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SOIL MICROBES: NATURE'S WORKFORCE FOR SOIL QUALITY MAINTENANCE, AND SUSTENANCE OF ENVIRONMENTAL INTEGRITY

by

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Eminent Scholars and Academics,
All Non-Teaching Staff,
Members of my family,
Gentlemen of the Press,
Distinguished Ladies and Gentlemen,
Great **FUNAABITES**

PREAMBLE

Mr. Vice-Chancellor Sir, I feel greatly honoured and privileged for the opportunity to present my humble contribution to knowledge in this 86th FUNAAB Inaugural Lecture series, the 18th in COLPLANT and the 3rd in the Department of Soil Science and Land Management. The lecture focuses on the ecological services of soil microbes and attempts to harness these services for the improvement of soil health and productivity as well as environmental health.

1.0 INTRODUCTION

1.1 **My journey in the academics so far**

My career in the academics started in 1990 at Department of Soil Science, Ahmadu Bello University (ABU), Zaria where I was employed as an Assistant Lecturer. Before then I had BSc and MSc. (Microbiology) from University of Ilorin. I had to register immediately for PhD (Soil Science), specializing in Soil Microbiology. The Programme started at 300 level, also included all the core and relevant courses in the MSc Programme and eventually ended with PhD which is by course work and research. The PhD lasted for 7 years (1990-1997). For me, the experience was like going through the B.Sc., M.Sc., and PhD Programmes (Soil Science) in one very long scoop. My PhD thesis was titled "Effect of microorganisms on rock phosphate solubilization in soybean and maize production in the Northern Guinea Savanna". On completion of the Programme, I expanded my research interest to include biological nitrogen fixation and phosphorus nutrition in groundnut, cowpea, and soybean. In 2001, I transferred my service to Federal University of Agriculture, Abeokuta (FUNAAB). Coming to Abeokuta and having to carry out research in a different agroecosystem, with soil of higher organic matter, where most farmers do not have access to inorganic fertilizers, led to further expanding my research interest. Therefore, my research in FUNAAB has been focused on sustainable soil organic matter

management, harnessing microbial activities to improve soil health and crop production, soil microbial ecology, bioremediation of polluted soils, and very recently, microbial ecology in forest soils.

1.2 **Definition of terms**

Mr. Vice-Chancellor Sir, permit me to validate the title of today's lecture from the holy scriptures and begin the lecture by defining/explaining the terms that are important in the delivery of this lecture.

Title: Soil Microbes: Nature's workforce for soil quality maintenance, and sustenance of environmental integrity.

For the earth (land) which drinketh in the rain that cometh oft upon it, and bringeth forth herbs meet for them by whom it is ***dressed****, receiveth blessing from God (Hebrew 6:7).*

The land was **dressed** by whom? many of us would believe that it was dressed by God but for the purpose of this scientific presentation, we will all agree that the land was dressed by nature. The whole purpose of this lecture is to unravel how it was dressed, and over the years my research has focussed on this subject.

1.2.1 Soil Microbes

Microorganisms are found in soil where their activities are crucial to soil management, agricultural production, and environmental quality. Hence, in studying them soil microbiologists evaluate the numbers and kinds of microorganisms found in soil, and the effect of these, and introduced microorganisms on soil ecological processes. The introduction of these microbes to soil ecosystem, has important consequences on crop production, environmental quality, and the restoration of disturbed or polluted soil environments.

1.2.2 Soil as microbial habitat

Soil is a complex habitat for microbial growth. It differs from other environments that microorganisms encounter in traditional microbiological culture media in two crucial ways. First, the soil in its natural state is a heterogeneous medium of solid, liquid and gaseous phases, varying in its properties both across the landscape and with depth in profile. Microbes generally exist as isolated micro-colonies on mineral particles, organic matter and roots. They are dependent on the movement of nutrients to them by mass flow of soil water or by diffusion. They must depend on passive means for the removal of toxins from their location unless they are motile and can move from site to site. Secondly, in soil, there is competition among variety of organisms for nutrients, space, and moisture. Competition occurs among bacteria, actinomycetes and fungi, as well as other life forms in soil, including animals and plant roots.

1.2.3 Soil quality

Soil quality is one of the three components of environmental quality, besides water and air quality (Andrews *et al*., 2002). Water and air quality are defined mainly by their degree of pollution that impacts directly on human and animal consumption and health, or on natural ecosystem (Carter *et al*., 1997; Davidson, 2000). In contrast, soil quality is not limited to soil pollution, but it is commonly much more broadly defined as "the capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health" (Doran and Parkin, 1994 and 1996). This definition reflects the complexity and site-specificity of the belowground part of terrestrial ecosystems as well as many linkages between soil functions and soil-based ecosystem services. Indeed, soil quality is more complex than the quality of air and water, not only because it constitutes solid, liquid and gaseous phases, but also because soils can be used for a larger variety of purposes (Nortcliff, 2006). The multi-functionality of soil is addressed when soil quality is defined from an environmental perspective as "the capacity of the soil to promote

the growth of plants, protect watersheds by regulating the infiltration and partitioning of precipitation and prevent water and air pollution by buffering potential pollutants such as agrochemicals, organic wastes, and industrial chemicals (Sims *et al*., 1997). Soil quality can be assessed both for agro-ecosystems where the main, though not exclusive ecosystem service is productivity, and for natural ecosystems where major aims are maintenance of environmental quality and biodiversity conservation.

1.2.4 Soil quality indicators

Various forms of soil assessment are encapsulated in different concepts. Apart from mining minerals, the main interest in soil has traditionally been in its potential for agricultural production. The suitability of soil for agricultural production is captured in the concept of soil fertility, which is 'the ability of the soil to supply essential plant nutrients and soil water in adequate amounts and proportions for plant growth and reproduction in the absence of toxic substances which may inhibit plant growth' (Patzel *et al*., 2000; FAO, 1976). Mader *et al*. (2002) extend that scope in proposing that a fertile soil "provides essential nutrients for crop plant growth, supports a diverse and active biotic community, exhibits a typical structure and allow for an undisturbed decomposition".

Typically, the concept of soil quality transcends the productivity of soil (Larson and Pierce, 1991; Parr *et al*., 1992) to explicitly include the interactions between humans and soil and encompasses ecosystem sustainability as the basis for the benefits that humans derive from soils as well as the intrinsic values of soil as being irreplaceable and unique (Carter *et al*., 1997). Recently, soil quality assessment is increasingly incorporated in land evaluation. This is because land evaluation procedures are now used in many ways for a range of purposes, including sustainable land management (Hurni *et al*., 2015), environmental risk assessments, monitoring of

environmental change (Sonneveld *et al*., 2010) and land restoration (Schwilch *et al*., 2012).

1.2.5 Importance of biological soil quality indicators

Van Eekeren *et al*. (2010) suggested that the ongoing reduction of external inputs in agriculture would imply an increasing reliance on ecosystem self-regulating processes and since biota plays an important role in these processes and in the provision of ecosystem services, biological parameters should be an integral part of soil quality assessment. Lima *et al*. (2013) posited that earthworms serve as indicators for both water and nutrient cycling. Soil organisms play a central role in soil functioning, therefore adding biological and biochemical indicators can greatly improve soil quality assessment (Barrios, 2006). Moreover, the assessment of biological indicators of soil quality is required to connect abiotic soil properties to changes in soil functions in terms of biochemical and biophysical transformations and aboveground vegetation performance (Lehman *et al*., 2015). The under representation of soil biological indicators is unfortunate because soil biota is considered the most sensitive indicators of soil quality due to their high responsiveness to changes in environmental conditions (Kibblewhite *et al*., 2008; Bone *et al.*, 2010; Nielson and Winding, 2017).

Researchers have advocated that there is an urgent need for indicators of soil-borne diseases (Kyselkova *et al*., 2014; Liu *et al*., 2016; Trivedi *et al*., 2017). In this context, soil suppressiveness, defined as the property of a soil to naturally reduce plant disease incidence (Hurnby, 1983), is of high interest. Specific soil suppressiveness is the result of the presence of specific antagonists to pathogens, while general soil suppressiveness is based on the collective capacity of soil and plant microbiomes to act complementarily against pathogens (Schlatter *et al*., 2017). The combination of both governs soil suppressiveness as a whole (Yadav *et al*., 2015). Several soil abiotic and biotic parameters have

been suggested to underlie suppressiveness, such as soil pH, specific cations like Mg and K, soil total N content, microbial biomass and activity, diversity and structure of microbial communities and specific microbial taxa (Janvier *et al*., 2007; Wu *et al*., 2015).

1.2.6 Microbes and environmental integrity

Environmental integrity is the retainment of the pure state, the unimpaired state of the natural conditions in which people, animals and plants live. It is also defined as the sustenance of important biophysical processes which support plant and animal life, and which must be allowed to continue without significant change. The objective is to assure the continued health of essential life support systems of nature, including air, water, and soil, by protecting the resistance, diversity and purity of natural communities (ecosystems) within the environment. Environmental integrity paints a picture of an environment void of all forms of pollution from polluting substances, which are consequences of human activities.

Microbes are omnipresent in the biosphere, and their presence invariably affects the environment in which they grow. The effects of microbes on the environment can be beneficial or harmful or unapparent. The most significant effect of the microbes on earth soil is their ability to recycle the primary element that make up all living systems, especially carbon, oxygen and nitrogen (Gupta *et al*., 2017). Primary production involves photosynthetic organisms which take up CO_2 from the atmosphere and convert it to organic (cellular) material. The process is also called CO_2 fixation and it accounts for a large portion of organic carbon available for synthesis of cell material. Decomposition or biodegradation results in breakdown of complex organic materials to other forms of carbon that can be used by other organisms. There is no naturally occurring organic compound that cannot be degraded by some microbes. Some synthetic compounds such as Teflon, plastics,

insecticides, and pesticides are broken down very slowly or not at all. Through microbial metabolic processes of fermentation and respiration, organic molecules are eventually broken down to CO_2 which is returned to the atmosphere for continuous processing of primary production. Biological nitrogen fixation is a process found only in some bacteria, the process removes N_2 from the atmosphere and converts it to ammonia, for use by the plants and animals. Nitrogen fixation also results in replenishment of soil nitrogen removed by agricultural processes.

Microbes play key roles in the generation of some greenhouse gases as well as in carbon sequestration. According to ASM (2021), the soil is the largest terrestrial reservoir of carbon, containing 3 times the amount of carbon that is in the atmosphere and 4 times as much as all vegetation on Earth. Agricultural practices and decomposition by microbes can build soil carbon which has 2 important outcomes: carbon enriches and stabilizes soil making it more suitable for crop production and carbon is sequestered from the environment where it would otherwise end up polluting the atmosphere as greenhouse gases.

2.0 MY CONTRIBUTIONS TO KNOWLEDGE

Mr. Vice-Chancellor Sir, my research effort has led to additional information on the contribution of soil microbial activities in enhancement of P access from insoluble sources by plants, maintenance of soil health, improved crop production and restoration of environmental integrity. During my career as a researcher, I have collaborated with soil scientists, cropping system scientists, weed scientists, plant physiologists, plant pathologists, microbiologists, agricultural economists, environmental scientists and forest soil ecologists.

2.1 Studies on microbiological enhancement of P release from Sokoto and Ogun Phosphate rocks

Phosphate rock (PR) is a naturally occurring ore of marine sedimentary origin, it may have composition of 0-30- 0 (NPK), but the grade is noted as 0-3-0. Thus, PR is sparingly soluble and only a little of the phosphorus is available to crops. The use of PR as an alternative to chemical fertilizer was advocated by researchers many decades ago (Balasubramanian *et al*., 1978; Mokwunye, 1994). The dissolution of PR into forms readily taken up by plants is however a primary concern in its direct application as a fertilizer. Studies have revealed that microbes release large quantities of numerous organic acids such as 2-ketogluconic, lactic and glycolic acids which dissolve minerals containing magnesium, calcium, and phosphorus (Muller and Foster, 1961; Webley et al., 1960; Bromfield, 1959). In view of this, I undertook studies to assess the fertilizer potential of microbial inoculations and PR application in soybean and maize production.

2.1.1 Soybean

In a two-year field study, we inoculated three PR solubilizing fungi and two bacteria isolated from the soil to field soil, with application of Sokoto phosphate rock (SPR) and the soil was cultivated to soybean. The result revealed that all the microbe treated plots had higher number and weight of nodules, P uptake, number of pods, dry matter and grain yields (Table 1 and Figure 1). However, *Rhizopus* sp treated plots had the significantly highest values of all these parameters (Babalola and Amapu, 1999).

Table 1: Influence of microbial inoculations on soybean nodulation, growth and yield in 1993 and 1994 cropping seasons.

Microbes	Wt. of nodules (g plant^{-1})	P uptake (g kg^{-1})	Dry matter yield (g plant^{-1})	Grain yield (Kg plot^{-1})
Rhizopus sp.	0.34	104	30.6	2.053
Aspergillus niger	0.29	61.3	25.4	1.780
Penicillium sp.	0.30	65.2	22.5	1.739
Pseudomonas striata	0.28	105	29.1	2.047
Bacillus megatarium	0.28	96.9	28.5	1.639
Control	0.26	65.1	21.7	1.702
LSD	ns	8.23	ns	ns

Source: Babalola and Amapu, 1999.

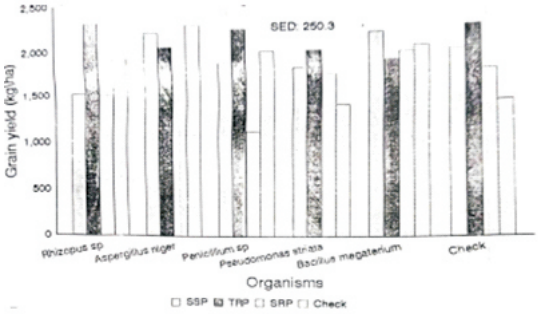

Figure 1: Interaction of phosphate rock and microbes on grain yield of maize
Source: Babalola and Amapu, 1999.

As a follow up to this study, we carried out an incubation experiment to investigate the incidence of phosphorus solubilizing microorganism (PSM), and their pattern of P release in soil. A total of 44 phosphorus solubilizing bacteria and 21 phosphorus solubilizing fungi were isolated from rhizosphere of crops. The P_2O_5 release ranged from 10.5 to 25.9 µg/g soil among the bacteria isolates, and 10.1 to 28.9 µg/g soil among the fungi isolates. Over a period of 6 weeks, the phosphorus solubilizing bacterial isolates had their peak phosphorus release in most of the isolates by the first week of incubation (Figure 2) while in P solubilizing fungi, peak P release was attained by most isolates between 4 and 5 weeks after incubation (Figure 3) and the total P release was higher in fungi than in bacterial isolates (Babalola *et al*., 2000a).

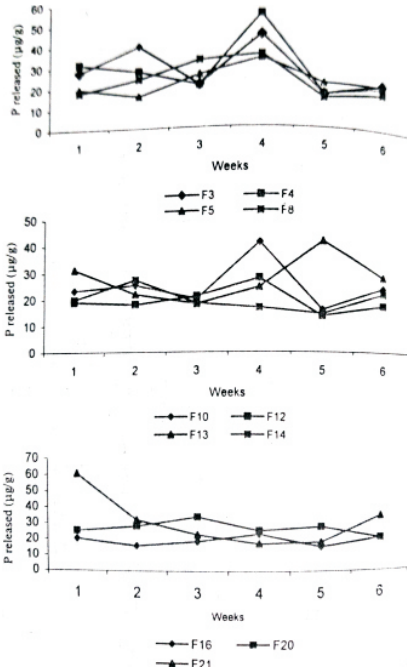

Figure 2: Pattern of P release in soil amended with SPR and fungal isolates and incubated for 6 weeks
Source: Babalola *et al*., 2000a

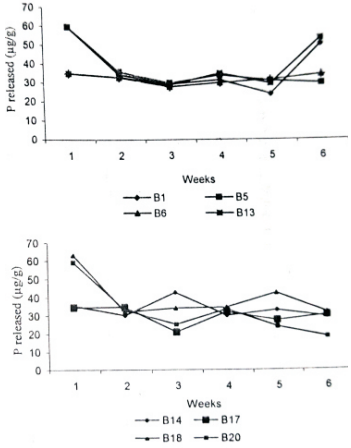

Figure 3: Pattern of P release in soil amended with SPR and bacterial isolates and incubated for 6 weeks
Source: Babalola *et al*., 2000a

The effect of this was further demonstrated in another publication (Babalola *et al.*, 2000b), where the interaction between PR and microbial inoculation gave high values of grain yield in most microbial treated plots, while for P uptake, the values were significantly higher only in *A niger* and *B megaterium* treated plots (Figure 4).

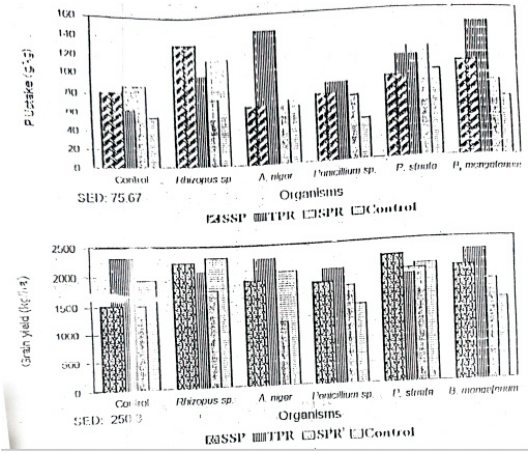

Figure 4: Interaction of Source of and microbes on P uptake and grain yield of soybean
Source: Babalola *et al*., 2000b

In another study (Babalola *et al*., 2009a), we inoculated two species of arbuscular mycorrhizal fungi (AMF) into the rhizosphere of soybean with and without the application of Sokoto PR. The plants treated with the two AMF had significantly higher infection rates and uptakes of nitrogen and phosphorus than plants without AMF treatments. In treatments with combination of AMF and PR, the infection rate was significantly higher than treatments with sole applications of AM, PR and SSP as well as control (without any amendment) and the P uptake in these combined treatments were comparable to uptake in plants supplied with SSP, while treatments with *G deserticola* alone gave significantly higher P uptake than all the other treatments (Table 2).

Table 2: Effects of AMF and Sokoto PR on percent mycorrhizal infection rates at 3 and 9 weeks after sowing (WAS) and N and P uptakes at 6 WAS of soybean.

Treatments	% AMF infection rate		Nutrient uptakes (mg/g)	
	3WAS	9WAS	N	P
Glomus moseae	37.3	61.0	0.26	2.72
G deserticola	37.3	61.3	0.31	3.85
PR	24.3	36.7	0.24	2.36
G. moseae/PR	46.0	72.3	0.23	3.35
G. deserticola/PR	47.3	74.3	0.26	3.40
SSP	26.3	39.7	0.25	3.35
Control	22.0	31.7	0.21	0.75
LSD	7.23	7.16	0.15	0.13

Source: Babalola *et al*., 2009a.

2.1.2 Maize

In screen house and field studies between 1993 and 1995, we investigated the microbial enhancement of P release from Sokoto PR in maize production (Babalola, 2005; Babalola, 2009). The quality of PR as a labile soil P is demonstrated in Table 3 below which showed a more significant impact of microbial inoculation on the second crop of maize. Unlike earlier observation made in soybean, microbial inoculation did not seem to benefit P uptake and yield parameters in maize in the short-term but rather in the long-term.

Table 3: Effect of microbial inoculations on maize growth and yield in PR amended soil in the screen house

Microbes	P uptake (g/kg)		Plant height (cm)		Dry matter yield (g/plant)	
	First	Second	First	Second	First	Second
Rhizopus sp.	0.9	0.85	35.9	43.3	16.6	13.3
A niger	0.8	0.86	37.0	41.2	16.5	12.5
Penicillium sp.	1.0	0.96	37.6	40.2	17.1	14.8
P striata	1.1	0.77	39.6	42.1	17.0	10.8
B megatarium	0.9	0.78	38.2	36.0	18.2	11.2
Control	0.9	0.15	43.1	24.8	19.8	2.1
LSD	ns	ns	ns	4.06	ns	4.29

Source: Babalola, 2005

Interaction between P sources and microbial inoculation showed that single super phosphate in combination with most of the microbes gave higher P uptake, dry matter and grain yields (Figure 5 & 6), but PR fertilizer quality was not enhanced by microbial

production (Babalola and Salako, 2006) and observed that the effect on maize and cowpea growth and yield was comparable to SSP, and both gave better performance than control, where no fertilizer was applied (figure 7).

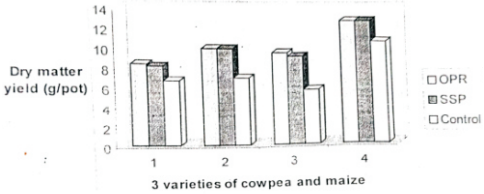

Figure 7: Effect of sources of P on dry matter yield of cowpea varieties (1-3) and maize (4)
Source: Babalola and Salako, 2006

In Olla *et al*. (2010), we evaluated the NPK made from Ogun PR (Gateway fertilizer) for maize and cowpea production and reported that although soil amended with the standard fertilizer produced significantly higher yield in the first cropping cycle, the performance of the two fertilizers on maize were however at par in the second cycle and in the final soil (Table 4 & 5), this result tends to agree with my earlier submission on Sokoto PR.

Table 4: Dry matter yield as affected by the soil types, fertilizer sources and rates of application at first and second cropping.

	First maize cropping (g plant^{-1})	Second maize cropping (g plant^{-1})	
Soil types (S)			
Iwo	26.98c	10.36d	18.67
Agege	23.88c	12.50c	18.19
Egbeda	42.25b	22.42a	32.34
Alagba	49.34a	20.40b	34.87
Fertilizer types (F)			
Gateway	32.71b	16.75a	24.73
Standard	38.51a	16.10a	27.31
Rate (R) (kg ha^{-1})			
0	24.62c	18.06a	21.34
60: 30: 30	36.78b	15.73b	26.26
120: 60: 60	45.44a	15.48b	30.46
Interactions DMRT (5%)			
S×F	ns	ns	
S×R	ns	ns	
F×R	ns	ns	
S×F×R	ns	ns	

Source: Olla *et al*., 2010.

inoculation at short duration in maize production, because of its insoluble nature. The more positive response of soybean to PR application and microbial inoculation at a shorter-term duration is due to the acidic condition at soybean root zone which tends to acidulate the PR thereby making the P in PR more available for microbial processing and subsequently to the crop.

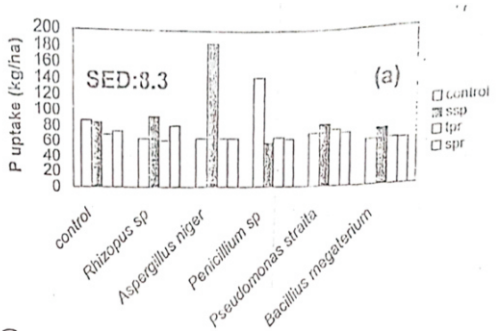

Figure 5: Interaction of source of phosphorus and microbial inoculation on P uptake in maize
Source: Babalola, 2009

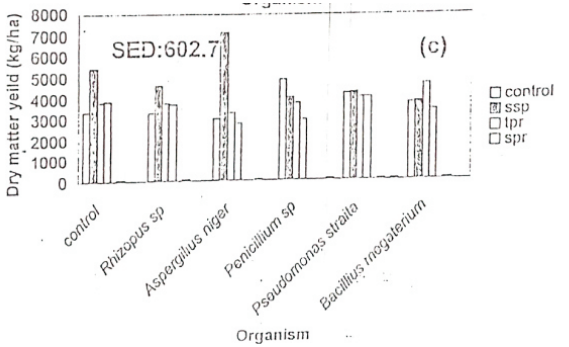

Figure 6: Interaction of source of phosphorus and microbial inoculation on grain yield of maize
Source: Babalola, 2009

2.2 Studies on Ogun Phosphate Rock

Ogun PR is in Oshosun formation at Ifo Local Government Area of Ogun State (Adegoke et al., 1991). It is reported to contain P_2O_5 of 31%, only 0.3% of the P is soluble in water which is 2.7% of the total P (Jones and Dempster, 1969). We carried out a comparative study on the fertilizer quality of this PR in maize and cowpea

Table 5: Soil chemical properties as affected by fertilizer types and rate of application

	PH	OC ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	P ($mg\ kg^{-1}$)	cmol/kg Ca	Mg	K	Na
Fertilizer types (F)								
Gateway	6.43a	6.91a	0.64a	13.15a	2.45a	1.88a	0.21a	0.61a
Standard	6.26b	6.87a	0.63a	15.29a	2.12a	1.82a	0.21a	0.60a
Fertilizer Rates (R) ($kg\ ha^{-1}$)								
0	6.37a	6.73a	0.60a	13.63a	1.99a	1.72b	0.20a	0.58a
60: 30: 30	6.42a	6.77a	0.63a	13.25a	2.37a	1.89a	0.21a	0.62a
120: 60: 60	6.25a	7.17a	0.68a	15.79a	2.50a	1.94a	0.22a	0.62a
Interactions DMRT (5%)								
F×R	ns	ns	ns	ns	ns	ns	ns	ns

ns = Not significant

Source: Olla *et al*., 2010

In Akintokun *et al*. (2007), we investigated the solubilization of Ogun PR by organic acid-producing fungi isolated from the soil. The study revealed thirty-one (31) fungi species with capacity to solubilize P from insoluble sources, the total P released ranged from 1.9 to 6.25 mg/100ml. We also reported that about nine of the microorganisms were able to release substantial amount of P, and could produce acetic, citric, fumaric, gluconic, lactic, maleic, malic, and tartaric acids when the soil was modified with Ogun PR (Table 6).

Table 6: Organic acids produced by selected soil fungi in medium modified with phosphate rock

at 14 days of incubation

Fungi isolate		Acetic acid (mg/100 mL)	Citric acid (mg/100 mL)	Fumaric acid (mg/100 mL)	Gluconic acid (mg/100 mL)	Glutaric acid (mg/100 mL)
Control	R	0.00k	0.05i	1.78a	0.00m	0.20e
Aspergillus flavus	R	4.82g	19.32g	19.00a	12.50l	5.00d
Aspergillus candidus	R	1.85j	27.05f	22.78a	28.75h	7.00b
Aspergillus niger	R	6.30f	57.96c	25.00a	20.00i	0.00e
Aspergillus terreus	R	5.56g	54.09c	28.89a	033.75g	0.00e
Aspergillus wentii	R	5.93f	69.80a	26.67a	17.50j	0.00e
Fusarium oxysporum	R	3.34i	50.23d	18.34a	26.25h	0.00e
Penicillium chermestinum	R	4.10h	34.78e	21.11a	15.00k	0.00e
Trichoderma isridae	R	7.41e	11.59h	16.11a	18.75j	0.00e
Trituraclum species	R	11.85b	54.09c	25.56a	22.50i	0.00e

Fungi isolate		Lactic acid (mg/100 mL)	Maleic acid (mg/100 mL)	Malic acid (mg/100 mL)	Succinic acid (mg/100 mL)	Tartaric acid (mg/100 mL)
Control	R	0.00g	0.05m	0.15p	0.00i	0.35n
Aspergillus flavus	R	3.26e	97.18f	75.00h	0.00i	22.12b
Aspergillus candidus	R	2.83e	128.60a	130.30b	0.00i	13.46f
Aspergillus niger	R	4.35d	111.40d	138.20a	0.00i	24.04a
Aspergillus terreus	R	3.91d	105.70e	106.60c	0.00i	11.54h
Aspergillus wentii	R	3.05e	114.30c	102.60e	0.00i	25.96a
Fusarium oxysporum	R	2.58f	120.00b	110.60c	0.00i	20.19c
Penicillium chermestinum	R	3.70d	102.90e	98.69f	0.00i	17.30d
Trichoderma isridae	R	3.26e	82.80h		0.00i	16.35e
Trituraclum species	R	4.57d	117.20b		0.00i	12.50g

*Values followed by different alphabet within columns are significant at P= 0.05

Source: Akintokun *et al*., 2007

2.3 Studies on effect of other biofertilizers on soybean performance

Biofertilizers are materials which contain living microorganisms and when applied to seed or soil colonize the plant rhizosphere and promote growth by increasing the supply or availability of primary nutrients to the host plant. In Babalola *et al*. (2009a), we examined the influence of *Bradyrhizobium japonicum* and AMF species on soybean production. It was revealed that all the AMF/*Bradyrhizobium* interaction increased AMF root colonization, while *G moseae/Bradyrhizobium* interaction gave significant increase in the root mycorrhizal colonization (by 59.5%), N and P uptake (by 68.9% and 80% respectively), and in all growth parameters (Table 7). Ultimately, grain yield increased in the pots by 37.5% than in pots with *B japonicum* alone, 28% than in pots with SSP and 33.3% than in control. Thus, suggesting that the synergistic interaction of *B japonicum with G moseae* was more beneficial to soybean production than the interaction with *G deserticola*.

Table 7: Influence of *Bradyrhizobium japonicum* and *Glomus* species on soybean performance

Treatment	Root colonization (%)	N uptake (mg/kg)	P uptake (mg/kg)	Grain yield (g/plant)
G moseae	58.3	0.42	3.0	14.4
G deserticola	64.0	0.27	3.4	14.2
G moseae/Brad	77.0	0.75	4.0	15.0
G desert/Brad	78.3	0.37	2.5	14.4
B japonicum	48.0	0.41	1.9	9.0
SSP	40.1	0.22	2.9	10.8
Control	31.7	0.22	0.8	9.6
LSD	10.56	0.17	1.02	4.35

Source: Babalola *et al*., 2009a

The study also revealed that soil N, P and AMF spore counts were higher in soils co-inoculated with *Bradyrhizobium japonicum* and AMF, but organic matter was highest in soil treated solely with either *Glomus deserticol*a or SSP (Table 8).

Table 8: Effect of AMF and Bradyrhizobial inoculation in soybean on N and P uptake, organic matter and AMF spores in the final soil.

Treatment	Nutrients		SOM	Spore counts (100 g-1 of soil)	
	N (%)	P(mg/kg)	(%)	3 WAP	9 WAP
G. mosseae	0.82	8.7	0.49	38.33	60.67
G. deserticola	0.20	8.8	0.57	39.67	71.0
G. mosseae/ Brad	1.15	9.9	0.34	53.67	134.33
G. deserticola/ Brad	1.24	11.1	0.40	47.0	89.33
B. japonicum	0.41	9.4	0.25	32.33	45.33
SSP	0.36	11.7	0.50	31.0	33.33
Control	0.21	6.7	0.30	31.67	34.0
LSD (0.05)	0.358	1.162	0.096	5.641	24.908

Source: Babalola *et al*., 2009a

In Adigun *et al*. (2017) and Adigun and Babalola (2016), we demonstrated that poultry manure application and inoculation of mycorrhizal fungi with or without *Bradyrhizobium japonicum* in soybean production, compared favorably with SSP in N uptake, nodulation, dry matter, and grain yields (Table 9 & 10).

Table 9: Main effect of treatments on nodules, roots, shoot biomass, plant and soil in soybean production

Treatments	Nodules No	Nodules Wgt(g)	Root (g/plant)	Shoot (g/plant)	Dry Matter	N Content	N uptake (mg/kg)
Bradyrhizobium							
Bradyrhizobium+	7.22ᵃ	0.28ᵃ	0.32ᵃ	2.35ᵃ	2.67ᵃ	1.73ᵃ	4.92ᵃ
Bradyrhizobium-	5.67ᵃ	0.21ᵃ	0.44ᵃ	2.22ᵃ	2.66ᵃ	1.65ᵃ	4.73ᵃ
P- sources							
Mycorrhiza	6.33ᵃ	0.25ᵃ	0.40ᵃ	2.44ᵃ	2.84ᵃ	1.90ᵃ	5.37ᵃ
SSP	6.56ᵃ	0.24ᵃ	0.37ᵃ	2.13ᵃ	2.49ᵃ	1.74ᵃ	4.28ᵃ
Poultry manure							
0 kg/ha	7.00ᵃ	0.27ᵃ	0.34ᵃ	2.52ᵃ	2.86ᵃ	1.71ᵃ	4.95ᵃ
5 kg/ha	4.92ᵃ	0.26ᵃ	0.44ᵃ	2.09ᵃ	2.53ᵃ	1.92ᵃ	4.82ᵃ
10 kg/ha	7.42ᵃ	0.20ᵃ	0.36ᵃ	2.25ᵃ	2.61ᵃ	1.83ᵃ	6.68ᵃ

Source: Adigun et al., 2017

Table 10: Main effect of treatment on soybean yield

Treatments	Yield	HSW (Kg/plot)
Poultry manure		
0 (ton)	100.1ᵃ	8.84ᵃ
5 (ton)	103.5ᵃ	9.04ᵃ
10 (ton)	106.8ᵃ	8.32ᵃ
LSD	8.20	1.12
P source		
Myc	109.8ᵃ	9.07ᵃ
SSP	97.1ᵇ	8.40ᵇ
LSD	5.12	0.89
Bradyrhizobium+	106.1ᵃ	8.66ᵃ
Bradyrhizobium-	100.1ᵃ	8.82ᵃ
LSD	6.54	0.92

Source: Adigun *et al*., 2017

2.4 Studies on legume nutrition

In a three-year field experiment, we estimated the effects of three rates of phosphorus supplied as SSP and Sokoto PR on ten soybean genotypes (Babalola and Amapu, 2006). It was revealed that five of the genotypes produced their maximum yields at 7.92 kg P/ha SSP (half of the recommended rate), while two gave optimum biomass yields, N, P and K uptakes and grain yields with no application of P

(control), two genotypes had maximum growth and yield with 15.84 kg P/ha SPR, and only one genotype gave optimum growth and yield performance at 15.84 kg P/ha SSP (Table 11).

Table 11: Mean P uptake and yield (kg/ha) in a three-year field trial as influenced by P rates in SSP and SPR

	Control		7.92 SSP		15.84 SSP		15.84 SPR	
Genotype	P-uptake	Grain yield	P uptake	Grain yield	P uptake	Grain yield	P uptake	Grain yield
Sampea 1	3.35	1193	3.42	1116	3.06	798	3.12	956
Sampea 2	3.34	945	4.46	1118	3.18	948	3.97	1223
Sampea 3	3.39	918	3.85	1090	2.62	1022	3.05	963
Sampea 4	4.19	1098	3.16	1029	4.03	960	3.94	1065
Sampea 5	2.26	1156	4.49	1210	3.48	840	3.65	999
Sampea 6	4.45	1129	5.26	1316	3.23	965	4.12	144
Sampea 7	2.11	1049	2.58	1149	3.51	1010	2.85	965
4/48-15-1	3.16	1063	4.08	1161	4.04	1092	5.29	950
7/180-4-5	4.44	1138	3.88	993	3.70	1173	4.0	1267
7/180-4-5-1	2.53	1158	4.20	1389	2.80	1134	5.38	987

Source: Babalola and Amapu, 2006

In another study aimed at determining the soil cover potential of some grain legumes, we carried out three-year field experiments on farmer's fields at three villages (Dunki, Turawa, Dan Birni) and on-station at Institute for Agricultural Research, Samaru, Zaria from 2000 to 2002 (Odunze *et al*., 2004). It was revealed that over a 3-year period, maize grain yield improved by 20 % under sole maize, but 95 % in maize/groundnut, 92.8 % in maize/soybean and 98.4 % in maize/cowpea intercrops and this was attributed to improvement in the soil physical and chemical parameters due to amount of ground cover produced by the different legumes and addition of nitrogen to soil due to nitrogen fixation by the legumes (Table 14).

Table 12: Maize grain yield means across years (2000-2002 (t ha^{-1})

Treatment	Mean	2000	2001	2002
Sole maize	1.06a	0.96	1.27ab	1.42ab
Groundnut/maize	1.23a	0.90	1.49a	1.89ab
Cowpea/maize	1.31a	0.93	1.22ab	2.2a
Soybean/maize	0.97ab	0.94	0.62ab	1.90ab
MSE	0.63	0.06 (ns)	0.67	1.15

Means with the same letters are not significantly different (DNMRT); ns: means differences are not significant ($P \leq 0.05$).
Source: Odunze *et al*., 2004

2.5 Studies on arbuscular mycorrhizal fungi association with rice

Mycorrhizal fungi form symbiotic associations with the roots of green plants, this association play important roles in plant physiology and nutrition, especially under biotic and abiotic stresses. The association is also important in soil biology and chemistry. In a survey that we carried out on rice fields in Oyo, Osun, Ekiti and Niger States, it was revealed that occurrence of arbuscular mycorrhizal fungi associations on the field were significantly influenced by the varieties of rice grown on each field (Babalola *et al.*, 2015). However, the AMF spores encountered were more abundant and diverse in Ogun State (Figure 8).

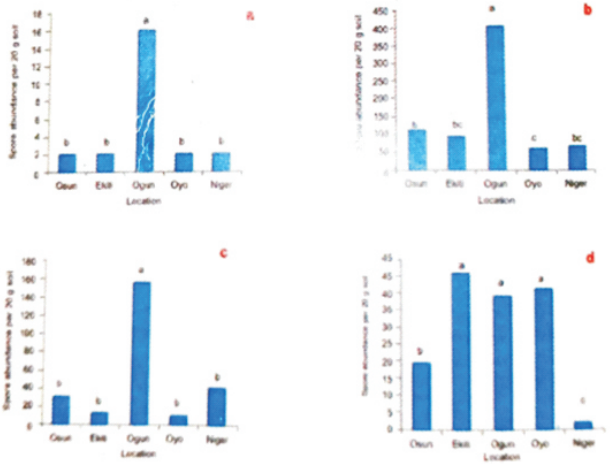

Figure 8: Spore abundance of *Gigaspora* sp (a), *Glomus* sp (b), *Glomus moseae* (c) and *Glomus intaradices* (d) in five Nigerian States
Source: Babalola *et al*., 2015

Furthermore, in Olubode *et al*. (2020) we clearly demonstrated that *Ofada,* a local variety commonly cultivated in Ogun State and ITA 150 an improved variety had high propensity for AMF colonization and high AMF spore density at their rhizosphere and high diversity of the spores. (Figures 9, 10 & 11). A strong relationship was observed between spore density and AMF colonization (Figure 12).

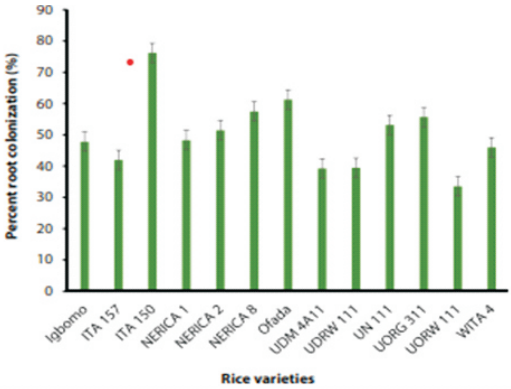

Figure 9: Percent AMF colonization in 13 Nigerian varieties rice
Source: Olubode *et al*., 2020

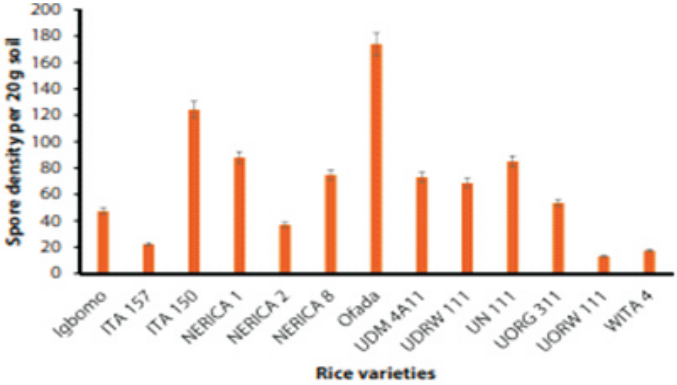

Figure 10: Spore density of AMF at the rhizosphere of 13 Nigerian rice varieties

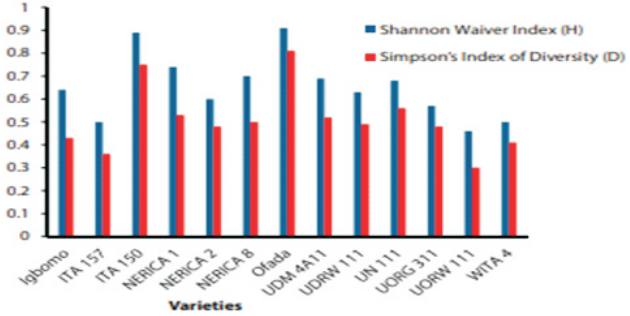

Figure 11: Diversity of AMF spores in the rhizosphere of 13 Nigerian rice varieties
Source: Olubode *et al*., 2020

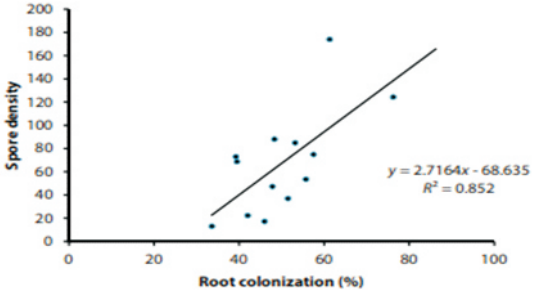

Figure 12: Relationship between AMF spore density and AMF colonization of Nigerian rice varieties
Source: Olubode *et al*., 2020

In Babalola *et al* (2023, in press), we assessed the inoculation of *Glomus* species on rice field under different water stress conditions and reported that, the inoculation of *Glomus moseae* or *Glomus etunicatum* improved the density and activities of the indigenous AMF species in the soil and thus improved some physiological and nutritional properties as well as growth and yield of rice. Although moisture stress had a negative impact on rice yield, inoculation of *Glomus moseae* or *Glomus etunicatum* reduced this negative impact by 52% and 24% respectively under moderate water stress condition, 216% and 158% respectively under severe water stress condition (Table 13).

Table 13: Effect of water stress and Glomus inoculation on spore density of indigenous AMF species (per 20 g soil) and grain yield (t ha^{-1})

Treatment	Acaulo	Enthrop	Gigasp	Glomus	Scutel	Tspore	Grain yield
Planting period							
Unstressed	32.8	5.9	80.4	31.8	15.38	166.2	0.49
Moderately stressed	77.8	17.4	38.5	78.8	8.76	214.3	0.25
Severely stressed	183.7	43.7	11.5	118.8	0.0	357.6	0.12
LSD	8.4	2.97	3.62	5.93	1.07	16.42	0.03
AMF inoculation							
Glomus etunicatum	112.3	24.9	41.8	87.0	5.33	271.3	0.31
Glomus interadices	87.1	19.8	42.9	70.3	5.94	226.2	0.18
Glomus moseae	95.6	21.1	42.6	77.2	4.0	240.4	0.38
Control	97.3	23.4	46.5	71.3	7.78	246.3	0.27
LSD	9.71	3.43	4.17	6.84	1.24	18.96	1.24
LSD PD x AMF	16.82	5.95	7.25	11.85	2.14	0.06	2.14

Acaulo ≤ *Acaulospora* specie, Enthrop ≤ *Enthrophospora* specie, Gigasp ≤ *Gigaspora* specie, *Glomus* specie Scutel ≤ *Scutelospora* specie and Tspore ≤ Tota l spore
Source: Babalola *et al*., 2023 (in press)

2.6 Microbial remediation of contaminated soil

Soil pollution is an undesirable change in the physical, chemical, and biological characteristics of soil because of contamination caused by human activities. Spent lubricant oil is a common source of soil contamination, and the remediation of such soils is imperative for increased crop production, food safety as well as soil and environmental health. Mycorrhizal fungi have been commonly used in bioremediation process to decontaminate the soil. In view of this, I carried out an experiment to assess the capacity of AMF, poultry manure and NPK in remediating spent engine oil contaminated soil (Babalola, 2012). The experiment revealed that spent engine oil contamination significantly reduced soil quality and amendment with AMF significantly reduced the negative impact of contamination and improved soil chemical and biological properties (Table 14).

Table 14: Response of some soil chemical and microbiological properties to soil amendment and oil contamination

Treatment	OC (%)	Pb (C mol g^{-1})	Cd (C mol g^{-1})	% AMF colonization	Bacterial count (cfu g^{-1})	Fungal count (cfu g^{-1})	Actinomycetes count (cfu g^{-1})
AMF	7.5a	2.9c	3.4b	62.3a	7.0a	0.74a	1.2a
PM	6.2c	3.1b	3.2c	41.4b	4.9b	0.61b	1.0a
NPK	6.9b	3.1b	3.1c	43.4b	5.4b	0.67b	1.07a
Control	6.4bc	3.3a	3.5a	40.6b	3.8c	0.5c	0.53b
P value	<.0001	<.0001	0.0009	<.0001	0.0001	0.0221	0.0006
% Oil concentration							
0	5.9c	3.0b	3.7a	65.7a	5.7a	0.59	0.85b
0.75	7.0ab	3.0b	3.9a	57.1b	4.9b	0.66	1.05a
1.5	6.7b	2.9b	3.2b	42.8c	4.9b	0.65	1.1a
3	7.4a	3.4a	2.3c	21.9d	5.5a	0.63	1.05a
P value	<.0001	<.0001	<.0001	<.0001	0.0367	0.052	0.0032
Interaction (P value)	<.0001	<.0001	0.0042	<.0001	<.0001	<.0001	<.0001

Source Babalola, 2012

In Adigun *et al*. (2019) we isolated eight indigenous hydrocarbon degrading microorganisms belonging to the genera *Pseudomonas, Bacillus* and *Staphylococcus* from oil polluted sites in selected Local Government areas in Ogun State. The isolates were evaluated

for their biodegradative abilities, and it was reported that the potential degradation capacity of the isolates ranged from 56.9 % to 73.9 % (Table 15).

Table 15: Potential degradation capacity index (PDCI) of isolated indigenous bacteria

Bacteria	PDCI (%)
Pseudomonas putida	73.90a
Pseudomonas nigrificans	66.60b
Staphylococcus aereus	66.50b
Pseudomonas florescences	64.40ab
Bacillus subtilis	64.30ab
Pseudomonas aeruginosa	59.10c
Pseudomonas gellucidium	58.70c
Bacillus licheniformis	56.90c

Source: Adigun *et al*., 2019

In a mining site experiment (Okoro and Babalola, 2022), we showed that the contents of Zn, Pb and Cu in farms close to the mining site were above the FAO permissible limit for agricultural soils, and using ecological risk indices, it was also revealed that the soil environment was increasingly polluted by these metals down the soil profile (Table 16). However, Okoro *et al*. (2022) demonstrated the potential of biochar and AMF in reducing the levels of these metals translocated into maize plant and ultimately reduce the contents in the grain, but the reduction of Zn was more significant. It was also revealed that increasing the rate of biochar enhanced the percent root colonization by AMF and increased the number of AMF spores, thereby ameliorating the negative impact of Zn, Pb and Cu mining on maize grown in fields near the site, and consequently, improving food safety in AMagu-Eyingba.

Table 16: Potential ecological risk assessment of farmland beside mining site

Depth (cm)	Lead	Copper	Zinc	RI	Risk grade
0 – 20	431.9	2.5	12.2	446.6	Considerable ecological risk
20 – 40	498.2	74.1	44.4	616.7	Very high ecological risk
40 – 60	722.4	191.9	86.9	1001.2	Very high ecological risk
60 – 80	1100.5	465.3	198.7	1764.5	Very high ecological risk
80 – 100	2471.3	640.5	292.5	3404.3	Very high ecological risk

Source: Okoro and Babalola, 2022

Dentiscutata niger was thought to be more prominent in enhancing phytoremediation of the site by maize due to its high number of spores and frequency of occurrence (Figures 13 & 14). Nevertheless, it was suggested that the production of food crops near the mining site should be discouraged for now, rather, the production of timber should be encouraged, to serve the dual purpose of production of much needed timber and phytoremediation of the polluted soil. The efficiency of phytoremediation could be further enhanced with the applications of biochar and AMF during the establishment of tree species.

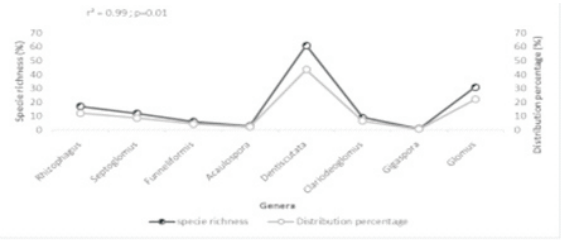

Figure 13: The relationship between specie richness and distribution percentage of AMF in mining site

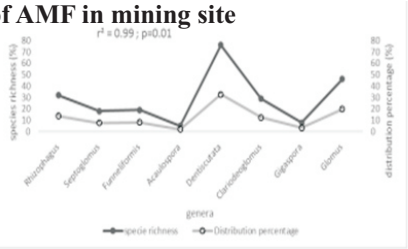

Figure 14: The relationship between specie richness and distribution percentage of AMF in control site
Source: Okoro and Babalola, 2022

In another study (Okoro *et al*., 2020), we assessed the influence of biochar on bioaccumulation of heavy metal in maize and reported that accumulation of heavy metal in the shoot and root of maize was significantly reduced by the application of up to 3 tha^{-1} of biochar (Table 17), lead accumulation reduced by 66.7% while Zn accumulation reduced by 37.5%. The bioaccumulation factor was highest for cadmium and lowest for lead (Figure 15). Values of heavy metals in the post-harvest soil sample were significantly or insignificantly reduced by the application of biochar, soil Pb was reduced by 12.11%, Cd was reduced by 65.98% and Ni was reduced by 30.04% due to soil amendment with 3 tha-1 of biochar (Table 18).

Table 17: Heavy metal concentration (mg/kg) in maize shoot and root at different rates of biochar

Treatment (t/ha)	Pb	Cd	Ni	Cr	Co	Fe	Cu	Zn
				Maize shoot				
0	1037.7	7.0	1.9	3.8	2.0	3222	52.1	498.7
1	416.3	4.8	8.5	2.6	1.8	2067	33.6	409.0
2	892.7	3.1	7.1	1.4	0.6	1310	26.8	292.0
3	647.7	1.8	4.6	2.0	0.3	923	16.6	178.6
$LSD_{0.05}$	175.29	0.98	2.6	0.9	1.1	530	12.1	129.1
				Maize roots				
0	1237.5	8.1	11.3	4.9	2.8	4584.1	59.6	732.3
1	1112.0	5.9	9.3	3.1	2.7	2987.4	32.8	614.3
2	819.5	4.4	6.4	3.5	1.6	1944.3	46.5	442.7
3	589.2	2.7	3.9	2.4	0.6	1678.0	21.6	393.3
$LSD_{0.05}$	158.3	1.0	3.1	0.6	2.0	470.5	10.8	204.6

*FAO (PI) = FAO Permissible limits; n.s = not significant

Source: Okoro *et al*., 2020

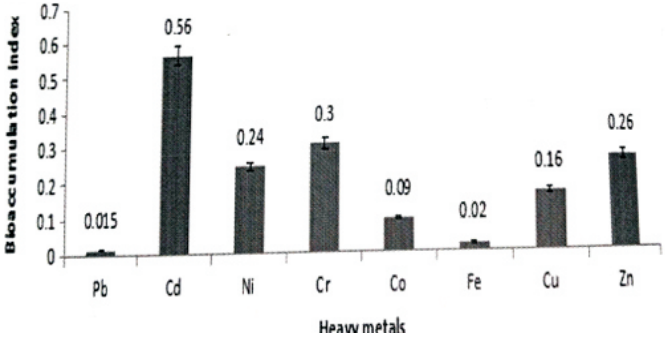

Figure 15: Bioaccumulation factor of heavy metal in maize at 3 tha^{-1}
Source: Okoro *et al*., 2022

Table 18: Heavy metal concentration in the post-harvest soil

Treatments (t/ha)	PB	Cd	Ni	Cr	Co	Fe	Cu	Zn
0	91666.7	24.4	49.6	29.0	13.8	209958.3	274.0	3465.3
1	84712.7	17.2	29.2	19.5	12.7	149041.2	259.6	2350.7
2	83751.0	9.0	36.5	31.3	11.5	141375.1	274.0	2125.3
3	80564.3	8.0	35.0	16.0	10.2	117541.0	237.3	2165.3
LSD $_{0.05}$	4353.1	9.0	19.3	n.s	n.s	n.s	n.s	n.s
FAO (PL)	100	3	50	100	50	50,000	100	300

Source: Okoro *et al*., 2022

2.7 Soil microbial ecology

Soil microbial ecology is the study of microorganisms within the soil environment. This will normally include the behavior and the activities of these microbes in the soil environment. In Olasantan and Babalola (2007), we investigated fungi and bacteria populations in the micro-environment of monocultured melon and melon intercropped with maize or cassava. It was demonstrated that intercropping melon increased rhizosphere fungi and bacteria of maize by 10-20% and cassava by 38-46%, and consequently decreased soil temperature and bulk density. Thereby increasing the total crop productivity, but the effect was more favorable when crops were planted early (Table 19). Correlation of microbial populations with growth and yield parameters was significant in maize and cassava but was not significant in melon (Table 20).

Table 19: Effect of sowing date of melon on soil temperature, soil moisture content and rhizosphere microbial populations in cassava and melon field

Melon sowing date		Soil temperate (°C)		Soil moisture (g kg^{-1})			Bulk density (g cm^{-3})		Rhizosphere fungi (× 10^4 CFU g^{-1})		Rhizosphere bacterial (× 10^4 CFU g^{-1})	
2002	2003	2002	2003	2002	2003		2002	2003	2003		2003	
		8+	8	8	8	12	8	8	8	12	8	12
Sole crop maize		32.8	37.1	117	95	102	1.48	1.45	117	113	197	203
Sole crop cassava		37.7	38.1	102	70	105	1.48	1.45	123	118	163	195
Sole crop melon												
28 August	–	27.5	–	137	–	–	1.40	–	–	–	–	–
11 September	20 September	28.7	28.5	105	105	115	1.35	1.38	116	116	219	123
25 September	4 October	29.2	29.7	88	75	80	1.39	1.40	107	92	131	104
Maize/melon intercrop												
28 August	–	28.5	–	129	–	–	1.34	–	–	–	–	–
11 September	20 September	29.0	29.2	116	108	120	1.34	1.32	135	128	254	250
25 September	4 October	29.2	30.0	103	84	75	1.39	1.34	124	104	251	161
Cassava/melon intercrop												
28 August	–	28.3	–	135	–	–	1.36	–	–	–	–	–
11 September	20 September	28.5	28.9	114	115	125	1.32	1.35	209	186	279	349
25 September	4 October	28.5	27.7	95	68	95	1.34	1.36	156	134	188	208
S.E. (20 D.F.)	(14 D.F.)	0.36	0.50	4.8	6.5	6.4	0.07	0.05	10.9	9.4	15.6	17.6

Source: Olasantan and Babalola, 2007

Table 20: Correlation analysis between fungi and bacterial populations content and crop parameters in 2003 at Alabata Abeokuta, Nigeria

(a) Melon		Vine length	No. of leaves	Leaf area	No. of branches	No. of fruits	Fruit weight	No. of seeds	Seed yield	
Rhizosphere fungi	8+	0.15	−0.21	−0.16	−0.40	0.16	0.19	0.34	0.15	
	12	0.24	−0.17	−0.14	−0.26	0.35	0.25	0.41	0.34	
Rhizosphere bacteria	8	−0.35	−0.35	−0.38	−0.37	0.13	−0.19	0.40	0.11	
	12	−0.20	−0.31	−0.32	−0.53	0.12	−0.18	0.25	0.34	
(b) Maize		Plant height	No. of leaves	Leaf area	50% flowering	No. of cobs	Cob weight	Cob length	No. of grains	Grain Yield
Rhizosphere fungi	8	0.99*	0.79	0.47	−0.98*	−0.75	0.69	−0.15	−0.99*	−0.46
	12	0.68	−0.14	0.97*	−0.89*	−0.76	0.13	0.25	−0.66	−0.94*
Rhizosphere bacteria	8	0.88*	0.99*	0.42	0.72	−0.44	0.98*	−0.35	0.89*	0.16
	12	0.59	0.14	0.94*	0.76	−0.77	0.13	0.26	−0.58	−0.97*
(c) Cassava		Plant height	No. of leaves	No. of tubers	Tuber yield					
Rhizosphere fungi	8	0.89*	0.93*	0.92*	0.98*					
	12	0.92*	0.98*	0.97*	0.99*					
Rhizosphere bacteria	8	0.92*	0.98*	0.98*	0.98*					
	12	0.96*	0.99*	0.99*	0.97*					

+Weeks after sowing. * Significant at $p < 0.05$.

Source: Olasantan and Babalola, 2007

In Egberongbe *et al.* (2010 a & b), we investigated the effects of *Glomus moseae* and *Trichoderma harzianum* on proximate analysis and mineral nutrients in soybean. The experiment demonstrated that the two microorganisms applied separately or together improved the contents of crude protein, carbohydrate, ash, moisture, dry matter, Mg and P in soybean (Table 21).

Table 21: Effect of dual inoculation of G moseae and T harzianum on seed composition of soybean

Treatments		%CP	%CF	%CHO	%Ash	%Oil	%MC	%DM
Soil treatment conditions	Sterilized	27.3800	0.0366	50.0000	0.0453	12.9300	9.6000	90.4100
	Unsterilized	30.1100	0.0355	46.3200	0.0442	13.8400	9.6200	90.3700
	LSD (0.05)	0.0700	0.0003	0.2300	0.0004	0.2000	0.0200	0.0400
Inoculation × soil treatmehts								
Sterilized	GT	28.9200	0.0375	50.0500	0.0470	11.6500	9.7300	90.690
	C	25.8700	0.0345	49.2600	0.0435	14.1700	9.3800	90.2600
Unsterilized	GT	31.5100	0.0370	46.8000	0.0450	12.1200	9.6300	90.5300
	C	27.1900	0.0335	47.8700	0.0425	15.2100	9.4600	90.3600
	LSD (0.05)	0.1000	0.0005	0.3300	0.0006	0.2800	0.0200	0.0600

DM - dry matter, CP - crude protein, CHO - carbohydrate, MC - moisture content, CF - crude fiber, T - *Trichoderma*, G – *G. mosseae* and C - control.

Source: Egberongbe *et al*., 2010a

In Adigun and Babalola (2016), we investigated the effect of co-inoculations of *Bradyrhizobium japonicum* and arbuscular mycorrhizal fungi on microbial activities in soybean rhizosphere. It was reported that the values of all microbial parameters were similar when either mycorrhizal fungi or SSP was applied, higher values were however recorded with inoculation of *Bradyrhizobium japonicum* than in the other treatments (Table 22). Interactive effects of the treatments reveals that the lowest values of microbial parameters and soil enzymes were generally observed in plots treated with only SSP, but where SSP was combined with *Bradyrhizobium japonicum* or poultry manure or both, the values increased (Tables 23).

Table 22: Response of microbial parameters to main treatments at 8 WAP of soybean

Treatments	Total bacterial Count	Total fungi Count	Microbial biomass C	Microbial biomass N	Microbial biomass P
Bradyrhizobium inoculants					
Bradyrhizobium	1.16^{a}	0.07^{a}	186.0^{a}	120.2^{a}	211.2^{a}
Control (0)	0.89^{b}	0.05^{a}	143.8^{b}	117.2^{a}	200.7^{a}
P value	0.000	0.011	0.002	0.361	0.514
Phosphorus source					
Mycorrhiza	0.99^{a}	0.06^{a}	155.3^{a}	114.3^{a}	205.3^{a}
SSP	1.05^{a}	0.06^{a}	174.7^{a}	123.2^{a}	206.0^{a}
P value	0.171	0.721	0.124	0.010	0.990
Poultry manure					
0 (tons)	0.75^{c}	0.05^{b}	138.7^{a}	111.4^{a}	186.7^{a}
5 (tons)	1.06^{b}	0.07^{a}	198.1^{a}	124.9^{a}	232.2^{a}
10 (tons)	1.26^{a}	0.06^{ab}	158.1^{b}	119.9^{a}	198.8^{ab}
P value	0.000	0.019	0.002	0.007	0.070

Source: Adigun and Babalola, 2016

Table 23: Response of some soil enzymes to treatment interaction among the treatments

Treatments	Protease (mg/kg)	Urease (mg/kg)	Cellulase (mg/kg)
MB + 5PM	0.12^{cd}	0.21^{a}	0.14^{bcd}
BM + 10PM	0.04^{g}	0.04^{e}	0.12^{cdef}
PM	0.14^{abc}	0.21^{a}	0.17^{ef}
BM	0.12^{cd}	0.14^{cd}	0.13^{bcde}
BS + 5PM	0.16^{a}	0.18^{ab}	0.15^{ab}
BS+ 10PM	0.13^{bcd}	0.20^{a}	0.15^{ab}
BS	0.07^{ef}	0.11^{d}	0.06^{g}
M +5PM	0.14^{abc}	0.15^{c}	0.16^{a}
M + 10PM	0.15^{ab}	0.16^{bc}	0.15^{a}
M	0.05^{fg}	0.04^{e}	0.18^{ef}
S +5PM	0.11^{d}	0.13^{cd}	0.13^{cdef}
S +10PM	0.09^{e}	0.16^{bc}	0.14^{abc}
S	0.05^{fg}	0.07^{e}	0.11^{f}
P value	0.0001	0.0001	0.0001

Source: Adigun and Babalola, 2016

In other experiments (Babalola *et al*., 2012; 2018a), we planted two varieties of tomato on soil amended with 3 rates of compost for one or two years. The experiments revealed that most of the soil biological characteristics were influenced by duration of compost application, variety and rate of amendment. Soil microbial biomass C and P, number of earthworms and organic matter were higher after one year of compost application, while microbial populations (bacterial and fungi) and microarthropod counts as well as biomass N were higher in soil sampled after two years of application of compost. All the soil biological parameters were higher in soil cultivated with the local variety (*Beske*), suggesting that variety adaption to soil due to long years of cultivation involves a more complex soil-plant interaction (Tables 24).

Table 24: Effect of duration and variety on some soil microbial properties

No. of years	Viable count (CFU x 105)	Fungal count (CFU x 105)	Biomass phosphorus (mg/kg)	Biomass carbon (mg/kg)	Biomass nitrogen (mg/kg)
1.	17.78b	0.37	2.27a	8.67a	0.30
2.	21.63a	0.48	1.70b	6.10b	0.34
Variety					
UCB8	17.40b	0.40	1.73	6.80	0.32
Beske	22.01a	0.46	2.24	7.97	0.32

Means with different alphabet indicate that they are significantly different as p=0.05

Source: Babalola and Adigun, 2018

In Babalola and Adigun (2013), we investigated activities of microbes at the rhizosphere of pepper and okra supplied with composted animal wastes. We reported that microbial populations were higher at the rhizosphere of pepper, particularly when no compost was applied. Also, the values of microbial biomass C and P were considerably higher at the rhizosphere of okra supplied with composted poultry manure, while microbial biomass N was higher in the rhizosphere of pepper supplied with the composted poultry manure (Table 25).

Table 25: Effect of compost and fruit vegetables on soil microbial properties

Crop	Treatment	Total Viable count (cfug-1)	Fungal count (cfug-1)	Microbial biomass carbon (mgkg-1)	Microbial biomass phosphorus (mgkg-1)	Microbial biomass nitrogen (mgkg-1)
Okra	Pig	11.50c	0.60b	8.20ba	2.86b	0.17a
	Poultry	13.50cb	0.76b	10.42a	10.77a	0.07b
	No amendmer	11.43c	0.53b	4.77b	2.86b	0.06b
Pepper	Pig	16.66b	0.80b	8.12ba	3.50b	0.20a
	Poultry	15.66b	0.70b	9.86a	3.49b	0.21a
	No amendme	**20.60a**	**1.20a**	**4.56b**	**2.70b**	**0.15ba**

Source: Babalola and Adigun, 2013

Effect of urea fertilizer was also investigated on soil microbial characteristics in a screenhouse experiment (Babalola *et al*., 2018a). The experiment revealed that soil microbial biomass N, P and C as well as soil enzymes (protease, urease and cellulase) and respiration increased with increasing rate of compost application as well as urea application (Tables 26 & 27).

Table 26: Effect of urea and compost on soil microbial biomass N, C and P (mg/kg) and microbial respiration

Treatment	Microbial biomass (N)	Microbial biomass (C)	Microbial biomass (P)	Microbial respiration
Urea (12)	128.85^{a}	141.6^{a}	275.86^{a}	3.25^{a}
Non urea (Ni1)	119.72^{a}	132.9^{a}	257.8^{b}	2.57^{b}
Compost (ton/ha)				
0	122.42^{a}	134.67^{a}	263.13^{a}	2.73^{a}
10	123.72^{a}	137.6^{a}	265.67^{a}	2.99^{a}
20	126.73^{a}	139.53^{a}	271.68^{a}	3.01^{a}
Interactions				
Urea+0t/h compost	128.33^{a}	139.37^{a}	267.97^{a}	3.06^{ab}
Urea+10t/h compost	128.93^{c}	142.33^{a}	268.97^{a}	3.32^{a}
Urea+20t/h compost	129.30^{a}	143.23^{a}	280.63^{a}	3.38^{a}
Non urea+0t/h compost	116.50^{a}	129.97^{a}	252.37^{a}	2.39^{b}
Non urea+10t/h compost	118.5^{a}	132.87^{a}	258.30^{a}	2.65^{a}
Non urea+20t/h compost	124.57^{a}	135.83^{a}	262.73^{a}	2.66^{ab}

Source: Babalola *et al*., 2018

Table 27: Effect of urea and compost on soil enzymes (mg/kg)

Treatment	Protease	Urease	Cellulase
Urea (12)	0.13^{a}	0.13^{a}	0.138^{a}
Non urea (Ni1)	0.11^{b}	0.11^{b}	0.115^{b}
Compost (ton/ha)			
0	0.113^{a}	0.113^{b}	0.12^{b}
10	0.122^{a}	0.124^{a}	0.125^{ab}
20	0.123^{a}	0.125^{a}	0.14^{a}
Interactions			
Urea+0t/h compost	0.12^{b}	0.121^{b}	0.127^{bc}
Urea+10t/h compost	0.13^{a}	0.134^{a}	0.133^{b}
Urea+20t/h compost	0.13^{a}	0.136^{a}	0.155^{a}
Non urea+0t/h compost	0.112^{bc}	0.105^{c}	0.11^{c}
Non urea+10t/h compost	0.112^{bc}	0.113^{bc}	0.12^{bc}
Non urea+20t/h compost	0.113^{bc}	0.114^{bc}	0.12^{bc}

Source: Babalola *et al*., 2018

Optimization of microbial activities in an organic crop production system is crucial to the realization of optimum productivity of crops. Consequently, I carried out screenhouse and field experiments to investigate the influence of microbial activities on growth and yield of tomato varieties supplied with 4 rates of compost (Babalola, 2019). The results corroborated the earlier reports (Babalola *et al*., 2012 & 2018b) that microbial parameters were higher in the rhizosphere of the local variety than that of the improved variety due to a more prolonged adaptation of the local variety to the agricultural environment (Tables 28 & 29). Microbial populations correlated more significantly with the growth and yield parameters at 6 weeks after application (WAP) of compost than at 3 WAP, this was attributed to optimum release of nutrient to plants through microbial processing at this time, which is also the period of highest vegetative and reproductive development of the tomato crop and consequently having impact on the yield.

Table 28: Soil bacterial (10^5 cfu g^{-1} soil) and fungal (104 cfu g^{-1} soil) populations in two pot experiments with 4 rates of compost and two tomato varieties.

Treatment	First experiment						Second experiment					
	Bacteria		Fungi		NB		Bacteria			Fungi		
Varieties	BT	HVT	BT	HVT	BT	HVT	BT	6WAT	HVT	BT	6WAT	HVT
Local	NA	15.1^{a}	NA	6.7^{a}	NA	0.77^{a}	NA	12.5	5.6	NA	9.7^{a}	5.6
Improved	NA	12.5^{a}	NA	6.0^{a}	NA	0.62^{b}	NA	11.3	5.2	NA	7.4^{b}	5.2
Compost (t ha^{-1})												
0	14.2^{b}	14.5	6.0^{b}	6.7	1.00^{c}	0.41^{c}	10.6^{c}	6.5^{c}	4.0$_{c}$	4.5^{c}	4.5^{c}	4.0^{c}
5	14.4^{b}	12.9	6.3^{b}	5.0	0.88^{c}	0.45^{c}	16.8^{c}	11.1^{b}	5.0^{b}	7.2^{b}	8.0^{b}	5.0^{b}
10	16.9^{a}	13.8	6.2^{b}	6.7	1.28^{b}	0.70^{b}	19.7^{b}	14.5^{ab}	5.8^{b}	7.8^{b}	10.5^{a}	5.8^{b}
20	16.9^{a}	14.0	7.3^{a}	7.2	1.47^{a}	1.03^{a}	22.1^{a}	15.5^{a}	6.7^{a}	15.0^{a}	11.2^{a}	6.7^{a}
Compost x variety												
Local												
0	15.0	13.7^{c}	6.3	4.0^{c}	1.5^{c}	0.70^{b}	10.5^{a}	4.9^{c}	4.3^{ef}	5.0^{cd}	4.7^{d}	4.3^{ef}
5	14.0	14.1^{c}	7.0	6.7^{ab}	1.8^{b}	0.40^{c}	17.0^{c}	13.2^{ab}	5.3^{cde}	7.7^{c}	9.0^{c}	5.3^{cde}
10	13.0	15.3b	6.7	6.7^{ab}	1.9^{b}	0.80^{b}	20.5^{b}	15.2^{a}	6.1^{abc}	7.3^{c}	12.3^{ab}	6.1^{abc}
20	13.0	17.2^{a}	6.7	6.7^{ab}	2.0^{a}	1.17^{a}	22.3^{a}	16.5^{a}	6.9^{a}	17.0^{a}	12.7^{a}	6.9^{a}
Improved												
0	13.4	11.8^{d}	8.0	6.7^{ab}	1.50^{c}	0.53^{bc}	10.5^{a}	7.6^{c}	3.8^{f}	4.0^{d}	4.3^{d}	3.8^{f}
5	14.9	10.0^{d}	5.7	6.0^{b}	1.37^{c}	0.43^{c}	16.5^{d}	9.0b^{c}	4.7^{def}	6.7^{cd}	7.0^{cd}	4.7^{def}
10	20.8	13.9^{c}	5.7	6.7^{ab}	1.9^{b}	0.60^{b}	18.9^{c}	13.8^{ab}	5.6b^{cd}	8.3^{c}	8.7^{c}	5.6b^{cd}
20	20.7	13.9^{c}	8.0	7.7^{a}	2.27^{a}	0.90^{b}	22.0^{a}	14.6^{a}	6.6a^{b}	13.0^{b}	9.7^{bc}	6.6a^{b}

Source: Babalola, 2019.

Table 29: Soil cellulase, amylase and protease activities (ug g-1) at 3 sampling periods in pot experiment amended with 4 rates of compost in 2 tomato varieties.

Treatment	Cellulase			Amylase			Protease		
Varieties	BT	6 WAT	HVT	BT	6 WAT	HVT	BT	6 WAT	HVT
Local	NA	0.1259^{a}	0.1168	NA	0.1175	0.1114	NA	0.1219^{a}	0.1068
Improved	NA	0.1249^{b}	0.1185	NA	0.1157	0.1123	NA	0.1171^{b}	0.1094
Compost (t ha^{-1})									
0	0.1238^{d}	0.1227^{c}	0.1085^{c}	0.1217^{d}	0.1130^{b}	0.1068^{c}	0.1107^{c}	0.1133^{c}	0.1030^{c}
5	0.1380^{c}	0.1250^{b}	0.1188^{b}	0.1378^{c}	0.1165^{a}	0.1118^{b}	0.1192^{b}	0.1190^{b}	0.1072^{bc}
10	0.1493^{b}	0.1265^{a}	0.1205^{ab}	0.1405^{b}	0.1175^{a}	0.1137^{ab}	0.1218^{ab}	0.1218^{ab}	0.1095^{ab}
20	0.1542^{a}	0.1275^{a}	0.1222^{a}	0.1435^{a}	0.1195^{a}	0.1150^{a}	0.1245^{a}	0.1283^{ab}	0.1127^{a}
Compost x variety									
Local									
0	0.1233^{a}	0.1137^{cd}	0.1043^{c}	0.1220^{a}	0.1136^{a}	0.1043^{c}	0.1103^{d}	0.1080^{c}	0.1030^{b}
5	0.1380^{d}	0.1173^{abc}	0.1120^{ab}	0.1383^{d}	0.1220^{abc}	0.1120^{ab}	0.1203^{bc}	0.1170^{b}	0.1050^{b}
10	0.1503^{bc}	0.1187^{ab}	0.1443^{a}	0.1413^{bc}	0.1250^{ab}	0.1143^{a}	0.1223^{abc}	0.1200^{ab}	0.1073^{ab}
20	0.1550^{a}	0.1207^{a}	0.1150^{a}	0.1443^{a}	0.1270^{a}	0.1150^{a}	0.1250^{a}	0.1220^{a}	0.1117^{a}
Improved									
0	0.1243^{a}	0.1123^{d}	0.1093^{c}	0.1213^{a}	0.1130^{a}	0.1093^{c}	0.1110^{d}	0.1090^{c}	0.1030^{b}
5	0.1380^{d}	0.1157^{cd}	0.1117^{ab}	0.1373^{d}	0.1160^{abc}	0.1117^{ab}	0.1180^{c}	0.1207^{ab}	0.1093^{ab}
10	0.1483^{c}	0.1163^{abcd}	0.1130^{ab}	0.1397^{cd}	0.1187^{abc}	0.1130^{ab}	0.1213^{abc}	0.1210^{ab}	0.1117^{a}
20	0.1533^{ab}	0.1183^{abc}	0.1150^{a}	0.1427^{ab}	0.1207^{bcd}	0.1150^{a}	0.1240^{ab}	0.1223^{a}	0.1137^{a}

Source: Babalola, 2019

In a study by Adigun *et al*. (2022), we assessed the effect of organic production of maize on soil microbial population and activities and reported that microbial biomass N was significantly higher in poultry manure, compost, NPK amended soils and control, while

microbial biomass P was higher in soil amended with organo-mineral fertilizer and microbial biomass C was higher in poultry manure and green manure amended soils. The populations of bacterial and fungi in the soil were significantly favored by the applications of NPK, neem and organo-mineral fertilizers (Table 30).

Table 30: Activities and populations of Microorganisms as affected by different fertilizers in maize production.

Fertilizers	Microbial BiomassP (mg kg^{-1})	Microbial BiomassC (mg kg^{-1})	Microbial BiomassN (mg kg^{-1})	TotalViable Count (cfug^{-1})	Tot Cou
Compost	9.78^{de}	10.21^{c}	1.11^{a}	18.4x10^{5ab}	0.4
Green manure	10.40^{bc}	10.03^{d}	0.58^{b}	18.2x10^{5ab}	0.5
NPK	10.79^{b}	10.56^{b}	1.06^{a}	16.65x10^{5ab}	0.7
Neem fertilizer	10.08^{d}	9.55^{de}	0.09^{c}	19.6x10^{5a}	0.6
Organo-mineral	11.33^{a}	9.29^{c}	0.09^{c}	19.15x10^{5ab}	0.4
Poultry manure	9.39^{c}	10.93^{a}	1.25^{a}	15.7x10^{5b}	0.5
Control	10.63^{c}	10.18^{bc}	1.03^{a}	18.55x10^{5ab}	0.6

Means with different superscript on the same column differ significantly (p<0.05)

Source: Adigun *et al*., 2022

2.8 Soil organic matter management

Soil organic matter is the most important attribute of soil, it is the most crucial indicator of soil quality and agricultural sustainability. Cultivation, cropping systems, residue and tillage management, fertilization and other crop management practices affect soil organic matter and carbon transformation. Soil organic matter is not only a source of carbon but also a sink for carbon sequestration. In view of this Babalola (2000) investigated the effect of farmyard manure, residues of soybean and maize on soil, maize, and cowpea growth. Growth of cowpea was comparable in all the treatments, but in maize, application of NPK gave significantly higher growth and the applications of the organic materials significantly increased the growth compared to control (Table 31). The soil organic carbon, P and N were higher in soils amended with organic materials than in other treatments. Organic carbon, phosphorus and potassium contents were higher in all corresponding treatments in soil cropped to cowpea than in soil cropped to maize (Table 32). The pH

values were however less in soil cropped to cowpea. This tends to affirm the more favorable impact of legume cropping on soil, and the more acidic condition at the root zone of legumes.

Table 31: Differences in some parameters of soil cropped to cowpea due to treatment effects.

Treatment	PH ($CaCl_2$)	PH (H_2O)	% Org. carbon	% N	% P	% K
Cereal residue	5.43	5.63	0.41	0.052	5.29	0.41
Legume residue	5.4	5.66	0.39	0.053	15.15	0.37
Cereal + Legume	5.83	6.2	0.44	0.052	5.98	0.26
FYM	5.8	6.0	0.18	0.052	13.26	0.17
Control	6.17	6.3	0.14	0.51	1.32	0.25
LSD (0.05)	-	-	-	-	*	-

Source: Babalola, 2000

Table 32: Differences in some parameters of soil cropped to maize due to treatment effects

Treatment	PH ($CaCl_2$)	PH (H_2O)	% Org. carbon	% N	% P	% K
Cereal residue	6.1	6.47	0.36	0.051	2.64	0.29
Legume residue	6.17	6.5	0.44	0.052	5.04	0.29
Cereal + Legume	5.63	5.77	0.14	0.052	2.37	0.37
FYM	6.3	6.47	0.23	0.053	3.56	0.24
NPK	6.13	6.2	0.31	0.052	3.29	0.13
Control	6.0	6.2	0.11	0.054	1.76	0.26
LSD (0.05)	-	-	-	-	*	-

Source: Babalola, 2000

In Babalola and Adigun (2009; 2011;2013), we also investigated the use of different sources of organic material as composts on the soil, tomato, pepper and okra. Nutrient uptakes, growth and yields were higher in all compost amended soils than in control (Tables 33).

Table 33: Effect of compost and crop on uptakes of N, P and okra and pepper

Crop	Treatment	N(mgkg-1)	P(mgkg-1)	K(mgkg-1)
Okra	Pig	1.15a	1.27a	0.49a
	Poultry	0.79a	1.29a	0.50a
	No amendment	1.17a	1.16ab	0.53a
Pepper	Pig	1.29a	0.91b	0.46a
	Poultry	1.33a	1.33a	0.42a
	No amendment	1.31a	1.27a	0.40a

Source: Babalola and Adigun, 2013

In another study using the same compost treatments (Adigun and Babalola, 2013), we reported that uptakes of N, P and K by celosia were similar in all the treatments, but in Amaranthus uptakes were considerably higher in plots amended with composted poultry manure (Table 34).

Table 34: Effects of composted pig dung (CPD) and poultry manure (CPM) on N, P and K uptake in *Amaranthus caudatus* and *Celosia argentia*

	TREATMENTS	N-UPTAKE(mg)	P-UPTAKE(mg)	K-UPTAKE(mg)
AMARANTHUS	CPD	18.120^{a}	20.653^{a}	7.810^{a}
	CPM	10.333^{b}	13.027^{b}	4.087^{b}
	NOA	11.830^{b}	16.013^{ab}	5.423^{b}
CELOSIA	CPD	12.200^{a}	20.443^{a}	
	CPM	10.373^{a}	10.860^{a}	4.527^{a}
	NOA	7.453^{a}	12.507^{a}	3.930^{a}

Source: Adigun and Babalola, 2013

In Adigun *et al.* (2022), we also assessed the effect of amendments on organic and inorganic forms of soil P and carbon. We reported that soil had maximum and significant values of organic and inorganic P when neem, organo-mineral and poultry manure fertilizers were applied to the soil, while the least values were recorded in control. At 3 and 6 WAP, maximum values of organic carbon were however recorded in soil amended with organo-mineral fertilizer, and neem fertilizer respectively, while at 3 and 6 WAP the lowest values of organic carbon were recorded in soil amended with poultry manure (Tables 35).

Table 35: Percent organic and inorganic phosphorus as affected by different fertilizer in maize production.

Fertilizers	OrganicP 3WAP	InorganicP 3WAP	OrganicP 6WAP	InorganicP 6WAP
Compost	0.52^{ab}	0.20^{ab}	0.42^{ab}	0.22^{b}
Green manure	0.47^{ab}	0.19^{ab}	0.38^{b}	0.18^{bc}
NPK	0.47^{ab}	0.19^{ab}	0.42^{ab}	0.23^{ab}
Neem fertilizer	0.59^{a}	0.24^{ab}	0.50^{a}	0.25^{a}
Organo-mineral	0.59^{a}	0.26^{a}	0.51^{a}	0.23^{ab}
Poultry manure	0.58^{a}	0.22^{ab}	0.34^{bc}	0.18^{bc}
Control	0.38^{b}	0.18^{b}	0.24^{c}	0.15^{c}

Means with different superscript on the same column differ significantly ($p<0.05$)

Source: Adigun *et al*., 2022

However, despite the obvious favorable impact of the organic amendments on soil, maximum values of plant height and leaf area were recorded in soil amended with NPK followed by compost and poultry manure while, the lowest values were recorded in control and green manure treated soils (Table 36). This suggests that while soil amendment with organic manure may have immediate impact on soil and the plant, but at such a short duration the impact of NPK on plant growth and yield is higher because of faster and higher availability of nutrients to plants.

Table 36: Effect of different types of fertilizers on plant height (cm) of maize

Fertilizers	3WAP	4WAP	5WAP	6WAP
Green manure	39.9^{c}	59.6^{c}	127.5^{ab}	198.7^{b}
Organo-mineral fertilizer	52.3^{b}	81.4^{b}	137.9^{ab}	226.7^{ab}
Neem fertilizer	54.7^{ab}	80.6^{b}	131.6^{ab}	210.9^{b}
Poultry manure	58.8^{ab}	101.6^{a}	157.3^{a}	235.9^{ab}
Compost	61.8^{ab}	112.2^{a}	170.8^{a}	261.6^{a}
NPK	66.4^{a}	102.5^{a}	164.4^{a}	262.1^{a}
Control	34.8^{c}	51.9^{c}	89.9^{b}	198.3^{b}

Means with different superscript on the same column differ significantly ($p<0.05$).

Source: Adigun *et al*., 2022

In Babalola *et al*. (2012), we reported the impact of compost amendments on soil biological, physical and chemical properties after 1 or 2 years of application, consequently, bulk density, total porosity and aggregate stability were positively and significantly impacted after 2 years of compost application especially in plots planted to *Beske* (Table 37).

Table 37: Residual effect of compost, tomato varieties and duration after the 2nd compost application/planting of soil physical properties at Abeokuta

Treatment	Bulk density (g cm^{-3})	Hydraulic conductivity (cm hr^{-1})	Aggregate stability (MWD)	Total porosity (%)
YACA/P				
1	1.46^{b}	59.2	1.02^{b}	44.8^{b}
2	1.39^{a}	56.7	1.21^{a}	47.7^{a}
LSD	*	NS	*	*
Depth (cm)				
0-20	1.34^{b}	55.1	1.03^{b}	49.1^{a}
20-40	1.5^{a}	60.8	1.24^{a}	43.4^{b}
Variety×compost				
UC82B 0	1.46^{a}	46.1^{b}	0.92^{b}	45.1
UC82B 10	1.47^{a}	39.9^{b}	1.10^{b}	44.6
UC82B 20	1.41^{a}	53.0^{b}	0.98^{b}	47.0
Beske 0	1.41^{a}	58.2^{b}	1.36^{a}	47.1
Beske 10	1.44^{a}	50.8^{b}	1.39^{a}	45.0
Beske 20	1.39^{a}	99.6^{a}	1.38^{a}	48.6
LSD	*	*	*	NS

Source: Babalola et al., 2012.

In Babalola (2019), I demonstrated that consequent to microbial activities, soil organic matter was higher with increasing rate of compost applied to the soil and thereby leading to increases in the contents of total N, NH_4-N, NO_3-N and P in the soil after the first cropping cycle (Table 38). This led to significantly higher growth and yield of tomatoes in the corresponding soils at the second cropping cycle in the two varieties (Table 39).

Table 38: Combined analysis of soil chemical properties at 2 sampling periods in pot experiments amended with 4 rates of compost in 2 tomato varieties

Treatment	Nitrogen (%)		Phosphorus (mg kg-1)		Organic carbon (%)		Soil NH_4-N (%)		NO_3-N (%)	
Varieties	BT	HVT	BT	HVT	BT	HVT	3WAT	6WAT	3WAT	6WAT
Local	NA	0.0264	NA	7.42^{a}	NA	0.3632	0.121	0.176^{a}	0.115	0.085^{a}
Improved	NA	0.0199	NA	6.63^{b}	NA	0.3467	0.084	0.052^{b}	0.061	0.068^{b}
Compost (t ha^{-1})										
0	0.1070^{c}	0.0090	9.57^{d}	6.06^{b}	12.09^{d}	0.2380^{d}	0.076	0.076^{b}	0.070^{b}	0.063^{a}
5	0.1233^{b}	0.0262	11.20^{c}	6.98^{a}	15.52^{c}	0.3433^{c}	0.095	0.127^{a}	0.049^{b}	0.073^{b}
10	0.1277^{ab}	0.0273	13.26^{b}	7.39^{a}	18.43^{b}	0.3995^{b}	0.132	0.121^{a}	0.065^{b}	0.062^{b}
20	0.1313^{a}	0.0302	15.85^{a}	7.66^{a}	21.50^{a}	0.4390^{a}	0.107	0.134^{a}	0.168^{a}	0.111^{a}
Compost x variety										
Local										
0	0.1073^{c}	0.0050^{b}	9.62^{g}	6.72^{b}	12.07^{e}	0.2367^{e}	0.031^{c}	0.104^{b}	0.057^{c}	0.036^{d}
5	0.1247^{b}	0.0090^{b}	11.70^{e}	7.31^{ab}	16.40^{c}	0.3667^{c}	0.077^{b}	0.184^{a}	0.055^{c}	0.088^{c}
10	0.1287^{ab}	0.0443^{a}	13.93^{c}	7.74^{ab}	19.90^{b}	0.4012^{bc}	0.10^{ab}	0.197^{a}	0.064^{c}	0.10^{b}
20	0.1340^{a}	0.0473^{a}	16.11^{a}	7.93^{a}	23.27^{a}	0.4480^{a}	0.130^{a}	0.220^{a}	0.283^{a}	0.117^{b}
Improved										
0	0.1067^{c}	0.0090^{b}	9.52^{g}	5.41^{c}	12.10^{e}	0.2393^{e}	0.031^{c}	0.048^{b}	0.053^{c}	0.029^{d}
5	0.2200^{b}	0.0130^{b}	10.70^{f}	6.66^{b}	14.63^{d}	0.3200^{d}	0.077^{b}	0.048^{b}	0.043^{c}	0.023^{d}
10	0.1267^{ab}	0.0103^{b}	12.60^{d}	7.05^{b}	16.97^{c}	0.3973^{bc}	0.10^{ab}	0.044^{b}	0.065^{c}	0.037^{d}
20	0.1287^{ab}	0.0473^{a}	15.60^{b}	7.40^{ab}	19.73^{b}	0.4300^{ab}	0.130^{a}	0.069^{b}	0.082^{b}	0.185^{a}

Source: Babalola, 2019

Table 39: Growth and yield characteristics of tomato varieties in response to field application of 3 rates of compost in 2014 and 2015

Treatment	Number of branches/ plant		Plant height (cm)		Dry matter yield (g plant^{-1})		Number of fruits per plant		Weight of fruits (t ha^{-1})	
	2014	2015	2014	2015	Shoot	Root	2014	2015	2014	2015
Improved variety										
0 t ha^{-1}	26	30	60.8	67.0	16.4	3.3	3.0	9.0	0.5	4.6
10 t ha^{-1}	35	49	55.5	77.0	15.4	2.9	3.0	8.0	0.9	4.1
20 t ha^{-1}	31	60	54.2	90.0	26.2	4.6	4.0	9.0	1.0	6.2
Mean	30.7	46.3	56.8	78.0	19.3	3.6	3.0	8.6	0.8	5.0
Local variety										
0 ha^{-1}	47	39	73.0	70.0	18.8	2.0	4.0	7.0	1.7	4.6
10 ha^{-1}	42	40	71.3	74.0	21.3	3.6	4.0	9.0	2.0	5.9
20 ha^{-1}	46	45	71.6	88.0	30.5	4.3	5.0	10.0	3.5	6.2
Mean	45	41.1	72.0	77.3	23.5	3.3	4.3	9.0	2.4	5.1
LSD	NS	NS	9.164	7.01	6.2	NS	0.967	NS	0.79	NS

Source: Babalola, 2019

In Oyebamiji *et al*. (2020), effect of incorporation of leafy biomass of trees as organic fertilizer in maize-based production system in semi-arid Nigeria was investigated for two years (2014 and 2015). *Albizia lebbeck* incorporated plots consistently had higher values of yield components than those amended with *Parkia biglobosa*. It was also demonstrated that the inclusion of up to 40 kg ha^{-1} nitrogen fertilizer to leafy biomass of trees also improved the yields of maize varieties (Table 40).

Table 40: Influence of biomass and nitrogen rate on yield components of maize in 2014 and 2105 (combine analysis of both years)

Treatment	Length of cob (cm)	Number of grains cob^{-1}	Grain yield (kg ha^{-1})
Biomass (B)			
Control	11.8b	276.7b	1392.4b
Albizia	12.9a	328.8a	1881.9a
Parkia	11.4b	272.0b	1171.9b
SE	0.35	13.8	136.18
Nitrogen rate (N)			
0	10.2c	217.2b	912.0b
40	11.9b	291.2a	1562.5a
80	12.9ab	332.6a	1581.0a
120	13.2a	329.0a	1872.7a
SE	0.37	14.81	152.62
Variety (V)			
DMR-ESR-7	11.8a	281.3	1407.4a
2009 EVAT	12.3a	303.6a	1556.7a
SE	0.3	11.69	117.56
Interaction			
B x N	*	*	*
B x V	*	*	*
V x N	*	*	*

Source: Oyebamiji *et al*., 2020

In Oyebamiji *et al*. (2017a), it was revealed that soil contents of organic carbon, lignin and N increased in *Albizia* amended plots, while polyphenols increased in plots amended with *Parkia*. Consequently, harvest index increased in plots amended with *Albizia lebbeck*, soil exchangeable K and Na were however not significantly affected by amendment (Table 41).

Table 41: Influence of biomass application on soil properties and yield index (mean of 2014 and 2015)

Tree species	% N	% C	% lignin	% polyphenol	Na	K	H index
Albezia lebbeck	3.2a	18.6a	11.06a	0.57b	0.32b	0.21b	23.4a
Parkia biglobosa	2.65b	16.7b	8.2b	0.75a	0.49b	0.22b	19.0b

Furthermore, according to Oyebamiji *et al*. (2016a & b: 2017b), 56% of the N in the litter was released the first 2 weeks of biomass incubation and progressively increased in the following weeks after incorporation (Figure 16). The decomposition rate constant ranged from 9.18 to 15.07 g per week and the rate of plant residue decomposition was higher in *Albizia lebbeck* than in *Parkia biglobosa* (Table 42).

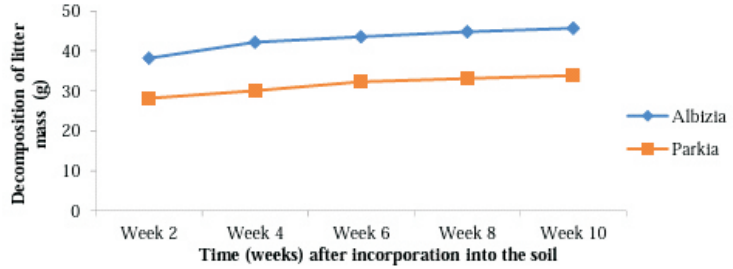

Figure 16: Weight loss of A. lebbeck and P. biglobosa leafy biomass over a period of 10 weeks

Source: Oyebamiji *et al*., 2017b

Table 42: Decomposition rate (kD) and N release (kN) constants and t heir coefficients of determination (R^2) values for the different residues in the semi-arid of Nigeria

Season	Plant residue	*kD*	R^2	*kN*	R^2
2014	*Albizia*	15.07a	0.98	10.81a	0.99
	Parkia	9.18b	0.98	7.92b	0.99
2015	*Albizia*	15.00a	0.93	10.67a	0.98
	Parkia	10.69b	0.93	7.85b	0.98

Source: Oyebamiji *et al*., 2016a

In Oyebamiji *et al*. (2022), we posited that because of the higher contents of N (32.4) and C (186.4 gkg-1) and lower C:N ratio (57.5) and polyphenol than in *Parkia biglobosa*, the decomposition rate in *Albizia lebbeck* was faster and N uptake in maize was higher (8.6 kg N ha^{-1}) compared to *Parkia biglobosa* (2.8 kg N ha^{-1}), and this had significant impact on maize growth and yield.

In Olowoboko *et al*. (2019, 2018a &b), we evaluated the effects of ashed and unashed animal manures on some chemical properties of the soil. From two weeks after application, the pH and electrical conductivity of soil were higher in soils amended with ashed cattle, goat and poultry manures than in the corresponding unashed treatments in samples taken from incubation, screenhouse and field experiments (Table 42 & 44).

Table 43: Effect of amendments on pH of soil in field experiment

Treatment	0 WAI	2 WAI	pH 4 WAI	6 WAI	8 WAI	10 WAI	LSD**
Control	5.55c	6.83c	7.06ab	7.11ab	7.20a	8.18ab	1.47
Dry cattle manure	6.15ab	6.90c	7.13ab	7.15ab	6.86a	8.15ab	0.81
Cattle manure ash	5.80abc	8.23a	7.68a	7.80a	7.28a	8.90a	1.30
Dry goat manure	6.06abc	7.05c	6.41b	7.03ab	7.15a	7.21b	0.73
Goat manure ash	5.76bc	8.10a	7.50a	7.41ab	7.30a	8.33ab	0.72
Dry poultry manure	6.38a	7.01c	6.98ab	7.13ab	6.83a	7.98ab	0.71
Poultry manure ash	5.70bc	7.60b	7.05ab	7.16ab	7.38a	8.86ab	1.04
NPK (15–15–15)	5.95abc	5.66d	6.35b	6.63b	6.36a	8.55ab	1.38

Source: Olowoboko *et al*. (2018)

Table 44: Effect of amendments on electrical conductivity of soil in field experiment

Treatment	0 WAI	2 WAI	EC 4 WAI	(dS m^{-1}) 6 WAI	8 WAI	10 WAI	LSD**
Control	0.11c	0.27d	0.10c	0.14d	0.11b	0.22e	0.072
Dry cattle manure	0.39bc	0.58d	0.27bc	0.57cd	0.39ab	0.74b-e	0.28
Cattle manure ash	0.12c	8.35a	0.88ab	1.74a	0.79a	1.31ab	1.36
Dry goat manure	0.42b	0.71d	0.17c	0.46cd	0.54ab	0.86bcd	0.29
Goat manure ash	0.21bc	4.10bc	0.95a	1.03abc	0.67ab	1.45a	1.65
Dry poultry manure	0.78a	1.04cd	0.48abc	0.54cd	0.43ab	0.66cde	0.58
Poultry manure ash	0.19bc	4.41a	0.70abc	1.44ab	0.95a	1.19abc	1.18
NPK (15-15-15)	0.13c	10.53a	0.36abc	0.67bcd	0.41ab	0.52de	2.90

Source: Olowoboko *et al*. (2018)

Incinerated manure also increased soil exchangeable cations, organic carbon, NH_4-N and NO_3-N significantly in the incubation and screenhouse studies, and insignificantly in the field experiment. The incorporation of manure ashes to soil increased

mineral N, and N release was higher in the screenhouse than in the field, suggesting that ashed manures might be more efficient under a controlled environment like greenhouse, than in the field.

Studies by Komolafe *et al*. (2021) and Adekunle *et al*. (2016) investigated the effect of plant materials and duration of composting on the fertilizer quality of compost. It was reported that composts made from cow dung in addition to maize stover or guinea grass or tridax weed gave the highest growth and yield of maize and application of 20 tha^{-1} of compost increased N and K uptake, cob weight and content of P in the final soil (Table 45).

Table 45: Mean effect of composted plant materials on yield and nutrient uptake by maize

Compost types	Fresh cob weight	Dry cob weight	Grain yield	N-uptake	P-uptake	K-uptak
		yield (t ha $^{-1}$)			(kg ha $^{-1}$)	
Maize stover compost	4.51^{a}	2.52^{a}	1.80^{a}	5840^{a}	1360^{a}	9600^{a}
Guinean grass compost	3.91^{ab}	2.08^{ab}	1.37^{ab}	5740^{a}	1420^{a}	11720^{a}
Tridax weed compost	3.2^{ab}	1.76^{ab}	1.18^{ab}	5100^{ab}	1240^{a}	9440^{a}
Siam weed compost	3.09^{b}	1.79^{b}	1.04^{b}	4820^{ab}	880^{b}	7060^{b}
Control (no compost)	2.84^{c}	1.4^{c}	0.91^{c}	2380^{b}	800^{b}	5600^{c}

Means values with the same letters along the column are not statistically different ($p \geq 0.05$) by Duncan Multiple Range Test; N - nitrogen; P - phosphorus; K - potassium

Source: Komolafe *et al.*, 2021

Popoola *et al*. (2011 & 2015) examined the use of tillage methods, varieties, and compost amendment in combating bacterial leaf spot and leaf speck diseases in tomato. The treatments included compost fortification with bactericidal plant materials namely, *Azadirachta indica* (neem), *Mangifera indica* (mango leaves) and *Chromolaena odorata* (siam weed). Soil amendment with bactericidal plant materials reduced the mean soil population of *Ralstonia solanacearum* by 4.78 x 10^{7} cfu g^{-1} soil, mean wilt incidence by 31.35%, percent severity index by 22.9 %, and increased yield by 50 % (Table 46). Disease intensity index in the variety UC82B was reduced by 57.35 % in bacterial leaf spot and 42.78 % in bacterial leaf speck (Table 47). Amendment of soil with compost fortified with bactericidal plants supported higher plant height and number of flowers significantly, consequently, yield was significantly

increased in amended plots (21.56 t/ha in amended compost plots compared to 15.28 t/ha in un-amended compost).

Table 46: Reduction in soil Ralstonia solanacearum (Rs) population at two and six weeks after application of amended compost at 2 and 6 weeks after compost application

Treatments	Soil *Rs* population ($\times 10^7$ cfu g^{-1} soil)					
	Late rainy season 2006		Early rainy season 2007		Mean	
	2 WACA	6 WACA	2 WACA	6 WACA	2 WACA	6 WACA
Soil alone	3.39	4.27	3.63	6.03	3.55	5.13
Soil + Unamended compost	4.68	6.76	4.17	4.47	4.47	5.50
Soil + Amended compost	2.45	1.26	1.70	0.16	2.04	0.45
$LSD_{0.05}$	ns	2.57	ns	2.04	NS	2.29
Reduction in *Rs* population[1]	0.94	3.01	1.93	5.87	1.51	4.68

ns = not significant
[1] Reduction in *Rs* population = *Rs* population in Soil alone – *Rs* population in Soil + Amended compost

Source: Popoola *et al*., 2015.

Table 47: Effect of compost application on the incidence and severity of bacterial wilt in two varieties of tomato

Cultivar	Compost application	Late rainy season 2006[1]		Early rainy season 2007		Mean	
		I (%)	PSI (%)	*I* (%)	PSI (%)	*I* (%)	PSI (%)
'Beske'	No compost	84.90	67.62	44.10	25.42	64.40	46.46
	Unamended compost	81.10	64.59	48.45	27.92	64.78	46.26
	Amended compost	41.80	33.29	22.50	12.97	32.15	23.13
		(43.10)	(34.33)	(21.60)	(12.45)	(32.25)	(23.33)
'UC82B'	No compost	79.80	63.55	42.90	24.73	61.35	44.14
	Unamended compost	88.70	70.64	42.55	24.52	65.63	47.58
	Amended compost	35.00	2.88	26.80	15.45	30.90	21.67
		(44.80)	(60.67)	(16.10)	(9.28)	(30.45)	(22.47)
$LSD_{0.05}$	Cultivars (V)	ns	ns	ns	ns	ns	ns
	Composts (C)	12.24	7.43	5.42	3.12	8.83	5.28
	V × C	ns	ns	ns	ns	ns	ns

ns = not significant
[1] *I* (%) = percentage incidence of bacterial wilt; PSI = percent severity index (Cooke 2006)

Source: Popoola *et al*., 2015

3.0 CONCLUSION

Mr. Vice Chancellor Sir, my research findings have demonstrated that soil microorganisms are nature's gift to humankind for sustainable agricultural productivity and environment. Their activities are wide and far reaching. Evolutionary studies have clearly shown that the evolution of plant from aquatic to terrestrial species was largely possible because of mycorrhizal fungi. Soil scientists are also conversant of the fact that microorganisms make up a very important component of **organisms** that are regarded as one of the five factors of soil formation. Microorganisms are

usually the first colonizers of habitats devoid of organic matter (such as parent materials, like rocks), many of such microbes especially Archaea, green algae and *Cyanobacteria* are phototrophs, nitrogen fixers or both. Their activities prepare the habitat for the eventual growth of plants, which leads to increase in organic matter and gradual increase in the populations of plants and other organisms.

Many soil processes that are of major importance to agricultural soil productivity are carried out by soil microbes. These include biological nitrogen fixation (symbiotic and non-symbiotic), organic matter decomposition, nitrification, denitrification, mineralization of P and S, immobilization of N, detoxification of some organic compounds, disease suppression through production of antimicrobials etc.

Organic agriculture is a crop production system which excludes the use of all synthetic compounds as inputs, and it is perceived as a more sustainable food production system, a source of healthier and more nutritious food, and contributes largely to a healthier environment. Soil microorganism are the major agents of productivity in this self-sustaining system, and organic farmers are aware that farm activities must be tailored towards providing optimum conditions for these microbes to thrive.

It is therefore imperative to make deliberate and determined efforts in protecting these microbes and maximizing their positive effects on food production. It is known that climate change and some anthropogenic activities are adversely affecting the existence of some organisms including microorganisms, therefore it is becoming increasingly important to assess the effect of these on soil microorganisms, established soil microbiologist are of the opinion that many useful soil microbes are already extinct or endangered.

4.0 RECOMMENDATIONS

1. Strengthening basic and applied research as well as extension activities

Mr. Vice Chancellor Sir, I commend the efforts of FUNAAB in creating conducive environment for research by providing research facilities and assisting staff to obtain research funding, thereby enhancing research activities. However, a lot still needs to be done with regards to providing research facilities, such as well-equipped laboratories, research farm with irrigation facilities, availability of needed agricultural inputs and support staff. There is also the need to intensify efforts on obtaining research funding.

Many of our research efforts have demonstrated high agricultural potentials of some materials, however many of these materials have not been packaged into adaptable technologies that can be made available to farmers. There is therefore the need for more applied research to translate successful basic research into inputs that farmers can use, there is also the need for strong collaboration between researchers and agricultural extensionists.

2. Policy on agricultural practices in Nigeria should promote sound management of soil organic matter.

Soil organic matter is termed the 'life blood' of the soil and it is key to realizing optimal productivity of the soil, therefore it is imperative that crop production systems that promote high levels of organic matter in the soil should be encouraged through policy formulation. Soil is both a source and a sink of carbon. As a source of organic carbon, it provides the much-needed macro and micronutrients for crop growth, development, and yield. Soil is also a sink for carbon because carbon dioxide from the atmosphere is converted to organic compound and deposited into the soil where it is processed to organic carbon and stored for a very long period, and thereby mitigating the negative impact of atmospheric carbon on the environment.

3. There is need for government support for organic farming.

Organic agriculture requires a more deliberate and concerted support from all stakeholders, to encourage farmers' adoption and participation. This production system tends to promote soil health, ecosystem services, food safety and environmental health.

4. Conservation agriculture should be encouraged and promoted.

Farmers should be encouraged to embrace soil conservation practices such as: conservation tillage, cover cropping, crop rotation, intercropping and soil erosion control. These practices tend to protect and preserve the soil resources, thereby enhancing their contributions to soil productivity.

5.0 ACKNOWLEDGEMENTS

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All my life you have been faithful,
All my life you been so, so good,
With all the breath that I am able,
I will sing of the goodness of God.
(2 X)

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