the soil's water- holding capacity (Wild, 1996).

ii) **Aeration** – In normal agricultural soils, aerobes proliferate and carry out such biochemical activities as SOM decomposition and nitrification. At saturation when air is completely excluded from the soil, anaerobes and facultative anaerobes become dominant. In this situation, chemoheterotrophic facultative anaerobes e.g. *Pseudomonas denitrificans* carry out the process of denitrification which leads to loss of N as N_2 and nitrous oxide (N_2O) from the soil system. Apart from the reduction of N available for plant uptake, nitrous oxide is one of the gases implicated in climate change through global warming. Denitrification has been found to take place, however, at anaerobic microsites in otherwise well-aerated soil (Parkin, 1987; Olayinka, 2003).

iii) **Temperature** – According to Vant Hoff's rule, microbial activity doubles for every 10 ^{0}C increase in temperature until the optimum is reached. Olayinka and Adebayo (1984) found that the rate of decomposition of organic materials in soil doubled between 25 and 35 °C, and decreased at 40 °C indicating that the microorganisms were mesophiles. Extreme temperatures are detrimental to microbial activities.

iv) **Organic matter content** – Most of the soil microorganisms are chemoheterotrophs requiring preformed organic substrates as sources of energy and cell C. Hence, microbial population and activity increase with increase in the content of SOM.

v) **Soil reaction (pH)** – The soil microorganisms produce enzymes through which they mediate biochemical activities. They carry out their activities best in the neutral pH range (6.5 – 7.5). However, some fungi have been found to be acid tolerant (Alexander, 1977; Olayinka and Babalola, 2001).

vi) **Inorganic nutrients** - Apart from C, microorganisms also need other inorganic nutrients such as N, P, K, Ca and S for proper growth and development. This is why microbial population increases on application of inorganic and organic fertilizers as observed by Olayinka and Adebayo (1984).

Wastes in the Environment

As a result of man's activities, large quantities of wastes are generated daily. It has been estimated that about 50 million metric tonnes of wastes are generated in Nigeria annually. The factors responsible for this are population explosion, rapid urbanization and higher standard of living. Wastes can be defined as residual products of human activities deposited in the environment as being worthless and of no further value (Ogedengbe, 1990; Oyediran, 1994).

The different types are industrial (e.g. carbide sludge, sewage sludge, sawdust), mining (e.g. tin, iron-ore, gold), radioactive (e.g. nuclear waste), domestic (e.g. household and biowastes) and agricultural wastes (e.g. crop residues, poultry droppings, cow dung).

Problems of Waste Disposal

When wastes are concentrated in space, they pose problems of disposal to the society. Their improper disposal leads to environmental pollution of the air, soil, surface and underground waters. Specifically, these problems include the following:-

i) They constitute an eye sore in the environment.

ii) They are breeding grounds for disease-carrying vectors and organisms such as flies, rodents and cockroaches.

iii) The air is polluted by smoke and particulate matter when wastes are burnt

iv) Their anaerobic decomposition generates methane (CH_4), CO_2, N_2O and hydrogen sulphide (H_2S). The first three are greenhouse gases that are responsible for global warming and climate change (Kewei and Patrick, 2004). Hydrogen sulphide has offensive odour.

v) Heavy metals such as lead, mercury, cadmium, chromium and arsenic can accumulate in the soil and be toxic to living organisms including man (Del Val *et al.*, 1999; Taiwo *et al.*, 2003).

vi) The wastes can be carried by runoff into streams, rivers and lakes thereby enriching them with nutrients (N, P) that cause undesirable growth of aquatic weeds and algae. This is the consequence of the phenomenon known as eutrophication (Correll, 1998; Smith *et al.*, 1998). The amenity value of the water is reduced. Moreover, the dissolved O_2 concentration may be so low that fish and other aquatic life die.

vii) The underground water can be polluted with soluble nutrients especially nitrate nitrogen (NO_3^-). Nitrate exceeding 11 ppm in potable water may be hazardous to infants and babies (Aduayi, 1980; WHO, 1993).

viii) Losses of life and properties had been caused by floods precipitated by wastes dumped in streams and rivers. The Ogunpa flood disaster ('Omiyale') which occurred in Ibadan in 1981 continues to elicit painful memories.

Land Application of Wastes

The Vice Chancellor, Sir, from the foregoing, it is evident that improper disposal of wastes impacts negatively on the environment thereby posing serious threat to man's health and survival. One way of solving problems of waste disposal is through application to agricultural lands. Before the advent of chemical fertilizers, the only outside sources of plant nutrients were organic manures. The value of manure as fertilizer or soil conditioner had been recognized over time:

> "You will admit that when you bring dung onto a field, it is to return something that has been taken away" – Palissy (1563).
>
> "The fertility of the soil depends on humus since humus nourishes the plants; just as humus is a product of life, so it is also a condition of life" – Thaer (1809)
>
> "I sometimes think that never blossoms so red
>
> The rose as where some buried Caesar bled" – Omar Khayyam

Considering the high prices of chemical fertilizers, untimely supply and the supply of inappropriate ones (Chude, 1999), and increasing interest in chemicals-free organic farming, organic manures have become attractive alternative sources of plant nutrients. The wastes that can be applied to the soil are the biodegradable ones consisting of domestic, agricultural and organic industrial by-products such as sawdust. These organic wastes contain essential plant nutrients which are released through decomposition by soil microorganisms, specifically, the chemoheterotrophs. Apart from nutrients, an important soil constituent, SOM, is also formed. Soil organic matter affects all properties of the soil - physical, chemical and biological - and is a major indicator of the success of fallows. It is necessary to dilate on the importance of SOM.

Importance of Soil Organic Matter.

i) Cements soil particles together thereby improving soil structure and reducing the tendency for soil erosion to take place.

ii) Increases the soil's water-holding capacity

iii) Reduces the soil's bulk density so that roots can penetrate the soil easily

iv) Helps in buffering the soil reaction (pH) thereby making the ecosystem stable

v) A storehouse and source of plant nutrients such as N, P and S.

vi) Enhances the soil's cation exchange capacity (CEC), the ability of the soil to hold cationic nutrients in a form that they can be absorbed by plant roots. Soil OM contributes more to CEC in our soils than the clay (Udoh, 1973).

vii) Most soil microorganisms (chemoheterotrophs) obtain energy from SOM.

viii) The humic acids which are its components, solubilize nutrients from soil minerals.

ix) The micronutrient nutrition of plants is improved through direct supply or chelation.

x) The toxicities of natural and synthetic toxic substances are reduced through complex formation or maintenance of a diverse microbial population.

xi) Certain components exert growth-promoting effects on plants.

With this array of beneficial effects, SOM is an important, if not the most important soil constituent. Hence, my interest in the dynamics of SOM and nutrient cycling by soil microorganisms. Organic matter is crucial to soil productivity in the tropics because of its generally low content. It is further lost at a fast rate through decomposition due to the prevailing high rainfall and temperature regimes. Jenkinson and Ayanaba (1977) found a four-fold rate of decomposition under tropical conditions compared to temperate. Adepetu and Corey (1975, 1977) found that within a year of opening a fallow land for cultivation, Nigerian soil lost about 30% of its SOM and 27% of the organic P. The soils also contain mostly low activity clays (LAC) with low CEC. They are thus deficient in the 2:1 expanding layer clay minerals, which are complementary sources of CEC in temperate soils. As a result of these factors, the fertility and productivity of tropical soils are determined mainly by their contents of SOM. This is why students passing through the Bachelor of Agriculture Programme of our Faculty are given adequate knowledge about the transformations of SOM. Moreover, along with Professor 'Wale Adebayo, the course "Studies in Soil Organic Matter" was designed at the postgraduate level and has been taught for the past 25 years.

Roles of Carbon and Nitrogen in the Decomposition of Organic Materials.

Carbon, hydrogen (H) and O_2 are abundant constituents of organic materials. The other elements such as N,P,K, Ca and S are contained in relatively smaller quantities as shown in Table 1. The chemoheterotrophs decompose organic materials in the process of obtaining C for energy and cell formation. In the formation of the cell, C is combined with other nutrients at particular ratios. Apart from C, H and O, N is the nutrient needed in largest quantities for microbial cell formation. Because C is non-limiting while N, is usually in short supply, the N content in organic materials determines the extent to which decomposition takes place. The C:N ratio is, therefore, a critical factor in the decomposition of organic materials. The C:N ratios for soil microorganisms and SOM are 8:1 and 10:1, respectively (Tisdale *et al*., 1993; Hyvonen *et al*., 1996). This means that the microorganisms decomposing organic materials in soil will combine C and N in the ratio of 8:1 to form their protoplasm. The C:N ratio of the organic material determines whether N will be released (mineralized) for plant uptake or removed from the soil and tied up (immobilized) in microbial tissue. Nitrogen is mineralized for plant uptake when the C:N ratio of the organic material is 20:1 or below. Conversely, N is immobilized and the growing plant is deprived of N when materials having C:N ratios greater than 30:1 e.g. sawdust are being decomposed. Hence, while mineralization is essentially beneficial, immobilization might be detrimental to plant growth. One of the major reasons why organic materials are composted before application to the soil is to reduce the C:N ratio so that nutrients can be released readily for plant uptake. Other reasons include reduction in bulk, destruction of eggs of worms, pathogenic bacteria and seeds of weeds, production of an odourless and hygienic endproduct that is easy to store and handle (Olayinka, 2001).

Table 1: **Chemical composition (%) of sawdust (*Canarium schweinfurthii Engl.*) and sawdust-based dairy manure**

Organic amendment	Organic carbon	N	P	K	Ca	Mg	Na	C:N
Sawdust	65	0.11	2.25	0.40	0.38	0.09	0.06	590
Sawdust-based dairy manure	33	1.30	0.60	1.75	1.50	0.30	0.18	25

The Nexus Between Soil Microorganisms, Wastes and National Food Security

The activities of soil microorganisms are mainly beneficial but some may be detrimental to the environment, plants and man. Decomposition of organic materials is one of the most important activities being carried out by soil microorganisms as it results in SOM formation and the release of plant nutrients. The biodegradable wastes or manures that can be sources of SOM and plant nutrients have been mentioned earlier. Improved properties followed by increased plant growth and crop yields have been reported as a result of the applications of organic wastes and manures (Aina, 1982; Olayinka and Adebayo, 1983, 1985).

Poverty is a social problem that is of concern locally and internationally. The first objective of the United Nations Millennium Development Goals (2000) is ending poverty and hunger. This objective has always been high on the agenda of successive governments in Nigeria. There is a National Special Programme for Food Security in association with the Food and Agriculture Organization (FAO) of the United Nations. Food security and agriculture is second on President Yar'adua's Seven-Point Agenda. Food security encompasses the availability of adequate amounts, accessibility and affordability of nutritious foods either from local and/or outside sources. To this end, a country is expected to have a strategic grain reserve which can sustain it for at least 3 months. Adepetu (1997) emphasized the socio-political importance of national food self-sufficiency. It is recognized that the worst aspect of poverty is lack of good food.

Hence, the Yorubas say as follows:

Ti ounje ba kuro ninu ise, ise buse

(Access to good food takes the wind out of the sail of poverty)

The soil is the main focus of programmes designed to increase food production. For organic manures to improve the soil condition and increase crop yields, they need to be decomposed by soil microorganisms. I have thus focused my research effort on the microbial transformations of SOM, organic manures and wastes applied to the soil, factors affecting decomposition and release of nutrients, the patterns of microbial activity with the aim of synchronizing nutrient release with plant nutrient demand, N_2 fixation as affected by manure applications and the effects of xenobiotics (bioactive agents) on soil biochemical transformations. The Vice Chancellor, Sir, I hereby present highlights of our humble contributions to knowledge in the past years of research activities.

Determination of Soil Organic Matter Content

Soil organic matter is the factor that is most correlated with soil fertility and productivity. The critical content of SOM in our soils is 2.0%

(Adepetu and Adebusuyi, 1985). The Walkley-Black (1934) chromic acid digestion method is routinely used to determine the SOM contents of our soils. The procedure, which was developed for soils in temperate countries, assumes a 77% recovery of organic C. This necessitates a correction factor of 1.30 to convert organic C oxidized to total C. Olayinka *et al.* (1998a) adapted the wet combustion procedure for determining total C by dispensing with the laborious and expensive absorption train and carrying out a titration to determine the unreduced $Cr_2O_7^=$. With soils obtained from various locations in the rainforest and savanna zones over basement complex and sedimentary formations in Nigeria, we found that the modified procedure recovered total C. Moreover, there was no need to employ the Walkley-Black correction factor for Nigerian soils as it oxidizes the organic C 100%. This implies that the procedure overestimates the content of organic C by 30% thereby giving a wrong evaluation of the fertility of the soil. Shortly after this was established in Nigeria, similar results were reported in Ghana and Sierra Leone.

Sawdust as an Organic Soil Amendment

Sawdust is a potential source of SOM and nutrients but is difficult to decompose because it is carbonaceous and highly lignified. Allison (1965) added N to soft and hard woods but their decomposition was not improved. He attributed this to nutrient imbalance. Azevedo and Stout (1974) recommended the addition of N to sawdust to achieve a C:N ratio of 15:1. In order to aid its decomposition and improve the nutrient content, Olayinka and Adebayo (1983) amended *Canarium schweinfurthii* (Engl.) (Yor – Ole) sawdust with dairy manure (organic amendment) and N (NH_3) (inorganic amendment) thereby reducing the C:N ratio from 590:1 to 25:1 and 12:1, respectively. For the inorganically–amended sawdust, the NH_3 was neutralized with orthophosphoric acid, a source of P needed by plants and microorganisms. The first stage of our research was the addition of organically (OS) and inorganically (IS)) amended sawdust to an Alfisol (Iwo series) and allowing maize to grow for three consecutive 6 – week periods in the greenhouse. The loading rates were 0, 65, 260, 520, 780 and 1,040 mt/ha. Both amendments significantly increased the soil's CEC, and contents of SOM, N,P, K, Ca and Mg. The OS was superior to IS in increasing maize growth and dry matter yield (Figure 1). While the rates of OS above 260 mt/ha did not lead to further increase in height and dry matter, the IS adversely affected both because of increased acidity (pH 4.43 – 5.70) and nutrient imbalance due to high content of available P. Another important finding was the need to apply smaller amounts of organic amendments to the soil.

In the next investigation, two sources of N (NH_3 and urea) were neutralized with two sources of P (H_3PO_4 and P_2O_5). The treatments were applied at the rate of 65 mt/ha and decomposition was monitored at 25, 30, 35 and 40 °C for 13 weeks. While no need was found for P, addition of N either in the inorganic or organic form to accelerate the decomposition of sawdust was established, with the organic being superior to the inorganic source (Olayinka and Adebayo, 1984). The decomposition increased with temperature from 25 to 40 °C with the optimum between 30 and 35 °C meaning that the microorganisms were mesophiles. The pattern of microbial activity followed the classical pattern of microbial growth: lag phase (1 week), log phase (1 week), stationary phase (2 weeks) and the death phase (5th week to end of incubation) (Figure 2). It will be shown that this pattern has implications for the release of nutrients for plant uptake from organic materials applied to the soil.

Having established that organically-amended sawdust was superior to the inorganic one, Olayinka and Adebayo (1989) assessed the effect on maize growth of 0, 2, 4 and 6 weeks preincubation of OS (sawdust: cowdung 1:3; C:N 25:1). The amendments increased the SOM contents and CEC. The fresh sawdust caused reductions in heights, tissue N and P contents and their uptake (Table 2).

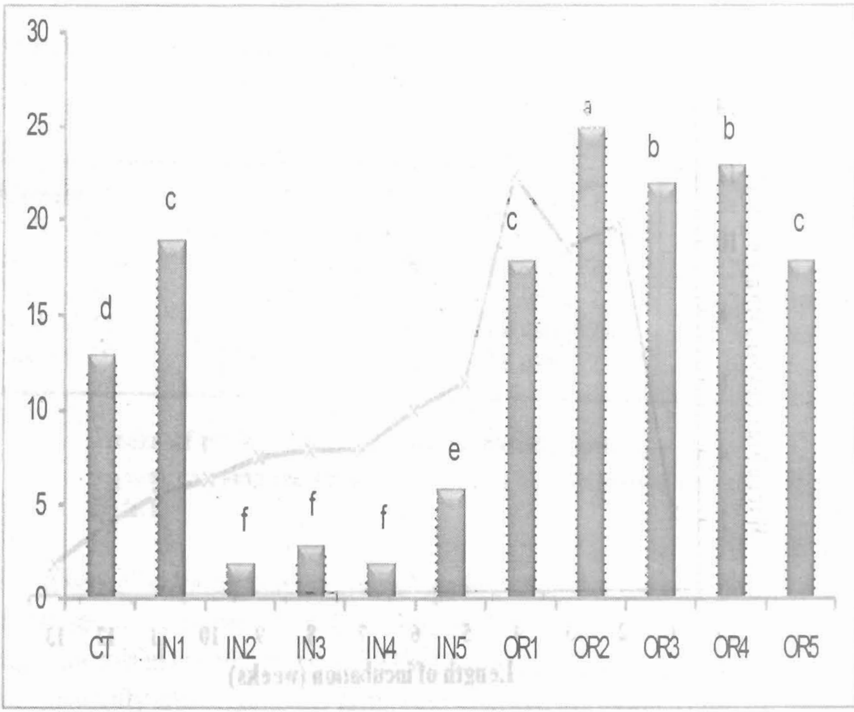

Figure 1: Effect of inorganic (IN) and organic amended (OR) sawdust on maize dry matter yields (g) at the end of the 3rd consecutive 6-week growth periods [CT = control, 1, 2, 3, 4 and 5 = 65, 260, 520, 780 and 1,040 mt/ha . Bars with the same letters are not significantly different (P < 0.05, DMRT)]

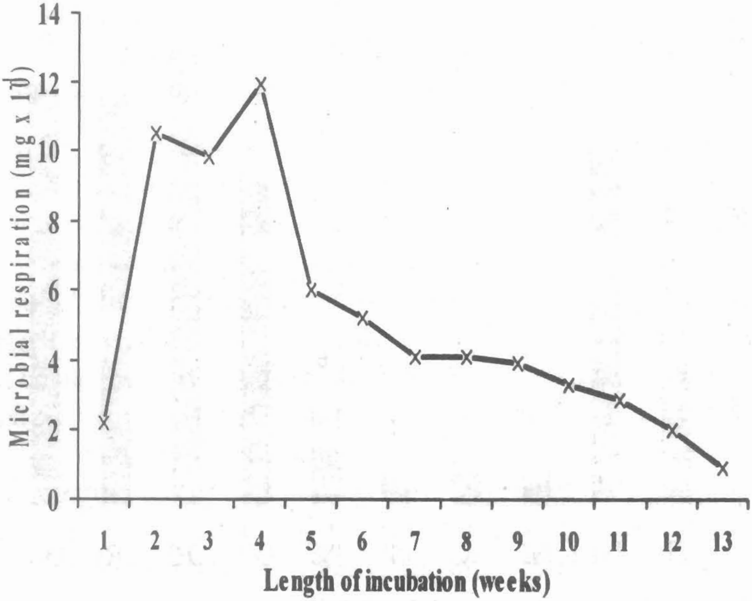

Figure 2: Microbial respiration (mg x 10-1) from soil amended with inorganic and organic amended sawdust over a 13-week incubation period at 30 °C

Table 2: **Mean heights, dry matter yields, tissue N and P and their uptake at the end of two 6-week plantings of *Zea mays L.***

Treatments	Plant height (cm)	Dry matter (g pot^{-1})	Plant tissue (%)		Total plant uptake (cm) (mg pot^{-1})	
			N	P	N	P
Control	86.3a²	1.4a	0.75a	1.74a	10.5a	2.44a
Soil + fresh sawdust	38.8b	0.3b	0.62b	1.24b	1.8b	0.37b
Soil + 0¹-SC	103.0c	3.9c	2.96c	2.24c	114.2c	8.74c
Soil + 2-SC	111.1c	4.2c	2.95c	2.41d	123.3d	10.12d
Soil + 4–SC	109.9c	4.1c	4.49d	2.42d	185.9e	9.92e
Soil + 6-SC	87.4a	2.2d	6.07e	2.45d	135.6f	5.39f

1. Weeks of preincubation of sawdust-based cowdung.
2. Figures carrying the same letter are not significantly different ($P < 0.05$, DMRT)

It was also found that the 4-week preincubated treatment significantly increased these parameters. Olayinka and Adebayo (1984) had reported high microbial activity during the first 4 weeks of incubation of untreated, inorganically and organically amended sawdust implying a high microbial demand for nutrients, especially N (Figure 2). In the microbial growth phases up to the end of the stationary phase, the growing plant may suffer because the microorganisms assimilate the nutrients as their roots are unable to compete. In the death phase, as the more resistant constituents of the organic material accumulates, the microorganisms die, and release nutrients earlier assimilated for plant uptake. From our findings, there developed the concept of 'synchrony' whereby the crops are planted in manure-amended soils at such a time that their increasing demand for nutrients coincide with the maximal release of nutrients in the death phase of microbial activity. In our subsequent researches, we ensured that organic amendments were preincubated for 2 to 4 weeks before planting.

Poultry manure is the richest organic manure in terms of its N content. Because of its low C:N ratio, it decomposes quickly and thereby tends to release excessive amounts of N and P for plant uptake (Carpenter *et al.*, 1998). Underground water can be polluted with NO_3^- and enrichment of rivers and lakes with N and P causes eutrophication (Correll,1998;Smith *et al.*, 1998). Sawdust and corn straw have relatively high C:N ratios and therefore cause N and P immobilization when applied to the soil (Olayinka and Adebayo, 1985). Olayinka (1990a) mixed poultry manure (C:N, 6:1) with sawdust (C:N, 65:1) and corn straw (C:N, 35:1) in the ratios of 1:1, 2:1 and 4:1. The treatments were applied at the rate of 60 mt/ha and the growth of tomato (*Lycopersicon esculentum L.*) was monitored over two 8-week periods of growth. Microbial activity was also assessed (Olayinka, 1996a). The organic amendments significantly increased plant height, dry matter yield, pH, SOM, NO_3^-, available P, tissue N and P and their uptake. It was only in the soil NO_3^- concentration that poultry manure was superior to its mixtures with sawdust and corn straw. Microbial activity was also significantly higher in treatments having the mixed organic amendments (Olayinka, 1996a). In a similar study in which 22 mt/ha of poultry manure and its mixtures with sawdust (*Albizea zygia*; Yor – Ayunre; C:N, 26:1) were added to Apomu series, Oladipo *et al.* (2005) found that N and P mineralized were significantly reduced as the ratios of sawdust increased (Figure 3). The reductions in the soil contents of N and P were due to their immobilization by the microorganisms because of the carbonaceous sawdust and corn straw added to the poultry manure. These results highlight poultry manure as a potential source of NO_3^- pollution of underground water. It was found that the C:N ratios of the organic amendments had significant negative correlation ($r = -0.91^*$) with microbial activity. In order to enhance plant growth and microbial activity, and at the same time reduce the potential of poultry manure to cause pollution, a 2:1 mixture of poultry manure and sawdust or corn straw was recommended.

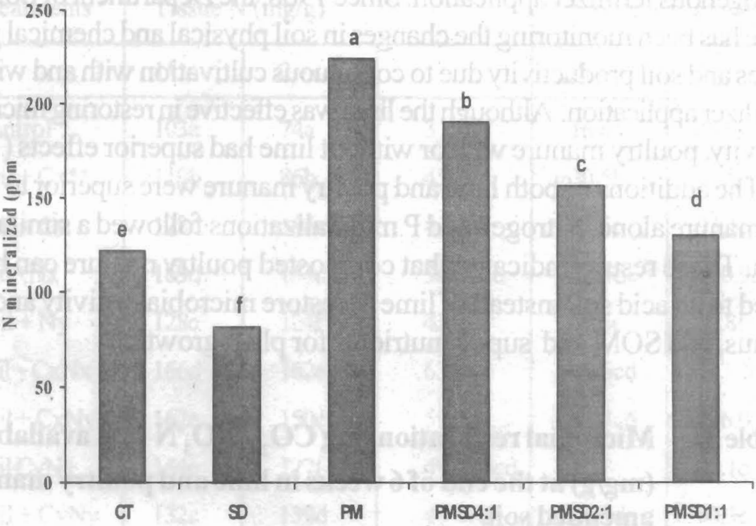

Figure 3: Cumulative N mineralized (ppm) from treatments at the end of 16 weeks of incubation at 30 °C [CT = control; SD = sawdust; PM = poultry manure; 4:1, 2:1 & 1:1 = rates of PM to SD; Bars with the same letters are not significantly different ($P < 0.05$, DMRT)]

One of the environmental problems that usually arise from long-term application of chemical fertilizers is soil acidity. Soil acidity is a widespread problem of tropical soils (Obi, 1976; Goladi and Agbenin; Chude *et al.*, 2005). Microbial activities such as SOM decomposition and nitrification (Stroo and Alexander, 1986), nitrogen fixation (Muchovej *et al.*, 1986), soil respiration and enzyme activities (Bitton and Boylan, 1985) are often depressed. Liming is an accepted agronomic practice used to ameliorate soil acidity in the temperate countries. It is either unavailable or expensive in Nigeria. The effects of additions of composted poultry manure (0,6, 12 and 18 mt/ha) with and without liming (pH 7.0) to an acid soil (pH 4.8) on microbial activity, N and P mineralization were assessed in a laboratory incubation (Olayinka, 1990b). The soil (Iwo series) obtained from the Department of Soil Science Acidity Plot, O.A.U. Teaching and Research Farm became acidic as a result of 15 years' continuous nitrogenous fertilizer application. Since 1968, the Department of Soil Science has been monitoring the changes in soil physical and chemical properties and soil productivity due to continuous cultivation with and without fertilizer application. Although the lime was effective in restoring microbial activity, poultry manure with or without lime had superior effects (Table 3). The additions of both lime and poultry manure were superior to poultry manure alone. Nitrogen and P mineralizations followed a similar pattern. These results indicated that composted poultry manure can be applied to an acid soil instead of lime to restore microbial activity and, as a bonus, add SOM and supply nutrients for plant growth.

Table 3: Microbial respiration (mg CO_2), NO_3^--N and available P (mg/g) at the end of 6 weeks in lime and poultry manure-amended soil.

Treatments	CO_2 evolution (mg)	NO_3^--N (mg/g)	Available P (mg/g)
Control	1.12a[2]	3.4a	12.9a
Soil + Lime (pH 7.0)	1.82b	6.5b	20.0b
Soil + Poultry manure 1[1]	2.37c	10.3c	21.3b
Soil + Poultry manure 1 + Lime	3.16d	12.4d	25.2c
Soil + Poultry manure 2	2.76e	9.2e	27.6c
Soil + Poultry manure 2 + Lime	3.80f	12.7d	30.6d
Soil + Poultry manure 3	3.25d	15.4f	42.1e
Soil + Poultry manure 3 + Lime	4.07g	18.1g	47.0f

1. Poultry manure application rates 1,2,3 = 6,12 and 18 mt/ha, respectively
2. Figures carrying the same letter are not significantly different ($P < 0.05$, DMRT)

Table 4: Maize (*Zea mays L.*) tissue N contents and N uptake at the end of two consecutive 8-week croppings in the greenhouse.

Treatments	Tissue N (mg/g)			N uptake (mg/plant)	
	1*	2	1	2	1+2
Control	103a	74a	31.4a	16.6a	48.0a
Soil + Cx**	119b	86b	45.3bc	30.5b	75.8b
Soil + Cy	128c	146cd	41.6ab	51.5c	93.1c
Soil +Nx	169d	151c	56.5cde	44.4de	100.9d
Soil + Ny	128c	124f	43.2b	39.6e	82.8f
Soil + CxNx	166d	162e	63.6e	49.6cd	113.2e
Soil + CxNy	162e	150c	59.7de	46.3cd	106.0g
Soil CyNx	154e	127f	49.45bcd	40.7e	90.1c
Soil + CyNy	132c	139d	46.0bc	44.3de	90.3c

* First and second croppings of maize

** C=cowdung; N=Inorganic N; x and y rates of C (12 and 24 mt/ha) and N(60 and 120 kg/ha).

Figures carrying the same letter are not significantly different (P < 0.05, DMRT)

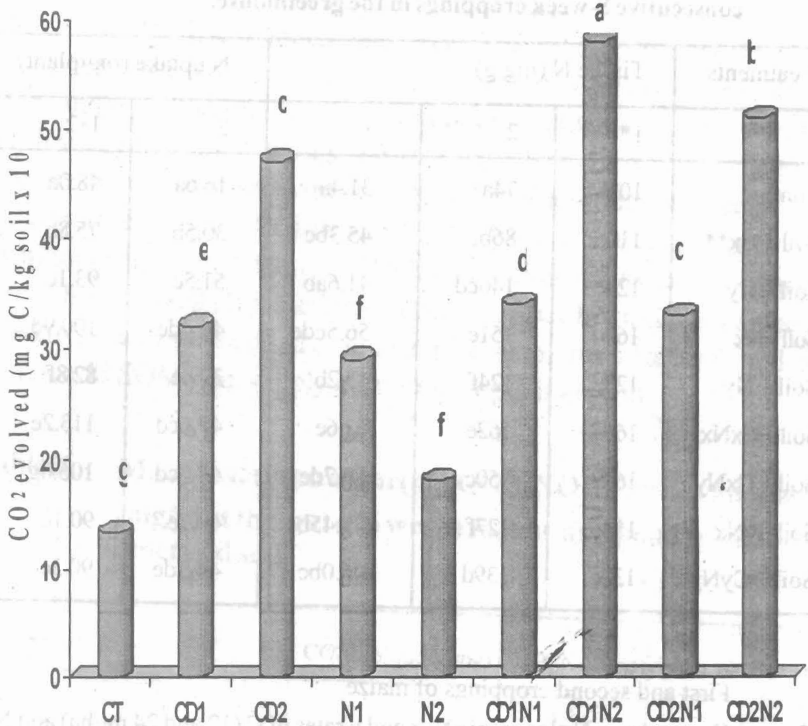

Figure 4: Carbon dioxide evolved (mg c/kg soil x 10) from treatments at 30 °C during 8 weeks of incubation [CT = control, C = cowdung; N = inorganic N; 1, 2, 3 = rates of CD and IN, 12 and 24 mt/ha, and 60 & 120 kg/ha, respectively. Bars with the same letters are not significantly different (P < 0.05, DMRT)]

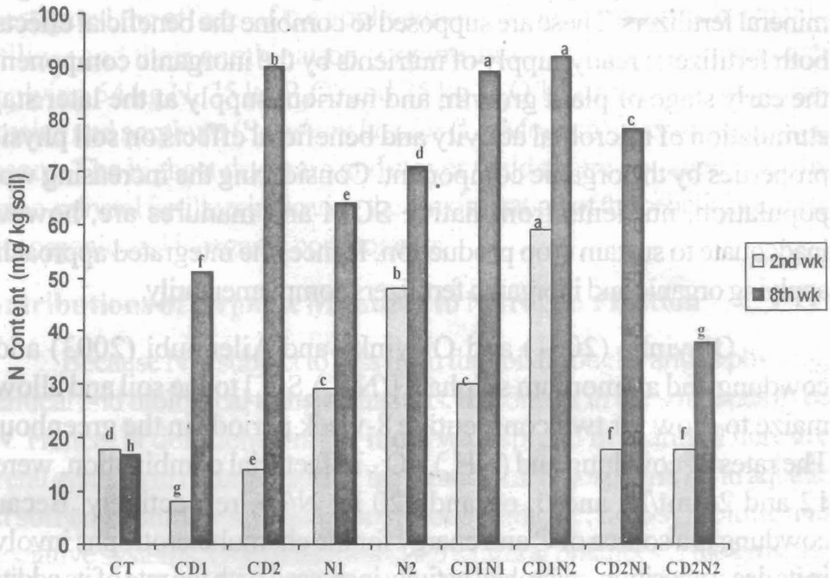

Figure 5: Inorganic N contents (mg/kg soil) in the treatments at 30 °C at the end of the 2nd and 8th weeks of incubation [CT = control; CD = cowdung; IN = inorganic nitrogen; 1, 2, 3 = rates of CD & IN; 12 & 24 mt/ha, and 60 and 120 mt/ha, respectively. Bars with the same letters are not significantly different ($P < 0.05$, DMRT)]

Complementary Applications of Organic Manures and Inorganic Fertilizers

Farmers embraced the use of chemical fertilizers because of their dramatic effects on plant growth and crop yields. The Summit on Food Security in Africa held in Abuja, Nigeria in 2006 resolved that the use of chemical fertilizers is the panacea for bringing about green revolution and ensuring food security. Because of the poor structure of soils in the humid tropics due to low SOM content and preponderance of LACs(Okusami *et al.*, 1997), rapid rate of SOM decomposition (Adepetu and Corey, 1975, 1977; Ayanaba and Jenkinson, 1977), constant OM addition was recommended (Agboola, 1973; Aoyama *et al.,* 1990). Hence, in the

African setting, researchers have been advocating the application of products containing organic manure and inorganic fertilizers, termed organo-mineral fertilizers. These are supposed to combine the beneficial effects of both fertilizers: ready supply of nutrients by the inorganic component at the early stage of plant growth; and nutrient supply at the later stage, stimulation of microbial activity and beneficial effects on soil physical properties by the organic component. Considering the increasing world population, nutrients from native SOM and manures are, however, inadequate to sustain crop production. Hence, the integrated approach of applying organic and inorganic fertilizers complementarily.

Olayinka (2001) and Olayinka and Ailenhubi (2003) added cowdung and ammonium sulphate [$(NH_4)_2SO_4$] to the soil and allowed maize to grow for two consecutive 8-week periods in the greenhouse. The rates of cowdung and $(NH_4)_2SO_4$, in factorial combination, were 0, 12 and 24 mt/ha and 0, 60 and 120 kg N/ha, respectively. Because cowdung is a source of C and energy for the chemoheterotrophs involved in its decomposition, microbial activity increased with the rate of its addition with and without N addition (Figure 4). Although microbial respiration was stimulated over the control, microbial respiration decreased with the rate of N addition. This was because ammonium sulphate without cowdung caused soil acidity. Nitrogen was immobilized at the end of the second week of incubation (Figure 5). However, there was remineralization of N at the end of the 8th week. Despite this, Figure 5 shows that N immobilization increased with the rate of cowdung added to the inorganic N, a result of the high microbial activity in the presence of cowdung (Figure 4). In line with this finding, the tissue N contents and N uptake by maize generally decreased with increase in the amount of cowdung added to inorganic N and did not reflect the amounts of inorganic N applied (Table 4). Terminal pH and mineralized N were positively correlated ($r = 0.69^*$; 0.89^{**}) with cumulative CO_2 evolved. It was concluded that, in order for the plant to obtain maximum benefit from complementary applications of cowdung and inorganic N, they should be banded separately and not mixed together. When constituted together as organo-mineral fertilizer, the organic component should be stabilized through adequate composting in order to minimize its potential to immobilize N. Amujoyegbe *et al.* (2007) investigated the effects of the applications of poultry manure, inorganic fertilizer and their combination (organo-mineral fertilizer) with each supplying 54 kg N, 25 kg P_2O_5 and 25 kg K_2O/ha on the performances of maize and sorghum (*Sorghum bicolor* (L.) Moench) over two cropping seasons. The highest dry grain and stover yields were obtained with the organo-mineral fertilizer indicating the maximization of the beneficial effects of its organic and inorganic components.

Contributions of Organic Manures to Nitrogen Fixation

Because N is subject to loss from the soil through various physical, chemical and biological transformations, its content in the soil tends to be low. Hence, N deficiency is the most widespread in plants. There are several systems in nature ensuring the fixation of atmospheric N_2 in aquatic and soil environments. These consist of symbiotic, non-symbiotic and associative systems. One of the oldest agricultural practices is the growing of legumes for soil improvement. The N fixed is environmentally - friendly unlike inorganic N and is made available to the succeeding crop. There is increasing research interest in symbiotic leguminous N_2 fixation in arable cropping in the tropics because of the high costs of animal protein and nitrogenous fertilizers. One of the strategies for improving N_2 fixation is by ensuring adequate mineral nutrition of the legume (Adebayo *et al*., 1986). For example, small amounts of N ('starter N') stimulated early growth and nodulation of Ife Brown cowpea (Daramola *et al*., 1982). Phosphorus improved nodulation and nodule activity (Adebayo *et al.*, 1986). Our researches have established that organic wastes are sources of organic C, N, P and other nutrients. Hence, organic amendments can be applied as sources of starter N. Moreover, Rhizobium is a chemoheterotroph requiring organic substrates as sources of energy and cell C. Olayinka *et al*. (1998b) therefore, investigated the effects of the additions of corn stover (C:N, 32:1), garbage compost (C:N, 2:1) and cowdung (C:N, 3:1) (0, 23, 69 and 115 mt/ha) on N_2 fixation in two successive plantings of Ife Brown cowpea. Soil reaction (pH), organic C and tissue N contents were increased by all the organic amendments. The amounts of N_2 fixed by cowdung and garbage compost treatments were higher than that of the corn stover (Figure 6). The trend obtained with corn stover was attributed to its high C:N ratio. In order to enhance N_2 fixation, a maximum rate of 23 mt/ha of cowdung and garbage compost was recommended. In a later study, Adegbite (2004) found that cowdung and its mixture with corn cob at the ratio of 1:1 applied at the rate of 12 mt/ha enhanced cowpea dry matter and seed yields, pH, nodulation and N_2 fixed.

Effects of Xenobiotics on Soil Microbial Activities

Two of the factors militating against food self-sufficiency in the tropics are weed and pest infestations. Nowadays, farmers often apply herbicides and pesticides on their farms. These are toxic antibiological agents which eventually enter the soil through drift deposition, runoffs from the site of application or as root exudates (Primental and Levitan, 1986). Although some soil microbiota can utilize and degrade pesticides (Okoya, Personal communication), they have been found to adversely affect microbial populations and diversity and their biochemical activities such as ammonification, nitrification, denitrification and urea hydrolysis (Greaves and Malkomes, 1980; Roslycky, 1986; Taiwo and Oso, 1997). Olayinka and Lokoyi (1996b) found that ammonification, nitrification and P mineralization were unaffected by glyphosate and alachor at recommended rates.

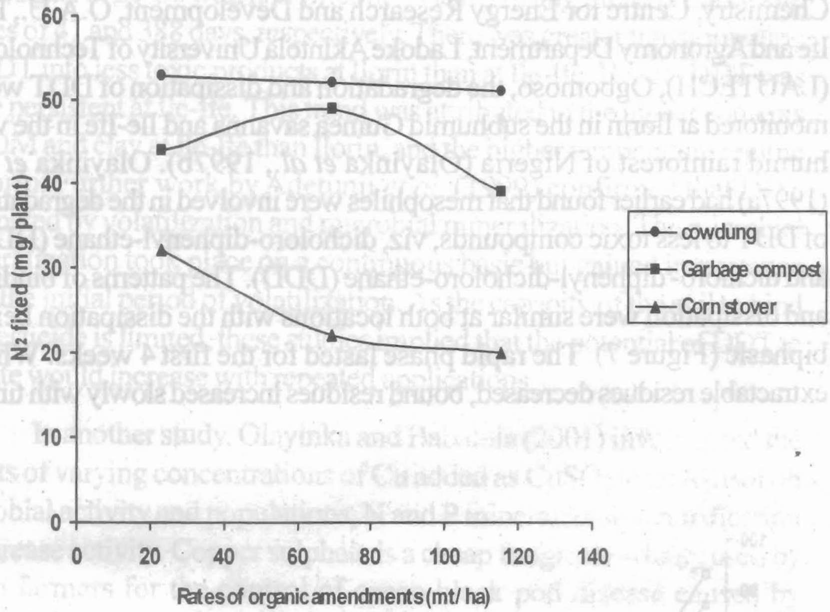

Figure 6: The combined effects of organic amendments on N_2 fixed at the end of two consecutive 6-week growth periods of *Vigna unguiculata* (L.) var. Ife Brown.

There is concern about the cumulative adverse effects of pesticides on microbial activities and population dynamics, nutrient cycling, soil fertility and productivity especially in peasant agriculture which depends mainly on native SOM and manures as primary sources of nutrients. Dicholoro-diphenyl-trichloro-ethane (DDT) is a cheap and effective broad-spectrum organochlorine compound. It is one of the most apolar compounds, hence its low water solubility (< 2 ppb) and persistence in the soil (Bayer and Gish, 1980). It has deleterious effects on non-target organisms (Perfect, 1980). This is why its use has either been restricted or banned since the 1970's in the industrial countries. Its continued use in the tropics was based on the supposition that it might not be persistent under the prevailing high temperature and rainfall regimes. With funding from the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture and cooperating researchers from the Departments of Soil Science, and

Chemistry, Centre for Energy Research and Development, O.A.U., Ile-Ife and Agronomy Department, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, the degradation and dissipation of DDT were monitored at Ilorin in the subhumid Guinea savanna and Ile-Ife in the wet humid rainforest of Nigeria (Olayinka *et al.*, 1997b). Olayinka *et al.* (1997a) had earlier found that mesophiles were involved in the degradation of DDT to less toxic compounds, viz, dicholoro-diphenyl-ethane (DDE) and dichloro- diphenyl-dicholoro-ethane (DDD). The patterns of binding and dissipation were similar at both locations with the dissipation being biphasic (Figure 7). The rapid phase lasted for the first 4 weeks. While extractable residues decreased, bound residues increased slowly with time.

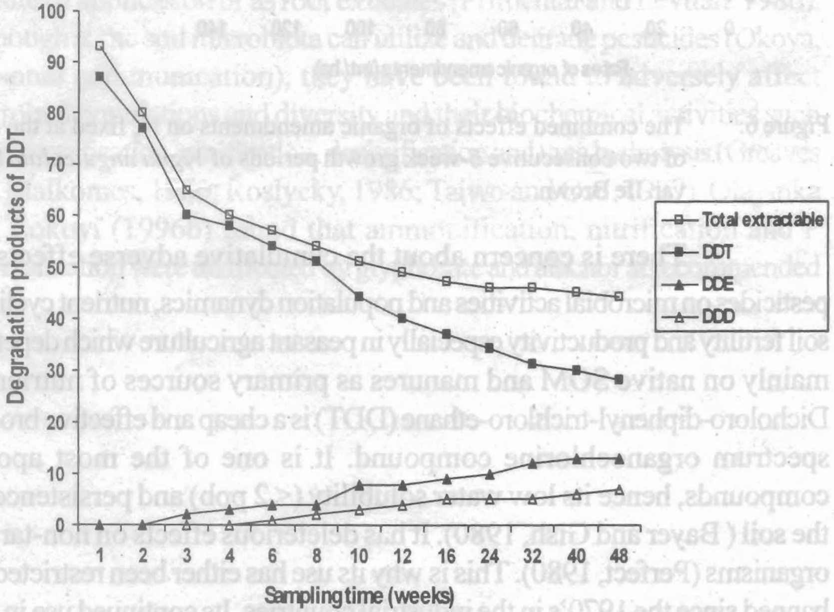

Figure 7: Degradation products of DDT in the top 10 cm of a sandy clay loam in Ile-Ife expressed as percent of applied dosage.

The rates of dissipation during the rapid phase and for the whole period were higher at Ile-Ife with half-lifes of 38 and 370 days, than at Ilorin with values of 41 and 388 days, respectively. There was greater transformation of DDT into less toxic products at Ilorin than at Ile-Ife. Hence, DDT was more persistent at Ile-Ife. This trend was attributed to the higher contents of SOM and clay at Ile-Ife than Ilorin, and the higher temperature regime at Ilorin. Further work by Adetunji *et al*. (1999) confirmed that DDT dissipated by volatilization and microbial mineralization. The microbial mineralization took place on a continuous basis but gained importance after the initial period of volatilization. As the capacity of the soil to bind the pesticide is limited, these studies implied that the potential of DDT to pollute would increase with repeated applications.

In another study, Olayinka and Babalola (2001) investigated the effects of varying concentrations of Cu added as $CuSO_4$ to an Alfisol on microbial activity and populations, N and P mineralization, nitrification and urease activity. Copper sulphate is a cheap fungicide widely used by cacao farmers for the control of cacao black pod disease caused by *Phytophthora palmivora*. Hence, high concentrations of Cu had been found in soils under cacao (Ayanlaja, 1983). The treatments acidified the soil, reduced bacterial and fungal populations, microbial respiration, N and P mineralization, nitrifier and urease activities. These findings showed that repeated applications of $CuSO_4$ could have detrimental effects on ecosystem functioning and nutrient cycling. Along with other factors, accumulations of Cu have been implicated in the difficulty encountered in rehabilitating old cacao farms.

Agriculture, Global Warming and Climate Change

Climate change due to global warming continues to engage the interest and concern of scientists and governments worldwide. Unchecked global warming will have undesirable consequences for the ecosystem and human survival. The issue is so serious and contentious that there has been set up a standing United Nations Panel on Climate Change (NNPCC). The earth's atmosphere is being heated up as a result of greenhouse gases, such as CO_2, CH_4, N_2O and chloroflourocarbons acting as a blanket allowing the solar radiation to pass but trapping the outgoing long wave terrestrial radiation. These gases arise from human industrial, agricultural and forestry activities. The UNPCC has predicted an average increase of 2 °C warning that this could increase to a disastrous 4 °C if urgent actions are not taken to reduce the emission of greenhouse gases. Carbon dioxide has been found to account for about half of the global warming (Batjes, 1996). The burning of coal, wood and forests, agricultural activities, deforestation and the burning of fossil fuels in vehicles and industry are some of the primary human activities resulting in the release of CO_2 to the atmosphere (Birdsey and Lewis, 2003). In a field experiment at the OAU Teaching and Research Farm, CO_2 emission was highest on cultivated land (60 mg C m^{-2} h^{-1}), followed by fallow (40 mg C m^{-2} h^{-1}) and lowest under forest (32 mg C m^{-2} h^{-1}) (Araloyin, 2006). This implies that deforestation has the potential of doubling CO_2 emission into the atmosphere. It is given that man must cultivate the soil in order to produce the foods and fibre he needs for survival. Cultivation exposes the soil to radiation leading to increased temperatures and microbial activity. Fallowing, mulching and agroforestry are agronomic practices that can moderate these changes. This is why there is increasing international pressure on Brazil and other Latin American countries to halt the deforestation due to logging and agricultural activities going on in the Amazon rain forest which occupies about 6% of the world's total land surface area and is a major sink for terrestrial C.

RECOMMENDATIONS

The beneficial activity of microorganisms in decomposing organic materials resulting in the release of nutrients and SOM formation has been highlighted. The soil, our common but finite heritage, holds the key to increased food production and security, and the continued march of our civilization. The following recommendations will ensure the overall well-being of Nigerians:

i) The management of the soil should be an integrated approach involving complementary applications of organic and inorganic fertilizers, and the inclusion of legumes into the cropping system.

ii) Because potential sources of soil organic matter and nutrients are lost, followed by soil degradation, the burning of bush, crop residues and weeds should be discouraged. The emission of carbon dioxide to the atmosphere is also reduced.

iii) For a cleaner and healthier environment, Government at all levels should accept waste disposal and utilization as a social responsibility. In order to make possible the three r's of 'reclaim, recycle and re-use', the wastes should first be sorted out at source into biodegradables, plastics, paper, wood, glass and metals. The biodegradables can then be converted into organic fertilizer through composting.

iv) Soils research should be intensified in order to ensure proper soil management. The establishment of a National Soil Research Institute by the Federal Government is long overdue.

v) To preserve the ecosystem and protect human life, cultural methods of weed and pest control should be encouraged while the use of bioactive agents should be minimized.

CONCLUSION

In the course of this lecture, I have tried to explain the roles that microorganisms play in improving soil properties and plant growth. Instead of wastes and organic manures being viewed as nuisance, they can be perceived as resources – out –of- place. If transformed by microorganisms under controlled conditions, environmental problems are alleviated and nutrients are released for plant growth. The organic fertilizers applied complementarily with inorganic fertilizers will sustain soil fertility and enhance crop production thereby helping to ensure national food security.

The Vice Chancellor, Sir, I ascribe whatever success I have had to God's grace. For, "It is not by might nor by power, but by My Spirit, says the LORD of hosts". (Zech. 4:6). It is also an integration of several factors. First was the opportunity 'Great Ife' [University of Ife (now Obafemi Awolowo University)] afforded an academic neophyte as a

Graduate Assistant in 1975. Becoming a full-fledged researcher with a home-minted Ph.D, the first in the Department of Soil Science, is credited to my Supervisor, Prof. `Wale Adebayo. Other teachers, mentors and co-researchers played significant roles. My graduate and project students were also instrumental in shaping my success. Last but not the least were the love and support I enjoyed from my darling wife and children at the home front.

To God be the glory for this opportunity to give an account of my odyssey in the academic world. On behalf of my wife and children, I sincerely appreciate the presence and patience of every one at this Lecture.

God bless you all.

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