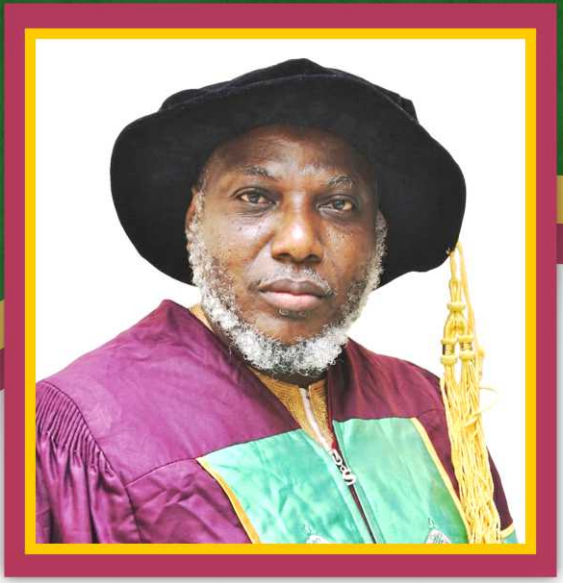
Ahmadu Bello University, Zaria

FROM SOIL CHEMISTRY TO SUSTAINABLE LAND MANAGEMENT: Bridging Environmental Quality, Nutrient Dynamics and Agricultural Resilience in Nigeria

AN INAUGURAL LECTURE

Series No. 06/26



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DATE WEDNESDAY, 2ND SEPTEMBER, 2026

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Dedication

To the loving memory of my mentor, late Sheikh Muhammad Auwal Adam Albaniy Zaria who was assassinated by unknown assailants.

Acknowledgements

I acknowledge the contributions of my teachers, mentors, colleagues, collaborators, students, professional societies, institutions, and family members whose support has shaped my academic journey.

I remain particularly grateful to Ahmadu Bello University, Zaria, for providing the intellectual environment necessary for scholarship and scientific growth.

I also acknowledge the numerous national and international collaborators, research institutions, farming communities, and professional organizations that contributed directly or indirectly to the success of the research activities summarized in this lecture.

I am especially grateful to Professor B.A. Raji for being much more than a mentor. You have been a father figure, a guardian, and a dependable source of strength, particularly during challenging times in the Department. Your guidance, generosity, and unwavering support have left an enduring mark on my academic and personal development.

May Almighty Allaah abundantly reward you for your kindness, preserve you in good health and faith, and continue to bless you with wisdom, strength, and a life filled with goodness. Aameen.

To my Executive Director, I express my profound gratitude for your mentorship, trust, and untiring support over the years. Beyond being my superior, you have been a valued colleague, an associate, and a partner in progress throughout much of my academic journey. Your guidance, particularly during our formative years as young academics, was instrumental in

shaping my appreciation of the rigor, ethics, and standards of scientific research and scholarly publishing.

I am especially grateful for the confidence you reposed in me by recommending me for appointment to serve as your Deputy. This trust has been both a great honor and a source of motivation to strive for excellence in service. I remain eternally grateful for your mentorship, encouragement, and the opportunities you have afforded me. May Almighty Allaah continue to bless you with wisdom, good health, and abundant rewards for your invaluable contributions to my professional growth.

To my Vice-Chancellor, I sincerely appreciate your unwavering support, visionary leadership, and steadfast commitment to the advancement of Ahmadu Bello University. Your inclusive and transformational leadership style has been instrumental in the unprecedented growth and remarkable progress currently being witnessed at both the Institute for Agricultural Research and the University at large.

I am deeply grateful for the confidence you have placed in me and for the enabling environment you have created for academic excellence, innovation, and institutional development. I pray that Almighty Allaah continue to guide your decisions, strengthen your wisdom and intuition, and grant you the strength, good health, and foresight to lead the University to even greater heights. Aameen.

I remain eternally grateful to my revered mentor and distinguished scholar, the late Sheikh Al-Muhaddith Muhammad Auwal Adam Albaniy of Zaria, for his immeasurable impact on my life. He was instrumental in nurturing my spiritual development and made invaluable contributions to my academic journey. May Almighty Allaah

continue to shower His mercy upon him and grant him the highest place in Jannatul Firdaus.

I am profoundly indebted to my brothers, Alhaji Abdurrasheed and Alhaji Abdulhakim, who ensured that I never lacked the resources needed during my preparation for the Senior Secondary Certificate Examination. Their sacrifices and unwavering support laid a solid foundation for my educational pursuits.

My heartfelt appreciation also goes to my beloved sister, Aunty Ta'ibat, who shouldered the financial responsibility of my undergraduate education. Her generosity and belief in me remain a source of lasting inspiration. To my other siblings, too numerous to mention individually, I sincerely thank you for your prayers, encouragement, and unwavering support throughout my academic and professional career.

To my in-laws, I express my deepest gratitude. Your constant prayers, goodwill, and encouragement have been invaluable to my success. May Almighty Allaah abundantly reward you all.

I wish to pay special tribute to my twin brother from other parents, Professor Jamilu Ya'u of the Department of Pharmacology and Therapeutics. Your friendship, loyalty, and unwavering support have been a priceless gift. I pray that Almighty Allaah preserves our bond in this world and reunites us in Jannatul Firdaus.

The Noble Prophet Muhammad (peace and blessings be upon Him) said that whoever is blessed with a righteous wife has been granted one of the greatest blessings of this world. By the infinite mercy of Allaah, I have been blessed with four righteous wives. To my four beloved queens, your love, sacrifices, patience, prayers, encouragement, and unwavering care have been indispensable to every success I have recorded.

You have stood by me through every challenge and every triumph. May Almighty Allaah reward you abundantly, preserve our love and unity, and reunite us all in Jannatul Firdaus.

To my beloved parents, Alhaji Abdulganiyu Raji and Hajia Sa'adatu Abdussalam, words can never adequately express my gratitude for the priceless gift of life and the sacrifices you made in nurturing and shaping me into the person I am today. My late father, your values, guidance, and prayers continue to illuminate my path even in your absence. May Almighty Allaah forgive your shortcomings, expand and illuminate your grave, and grant you the highest station in Jannatul Firdaus.

To my dear mother, your unconditional love, prayers, resilience, and countless sacrifices have been the bedrock of my success. Whatever I have achieved today is, in no small measure, a reflection of your unwavering support and devotion. May Almighty Allaah preserve you in good health, strengthen you in faith, bless you with a long and fulfilling life, and allow you to continue reaping the fruits of the seeds you have sown in your children. Aameen.

Above all, my greatest gratitude belongs to my Lord, Allaah, the Almighty, the Creator and Sustainer of the heavens and the earth, to Whom belongs all dominion, majesty, and perfection. Every blessing I have received is from Him alone, and His favors upon me are beyond measure. All praise is due to Him in the beginning and in the end. May His Name forever be exalted and glorified, and may He accept this modest contribution as an act of sincere devotion to Him. Aameen.

Thank you

Protocols

The Vice-Chancellor, Principal Officers of the University, Members of Senate, Distinguished Professors and Colleagues, Students, Invited Guests, Ladies and Gentlemen.

It is with gratitude to Almighty Allaah and a profound sense of responsibility that I stand before this distinguished audience to deliver this inaugural lecture. This lecture represents not merely a personal academic journey, but a collective intellectual effort involving mentors, colleagues, students, institutions, collaborators, farming communities, and development partners whose contributions have shaped my research trajectory over the years.

My academic and professional journey has revolved around one central scientific concern: understanding the chemistry of soils and their interactions with nutrients, contaminants, water, plants, microorganisms, and the environment. The overarching objective has been to contribute scientific knowledge capable of improving agricultural productivity, safeguarding environmental quality, and enhancing the sustainability of land resources in Nigeria and beyond.

This lecture synthesizes the major themes, findings, implications, and future directions emerging from my scholarly contributions in soil chemistry, environmental chemistry, nutrient management, soil contamination, geochemistry, and sustainable land use.

FROM SOIL CHEMISTRY TO SUSTAINABLE LAND MANAGEMENT: Bridging Environmental Quality, Nutrient Dynamics and Agricultural Resilience in Nigeria

1. INTRODUCTION

Soil remains one of humanity's most strategic natural resources. It supports food production, regulates water flow, stores carbon, cycles nutrients, sustains biodiversity, and serves as the foundation for terrestrial ecosystems. Soil functions as a major sink for numerous natural biogeochemical processes, including the decomposition and burial of dead plant, animals, and humans. Through its physical, chemical and biological properties, soil facilitates the stabilization, transformation, and recycling of organic matter and associated nutrients. In the absence of this buffering and assimilative capacity, the accumulation of dead organic materials on land surface could constitute a significant source of environmental pollution, public health hazards, and ecosystem degradation. Yet, despite its importance, soils in many developing countries face enormous threats arising from nutrient depletion, erosion, salinity, acidification, contamination, urbanization, mining, and climate change.

Nigeria, like many tropical countries, faces severe challenges associated with declining soil fertility, poor nutrient use efficiency, environmental pollution, and unsustainable land management practices. According to the FAO, 43% of the Nigeria's total landmass is degraded while about 33% of the general soil health is faced with severe degradation. Fertilizer use is very poor leading to low efficiency with a marginal physical product of about 8 kg of grain for maize and 9 kg for rice per kilogram of applied nitrogen. The soils are also faced with severe phosphorus deficiency due to high rate of fixation,

intensive weathering and continuous cropping. These challenges are intensified by rapid population growth, expansion of agriculture into fragile ecosystems, industrialization, artisanal mining activities, and inadequate environmental regulation.

My research over the years has therefore focused on answering numerous critical scientific questions:

1. How do nutrients behave in tropical soils?
2. What controls phosphorus fixation and nutrient availability?
3. How do contaminants interact with soil components?
4. What are the ecological and human health risks associated with contaminated soils?
5. How can biochar and other amendments improve soil quality?
6. What roles do soil microorganisms play in environmental remediation?
7. How can geochemical tools support sustainable land management?
8. How can soil science contribute to climate resilience and food security?
9. How can nanomaterials improve nutrient availability, environmental remediation and agricultural sustainability?

The answers to these questions have shaped my research philosophy and scientific contributions.

2. ACADEMIC AND RESEARCH JOURNEY

The aspiration to become a professor was formed during my first year as an undergraduate student. Guided by this vision, I devoted myself to academic excellence, professional development, and sustained scholarly productivity, ultimately achieving the goal I had set for myself at the beginning of my academic journey.

My journey as a teacher began during my second year as undergraduate at Ahmadu Bello University, Zaria. Driven by a passion for teaching and community service, I devoted my weekends to voluntarily teaching Chemistry to secondary school students at the Muslim Refresher Course Programme in Tudun Wada, Zaria. This rewarding experience spanned seven years and laid the foundation for my lifelong commitment to education and mentorship.

My passion for teaching continued during my National Youth Service Corps (NYSC). Although I was initially posted to a different organization, I specifically requested a rejection letter and was consequently redeployed to Federal Government Girls College, Bauchi, where I had the privilege of teaching Agricultural Science. This deliberate decision reflected my conviction that teaching is not merely a profession, but a calling through which I could inspire young minds and contribute meaningfully to national development.

Upon completing my NYSC, I briefly taught at Sardauna Memorial Nursery and Primary School, Tukur Tukur, Zaria. This experience, coupled with my earlier teaching engagement at the secondary school level and my subsequent academic career in higher education, has given me a rare privilege of serving as an educator across all tiers of the education system. These experiences have shaped my philosophy of teaching and learning and, I believe, qualify me as a true educator who understands the unique needs, challenges, and aspirations of learners at every stage of their education journey.

My academic training in Soil Science at Ahmadu Bello University provided the foundation for my interest in soil chemistry and nutrient dynamics. Further doctoral and postdoctoral training at the University of Kassel, Germany expanded my exposure to environmental chemistry, risk

assessment, urban agriculture, contaminant dynamics, and interdisciplinary environmental research.

During my PhD and postdoctoral research, I had the opportunity to undertake extensive fieldwork across several West African countries and Europe. My research activities took me to cities such as Leuven, Belgium, Bobo-Dioulasso and Ouagadougou in Burkina Faso, Tamale in Ghana, Sikasso in Mali, and Cotonou in the Republic of Benin. These experiences not only enriched my scientific understanding of diverse agroecological systems but also broaden my intellectual horizons through exposure to different cultures, traditions, and civilizations.

They strengthened my appreciation of the interconnected nature of environmental challenges across West Africa and underscored the importance of regional collaboration in advancing agricultural research and sustainable development.

Over the years, my research evolved into several interconnected thematic areas:

1. Soil chemistry and nutrient dynamics
2. The chemistry of phosphorus in tropical soils
3. Heavy metal contamination and ecological risk assessment
4. Soil-microbe-contaminant interactions
5. Biochar and soil amendments
6. Environmental geochemistry
7. Soil quality assessment and land evaluation
8. Sustainable soil management and climate resilience
9. Irrigation water quality and salinity management
10. Integrated soil fertility management
11. Nanotechnology and sustainable crop production

These research areas collectively address the broader challenge of sustainable agricultural production under conditions of environmental stress.

3. SOIL CHEMISTRY: THE FOUNDATION OF PRODUCTIVE AGRICULTURE

Soil chemistry governs the behavior and availability of nutrients and contaminants in soil systems. In tropical regions, soil chemical processes are particularly complex due to high weathering intensity, dominance of variable charge minerals, low activity clay, low organic matter contents, preponderance of iron and aluminum oxides (sesquioxides) and strong phosphorus sorption capacities. Soil chemistry governs tropical agriculture because it determines nutrient availability, soil acidity, cation exchange capacity, phosphorus fixation and precipitation, fertilizer efficiency, behavior of potentially toxic elements and the overall fertility of the soil.

My early research focused on understanding the charged properties of tropical soils and their implications for crop productivity.

The major findings from these studies include:

i. Tropical savanna soils are generally characterized by low organic matter and poor nutrient reserves.
ii. Soil acidity significantly influences nutrient availability.
iii. Exchangeable bases decline rapidly under continuous cultivation.
iv. Soil degradation processes accelerate nutrient mining.
v. Variable charge minerals strongly influence phosphorus retention.

These findings reinforced the need for site-specific nutrient management approaches rather than generalized fertilizer recommendations.

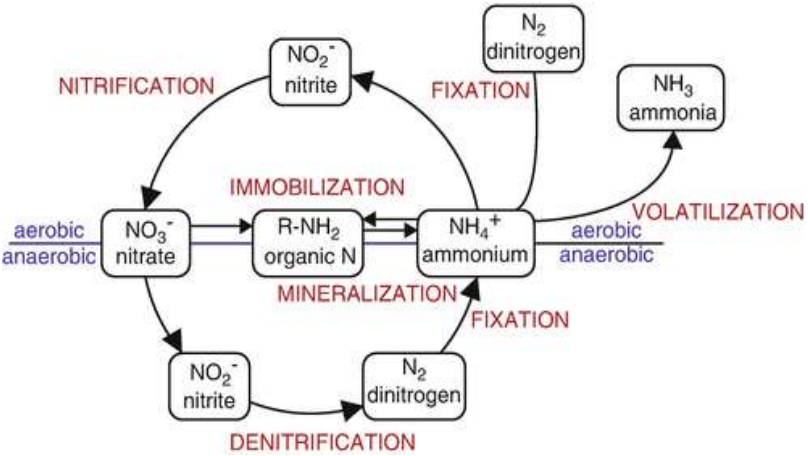

Figure 3a. A typical nutrient cycling with respect to nitrogen

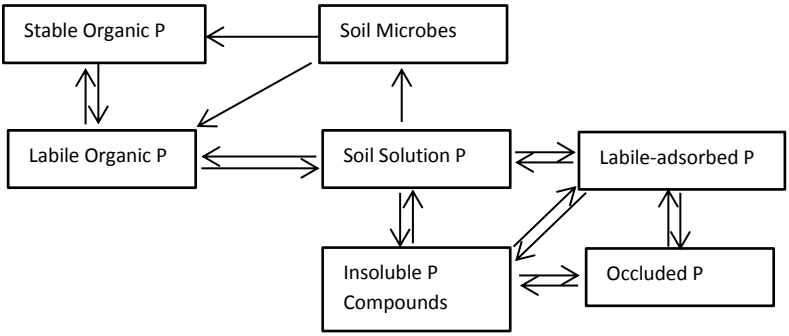

Figure 3b. A typical nutrient cycling with respect to phosphorus

4. PHOSPHORUS CHEMISTRY AND FIXATION IN TROPICAL SOILS

Among all plant nutrients, phosphorus presents one of the greatest management challenges in tropical soils. Phosphorus availability is governed by a narrow equilibrium between adsorption, desorption, precipitation and dissolution processes. Depending on soil pH, large proportions of applied phosphorus become fixed through adsorption or precipitation reactions involving iron, aluminum and manganese oxides, calcium compounds, and clay minerals.

$$P_{solution} \rightleftharpoons P_{adsorbed} \rightleftharpoons P_{precipitated}$$

Equation 1: Phosphorus transformation in the soil.

The precipitated phosphorus is converted into insoluble compounds such as iron phosphate (Fe-P), aluminum phosphate (Al-P) or calcium phosphate (Ca-P).

My research in phosphorus chemistry investigated:

i. Mechanisms of phosphorus fixation
ii. Sorption-desorption dynamics
iii. Influence of soil mineralogy on phosphorus chemistry
iv. Role of iron and aluminum oxides in phosphorus fixation and availability
v. Biogeochemistry of phosphorus in wetlands and upland soils
vi. kinetics, thermodynamics and energetics of phosphorus adsorption in soils
vii. Management strategies for improving phosphorus use efficiency

My contribution to phosphorus chemistry includes the following:

1. The studies shifted phosphorus management from static equilibrium concepts to dynamic kinetic modeling, enabling more accurate prediction of fertilizer P efficiency and phosphorus stability.
2. Highly weathered soils possess enormous phosphorus buffering capacities.
3. Iron and aluminum oxides and pH are major drivers of phosphorus fixation.
4. Phosphorus sorption in tropical soils is mostly controlled by particle diffusion.
5. Although parent material often influences clay mineralogy, Fe and Al oxides, this research however, showed that parent material from which the soil is formed has no influence on phosphorus sorption.
6. The studies linked phosphorus kinetics directly to measurable soil properties. This will enable better prediction of phosphorus availability and more informed fertilizer recommendations for tropical soils.
7. Wetland hydrology significantly alters phosphorus mobility.
8. Soil organic matter can either enhance or suppress phosphorus availability depending on environmental conditions.
9. Concretional nodules act as sinks for phosphorus sorption in non-responsive soils.
10. Integrated nutrient management improves phosphorus efficiency.

Our research on wetland soils provided one of the first comprehensive pedogeochemical characterizations of wetland soils in the Hadejia-Jama'are Basin which is an international Sahel wetland ecosystem. It revealed important biogeochemical relationships among phosphorus, iron, and aluminum under

fluctuating redox conditions. These findings are particularly important for irrigation agriculture and floodplain management in Nigeria.

The broader implication of this work is clear: improving phosphorus efficiency is critical for achieving sustainable food production, environmental management and reducing fertilizer losses.

My research on phosphorus chemistry culminated in the publication of several scholarly articles in high-impact, peer-reviewed international journals, many of which are ranked in the first quartile (Q1).

These publications have contributed to advancing knowledge on phosphorus dynamics, fixation mechanisms, and nutrient management in tropical soils, while providing scientific evidence to support sustainable soil fertility management and enhanced agricultural productivity. They have become important references in soil chemistry, pedogeochemistry, phosphorus dynamics, and tropical soils fertility, contributing both regionally and internationally to the understanding of phosphorus behavior in highly weathered tropical soils.

5. HEAVY METALS, SOIL CONTAMINATION, REMEDIATION AND ECOLOGICAL RISK

One of the major dimensions of my research has focused on environmental contamination and pollution resulting from mining, industrial activities, waste disposal, urban agriculture, and agricultural intensification. In most cases, contamination often lead to soil pollution that can cause harm to the entire ecosystem and hence remediation of heavy metal contaminated soils was also a focus of my research.

Particular attention was given to heavy metals such as:

Lead (Pb)
Cadmium (Cd)
Zinc (Zn)
Copper (Cu)
Chromium (Cr)
Nickel (Ni)
Arsenic (As)

Studies conducted in mining-affected regions, particularly in northern Nigeria (Dareta and Bagega villages in Anka and Bukuyyum Local Government Areas of Zamfara State), revealed alarming levels of heavy metal accumulation in soils.

Assessment of heavy metal contamination under urban vegetable production was also extensively studied in three West African cities of Kano, Nigeria, Bobo-Dioulassou, Burkina Faso and Sikasso, Mali.

A major novelty of my research on heavy metals in these soils was establishment of a soil-metal balance, representing the first comprehensive study of its kind in West Africa. The research also pioneered the quantification of human exposure to heavy metals by estimating dietary intake through vegetable consumption, dust inhalation, and the average daily dose of heavy metal ingestion among residents of Kano, Nigeria. These findings generated critical baseline data for evidence-based environmental management, food safety and public health policy in the region.

Our ecological risk assessment studies showed that:

- Artisanal mining activities significantly elevate heavy metal concentrations.
- Long-term wastewater irrigation may cause health risk

to producers and consumers.

- Wastewater irrigation is a major route of food chain contamination.
- Contaminants accumulate in agricultural soils and food crops.
- Soil properties strongly influence metal mobility and bioavailability.
- Children and vulnerable populations face substantial health risks leading to several deaths.
- Long-term contamination threatens food security and ecosystem health.
- The need for urgent legislation on use of untreated wastewater for food production.

A major contribution of this research area was the application of integrated ecological risk assessment models for evaluating contaminated soils.

These models include:

- Contamination Factor
- Geo-accumulation Index
- Enrichment Factor
- Ecological Risk Factor (Hakanson Model)
- Potential Ecological Risk Index

Table 5.1. Risk assessment tools (Abdu and Yusuf., 2012)

Carcinogenic and non-carcinogenic risk for ingestion and inhalation of heavy metals were calculated using the following formulas (USEPA, 2005):

Carcinogenic CDI (mg kg^{-1} day^{-1}) = CS x IF x EF/AT

where IF = (IR x ED/BW) Adult + (IR x ED/BW) Child

Non-carcinogenic CDI (mg kg^{-1} day^{-1}) = CS x IN x EF x ED/BW x AT

CDI (Dust inhalation) for carcinogenic and non-carcinogenic risk were calculated using the relation:

$$\text{CDI (mg m}^{-3}) = \frac{\text{CS x IF x EF (1/PEF + 1/VF)}(ET_{Outdoor} + (ET_{Indoor}DF_{Outdoor})}{AT}$$

Table 5.2. Risk assessment terms and their values (Abdu and Yusuf., 2012)

Variable	Value	Variable	Value
CS = Concentration of heavy metal in soil		IR = Ingestion rate (Adult)	100 mg/day
IF = Intake factor	-	IR = Ingestion rate (Child)	200 mg/day
EF = Exposure frequency	350 days/year	BW = Body weight (Adult)	60 kg
AT = Averaging time	365 days/year	BW = Body weight (Child)	15 kg
ED = Exposure duration (Adult)	30 years	IN = Inhalation rate (Adult)	3.6 m^3/hour
ED = Exposure duration (Child)	6 years	IN = Inhalation rate (Child)	2.2 m^3/hour
PEF = Particulate emission factor	1.3 x 10^9 m^3/kg	$ET_{Outdoor}$ = Exposure time	0.68
VF = Volatilization factor	11 m^3/kg	ET_{Indoor} = Exposure time	0.07
DF = Dilution factor indoor	0.4		

Volatilization and particulate emission factors are dependent on the climate of the region under study and were calculated based on the mean atmospheric humidity of 9.1 g of water per m^3 of air.

These indices are the most widely used tools in environmental pollution and ecological risk assessment studies because they help determine whether contamination exists, its source, severity and potential ecological consequences. Using these indices together produces a more robust and scientifically defensible environmental risk assessment.

These studies provided scientific evidence supporting environmental monitoring and remediation policies in mining-impacted communities. They provided one of the most comprehensive ecological risk assessments of mining-impacted soil in Zamfara. The studies identified the principal pollutants and distinguished contaminants hotspot.

Importantly, our work emphasized that contamination is not merely a chemical issue; it is also a social, security, economic, and public health challenge.

6. HEAVY METALS AND SOIL MICROORGANISMS

An important extension of my environmental chemistry research examined interactions between heavy metals and soil microbial communities. Soil microorganisms are essential in biological remediation of contaminated soils. They are central to nutrient cycling, organic matter decomposition, soil aggregation, and ecosystem stability. Heavy metals have profound effects on soil microbial biomass because they interact with microbial cells, soil minerals, and soil organic matter. Heavy metals interact with soil microbes either through adsorption into microbial cell walls, direct entry into microbial cells, binding to proteins and enzymes, interaction with nucleic acids or generation of reactive oxygen species (ROS).

However, heavy metals can disrupt microbial metabolism and reduce biological activity. They generally reduce microbial biomass, species diversity, population density and microbial community stability.

Our investigations demonstrated that:

- Soil microorganisms are essential components of biological remediation of contaminated soils.
- Heavy metal contamination suppresses microbial biomass.
- Enzyme activities decline significantly under metal stress.
- Soil respiration is affected by contaminant toxicity.
- Some microbial communities develop tolerance mechanisms.
- Organic amendments can moderate toxic effects.
- Some microorganisms evolve metal-resistance mechanisms that enable them survive heavy metal contamination and pollution and hence can be harnessed for bioremediation.

This research helped establish stronger links between soil chemistry and soil biology.

The findings also highlighted the importance of biological indicators in environmental monitoring and soil quality assessment.

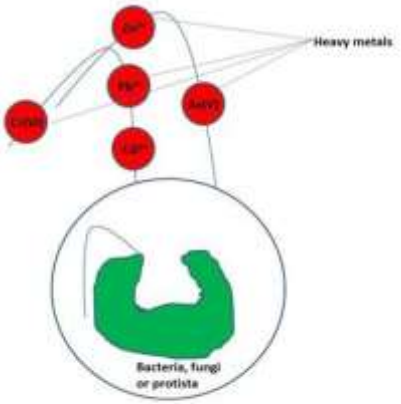

Figure 6.1. Microbial utilization of heavy metal through ingestion and subsequent removal or detoxification of the heavy metal. The microbes ingest, solubilize and assimilate the metal into its biological system. (Abdu et al., 2017)

Figure 6.2. Toxic effects of heavy metals on various stages of plant growth. (Abdu et al., 2017)

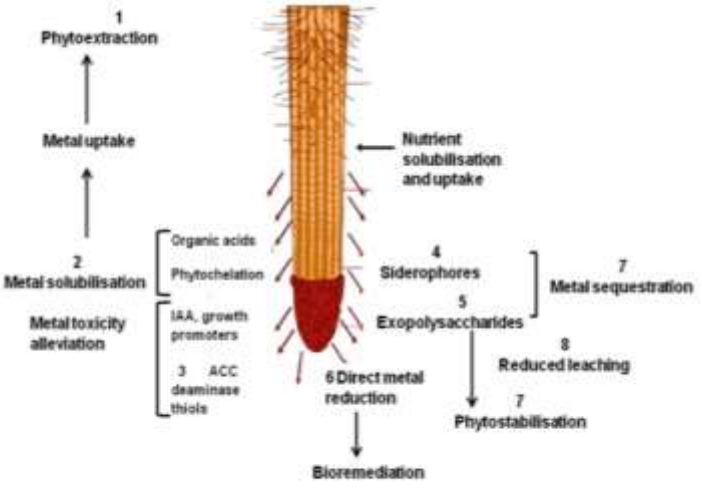

Figure 6.3. Mechanisms of heavy metal remediation by soil microbe (Abdu et al., 2017)

7. BIOCHAR, ADSORPTION PROCESSES AND ENVIRONMENTAL REMEDIATION

One of the emerging areas of my research has been the application of biochar for soil improvement and contaminant remediation.

Biochar possesses unique physical and chemical properties including:

1. Large surface area
2. High adsorption capacity
3. Porous structure
4. Numerous functional surface groups
5. Variable cation exchange properties

Table 7.1. Biochar characterization (Abdu et al., 2025)

Parameters	Maize cob MCB	Rice husk (RHB)	Cow dung (CDB)	Poultry litter (PLB)
pH (1:10 Biochar: H_2O)	10.3	7.90	7.60	7.80
pH (1:10 Biochar:0.01M $CaCl_2$)	9.50	7.20	7.10	7.50
EC (dS m^{-1})	3.50	2.70	2.60	3.10
Bulk density (Mg m^{-3})	0.41	0.41	0.35	0.58
Moisture content (%)	1.90	1.32	1.67	1.66
Biochar yield (%)	23.6	30.1	33.8	31.4
pH_{ZPC} (NaCl)	8.00	6.90	6.70	6.90
pH_{ZPC} (KCl)	8.00	6.90	6.80	6.90
Total ash (g kg^{-1})	690	490	589	480
Total C (g kg^{-1})	292	395	300	400
Volatile matter (%)	0.66	0.65	1.45	1.36
Nitrate (mg kg^{-1})	16.55	7.98	8.21	6.19
specific surface area ($cm^2 g^{-1}$) (Langmuir)	2.74×10^3	3.11×10^3	2.96×10^3	2.90×10^3

Our studies on nitrate adsorption by biochar demonstrated that biochar can significantly influence nutrient retention and environmental quality. Nutrient adsorption by biochar can

either be through specific adsorption as a result of inner-sphere complexation that may involve direct ligand exchange and a complex covalent bond or non-specific adsorption through an outer-sphere complexation involving weak electrostatic adsorption.

Studies on the influence of biochar on phosphorus and heavy metals adsorption, kinetic and thermodynamic analyses showed that:

- Biochar adsorption behavior depends on feedstock type.
- Surface chemistry influences phosphate and nitrate retention.
- Adsorption mechanisms involve both physical and chemical processes.
- Biochar can reduce nutrient losses from agricultural systems.
- Biochar application improves soil chemical properties.
- Biochar effectively immobilizes heavy metals in the soils thereby reducing plant metal uptake and soil contamination.

This work contributes to global discussions on climate-smart agriculture, carbon sequestration, nutrient recycling, and sustainable soil management.

The implication is that biochar may serve as a low-cost multifunctional amendment capable of simultaneously improving soil fertility and mitigating environmental pollution. This research also shifted the focus from simply producing biochar to designing biochar with targeted properties for environmental remediation.

8. ENVIRONMENTAL GEOCHEMISTRY AND LAND USE DYNAMICS

Another major component of my research has focused on environmental geochemistry and the influence of land use change on soil properties. Pedogeochemical cycling, landscape processes and weathering are interconnected in soil chemistry. They collectively determine the formation, transformation, movement, and fate of chemical elements in soils. During weathering, nutrients and ions are released which becomes raw materials for soil chemical reactions. These chemical elements undergoes movement and transformation within the soil profile in a process of pedogeochemical cycling involving several processes such as dissolution, adsorption-desorption, oxidation-reduction, precipitation, immobilization etc. These reactions regulate nutrient availability, heavy metal mobility, soil pH, soil salinity, cation exchange capacity and overall soil fertility. The soil materials generated through weathering and pedogeochemical cycling are redistributed across the landscape through processes like erosion, runoff, sedimentation, mass movement and so on.

Weathering supplies the soil chemical constituents, pedogeochemical cycling governs their transformation and redistribution within the soil, and landscape processes control their movement across terrains. These three processes in combination determine the chemical composition, fertility, contaminant behavior and long-term evolution of soil.

Land use conversion significantly modifies soil organic carbon, nutrient distribution; trace element dynamics soil acidity, aggregate stability, and hydrological processes

My research findings further corroborate several impacts of land use type on soil quality such as degradation of soil quality as a result of continuous cultivation, acceleration of nutrient

depletion due to deforestation, soil compaction and nutrient cycling alteration as a result of grazing, modification of trace metals distribution as a result of expanding urbanization and improvement of long-term soil resilience resulting from sustainable land management.

These studies emphasized the need for integrated land use planning and landscape-level soil management.

9. SOIL QUALITY ASSESSMENT AND LAND EVALUATION

Scientific land evaluation is fundamental for sustainable agriculture. My collaborative work in soil survey, land capability assessment, and land suitability evaluation focused on improving decision-making for agricultural production systems. I have conducted numerous land evaluation studies for private, corporate and public organizations in addition to researches undertaken for scientific publications. These studies have supported evidence-based land-use planning, agricultural development, and sustainable natural resource management.

My specific contribution to soil quality assessment include the evaluation of the suitability of Oil palm and Shea butter tree plantation pilot project site at Shakawatu for sugar beet production. This was done for the Raw Material and Research Development Council at Shakwatu, Bosso Local Government Area of Niger State. We used eight site specific criteria (temperature, soil depth, slope, drainage, texture, pH, salinity, and % organic matter) and applied weighted multi-criteria evaluation (MCE) technique in a geographic information system (GIS) environment to evaluate land suitability for sugar beet cultivation.

Sugar beet suitability map was prepared by integrating various parameters through weighted overlay analysis. The map was

categorized as highly suitable (S1), moderately suitable (S2) and marginally suitable (S3). The analysis revealed that of the total cultivable land of the study area (27.83ha), largest area (21.89 ha, 78.74%) was moderately suitable and marginally suitable (5.88 ha, 21.15%) for sugar beet cultivation. Excessively/poorly drained soils, temperature and nutrient availability were the major limiting factors responsible for variation in the land suitability for sugar beet cultivation in the survey area. For successful sugar beet production, there is need to construct ridges and drainage systems while balance of major nutrients required by sugar beet should be sourced from mineral and organic fertilizers and applied in recommended dosage. The study showed effectiveness of integrated GIS and MCE approach for land suitability analysis of sugar beet.

Another major contribution was on suitability assessment of the Ahmadu Bello University Farm.

This aspect of research integrated soil morphology, soil physical and chemical properties, geospatial analysis, water quality assessment, and crop suitability evaluation

These studies provided evidence based information that shows how soil variability significantly affects agricultural productivity, improvement of fertilizer recommendations through spatial assessment, dependence of irrigation suitability on both soil and water quality, and the role of sodium adsorption ration (SAR) and salinity in irrigation management.

$$\text{SAR} = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$$

Sodium adsorption ratio is essential in soil quality assessment and land evaluation because it is an index of soil sodicity, soil structural stability, soil permeability and influences water availability and soil aeration. High sodium level in the soil

slows down organic matter decomposition making nutrient cycling less effective. It helps in classifying irrigation water according to sodicity risk, prediction of long-term soil degradation and possible management requirements. SAR is a key soil chemical property that affects cation exchange capacity (CEC), exchangeable sodium percentage (ESP), clay dispersion, soil pH and nutrient availability.

Our land evaluation efforts contributed practical information for agricultural planning, irrigation development, sustainable land allocation, crop suitability assessment, and precision soil management.

10. INTEGRATED SOIL FERTILITY MANAGEMENT

One recurring conclusion across my research is that no single intervention can sustainably solve soil fertility problems in tropical agriculture.

This realization informed my engagement with Integrated Soil Fertility Management (ISFM).

ISFM combines several aspects of soil fertility management practices such as mineral fertilizers, organic amendments, crop residue management, biological inputs, improved agronomic practices and site-specific recommendations

My research and extension activities concluded that combining organic and inorganic nutrient sources improves nutrient efficiency, soil organic matter restoration enhances long-term productivity, farmer participation is essential for technology adoption, fertilizer optimization improves economic returns and that climate-smart nutrient management enhances resilience.

One major achievement of my research is the development of fertilizer optimization tool for soils of the Nigerian

agroecologies. In addition to this, we were able to establish method-specific recovery factors (RFs) for different analytical methods used for soil organic carbon determination. These recovery factors allow researchers to correct measured SOC values and improve comparability among laboratories using different analytical procedures.

This body of work aligns strongly with sustainable intensification goals for African agriculture.

Figure 12.8: Fertilizer optimization tool

Figure 10.1. Fertilizer optimization tool (Tarfa et al., 2016)

Another significant contribution of my research in soil fertility management culminated in the publication of a scientific research article in a leading Q1 journal on the determination of soil organic carbon in Nigerian soils. Soil organic carbon is one of the most important indicators of soil quality and fertility, playing a central role in nutrient cycling, carbon sequestration, and the long-term sustainability of agricultural production. This work has contributed to scientific understanding of different methods associated with organic carbon determination in highly weathered soils.

11. NANOTECHNOLOGY AND PHOTOCATALYSIS FOR SUSTAINABLE AGRICULTURE

With emerging challenges in food production and high cost of fertilizer production associated with high energy requirements and greenhouse gas emissions and the need for sustainable alternatives, my research interest shifted to the use of nanomaterials and photocatalytic nitrogen fixation in improving nutrient availability, environmental remediation, and agricultural sustainability.

Nanotechnology is not replacing conventional soil science but complementing and extending it. Conventional soil science provides the foundational understanding of soil properties and processes while nanotechnology offers advanced tools to investigate soil chemical processes at the nanoscale, improve nutrient use efficiency, remediation of contaminated soils, monitoring of soil health in real time, and promotion of sustainable land management. This makes nanotechnology an indispensable component of modern soil chemistry and environmental soil science.

The research was focused on:

- Photocatalysis and sustainable nitrogen fixation

- Use of bismuth ferrite ($BiFeO_3$) and graphitic carbon nitride (g-C_3N_4) as photocatalysts

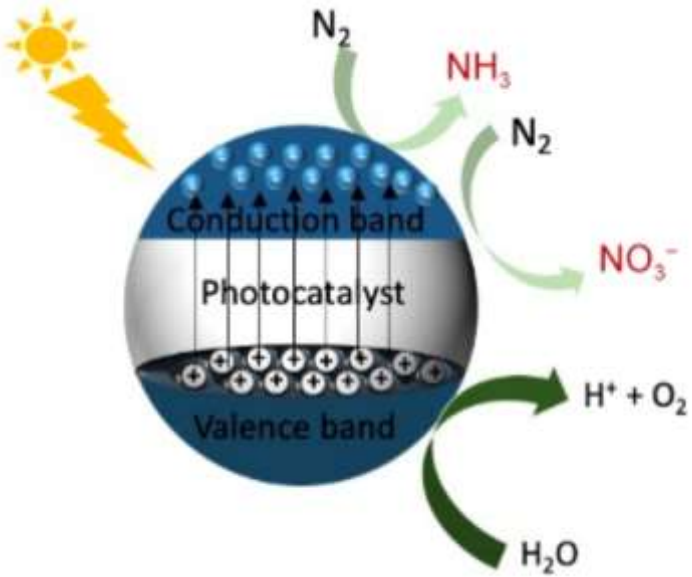

Figure 11.1. Photocatalytic reduction/oxidation of N2 to NH_3/NO_3^- (Yahaya et al., 2024)

- Green ammonia production
- Reducing dependence on industrial nitrogen fixation
- Developing or providing alternatives to Haber-Bosch fertilizer production
- Solar-driven nitrogen fixation
- Enhanced nitrogen use efficiency
- Sustainable fertilizer technologies

This research provided an earliest quantitative evidence for synthesis of photocatalysts for soil fertility management is soils of the Nigerian savanna. Our findings include the feasibility of

metal-free photocatalyst development, synthesis and characterization of nitrogen using solar radiation, visible-light photocatalytic activity, enhanced photocatalytic efficiency and improved nitrogen reduction performance.

Publications from this research provided baseline data for nanotechnology in soil fertility and soil health management in Nigeria.

12. SOIL CHEMISTRY FOR CLIMATE RESILIENCE AND NATIONAL DEVELOPMENT

Climate change presents one of the greatest threats to agricultural sustainability. Rising temperatures, erratic rainfall, flooding, drought, and land degradation are already affecting agricultural systems across sub-Saharan Africa.

My research contributions to climate resilience include:

- Soil carbon management
- Water conservation strategies
- Nutrient efficiency improvement
- Salinity management
- Wetland biogeochemistry
- Sustainable land use planning

Healthy soils are central to climate adaptation.

Soils regulate water availability, buffer climatic extremes, and support resilient cropping systems.

In this regard, soil science must occupy a central position in climate policy discussions.

13. TRANSLATING SCIENCE INTO POLICY AND PRACTICE

A major philosophy guiding my research has been that scientific knowledge must extend beyond journal publications.

Research should influence:

- Public policy
- Farmer practices
- Environmental regulation
- Extension services
- Agricultural planning
- Institutional development

This conviction informed my participation in:

- Soil quality advocacy
- Professional societies
- Farmer engagement programs
- Capacity building initiatives
- Agricultural extension activities
- National soil management discussions

The translation of scientific findings into practical recommendations remains essential for national development.


Resilience and Food Security
26th & 27th November 2025
NICON Luxury Hotel, Garki, Abuja

14. SUPERVISION, MENTORSHIP AND CAPACITY DEVELOPMENT

Academic legacy is not measured only by publications, but also by human capacity development.

One of the most fulfilling aspects of my academic career has been the opportunity to mentor and train the next generation of soil chemists in Nigeria. I am privileged to have supervised and mentored many young academics and researchers who are now contributing to teaching, research, and professional practices in institutions across the country. These include the Ahmadu Bello University, Zaria, Bayero University, Kano, Federal University of Technology, Minna, Usmanu Danfodiyo University, Sokoto, Abubakar Tafawa Balewa University, Bauchi, Federal University, Dutse, Kaduna State University, Kaduna, Modibbo Adama University, Yola; and Federal University, Wukari, among others. I take great pride in seeing my mentees make meaningful contributions to the advancement of Soil Chemistry and Soil Science in Nigeria and beyond.

15. CHALLENGES FACING SOIL SCIENCE IN NIGERIA

Despite the strategic importance of soil resources, soil science in Nigeria still faces several challenges:

1. Inadequate research funding
2. Weak laboratory infrastructure
3. Limited long-term soil monitoring systems
4. Poor soil data management
5. Low farmer access to soil testing services
6. Weak linkage between research and policy
7. Declining soil fertility across farming systems
8. Increasing environmental contamination
9. Climate change pressures
10. Limited investment in advanced analytical facilities

Addressing these challenges requires coordinated national action.

16. THE FUTURE OF SOIL CHEMISTRY RESEARCH IN NIGERIA

Future research directions should focus on:

1. Digital Soil Mapping: Advanced geospatial tools, remote sensing, and artificial intelligence should be integrated into soil resource assessment.

2. Precision Nutrient Management: Site-specific fertilizer recommendations must replace blanket fertilizer applications.

3. Climate-Smart Soil Management: Research should prioritize carbon sequestration, water conservation, and resilience.

4. Emerging Contaminants: Greater attention should be paid to microplastics, pharmaceutical residues, electronic waste, and industrial pollutants.

5. Soil Health Monitoring: Nigeria requires a national soil health monitoring framework.

6. Circular Bioeconomy Approaches: Agricultural wastes should be transformed into biochar, compost, and value-added soil amendments.

7. Phosphorus Sustainability: Given global phosphorus concerns, improving phosphorus recovery and recycling must become a national priority.

17. REPOSITIONING SOIL SCIENCE FOR NATIONAL DEVELOPMENT

Soil science must move from the background to the center of national development planning.

No nation can achieve food security, environmental sustainability, climate resilience, agricultural transformation and sustainable industrialization without sustainable soil management. Nigeria must therefore invest strategically in:

1. Soil research
2. Soil laboratories
3. Soil information systems
4. Soil extension services
5. Soil conservation programs
6. Human capacity development

The future of agriculture depends fundamentally on the future of soils.

18. CONFERENCES

Throughout my academic career, I have actively participated in numerous scientific conferences, workshops and professional training programmes in Nigeria, across Africa, and in Europe. These engagements have provided invaluable opportunities for knowledge exchange, research collaboration and professional development. My international academic activities have taken me to several countries including Republic of Benin, Mali, Burkina Faso, Ghana, Senegal, Tanzania, Spain, the Czech Republic, Germany and Belgium. These experiences have broadened my scientific perspective, enriched my research capacity, and strengthened my international collaborative network.

19. ROUTINE ADMINISTRATIVE DUTIES AND OTHER RESPONSIBILITIES

Beyond teaching, research, and community service, I have had the privilege of serving Ahmadu Bello University and other organizations in various academic, administrative, and leadership capacities.

Prior to my current appointment as the Deputy Director of the Institute for Agricultural Research (IAR), Ahmadu Bello University, Zaria, I served as the Deputy Director (Quality Assurance), Directorate of Academic Planning, ABU, Zaria. Within the Department of Soil Science, I progressed through several leadership positions, serving as Undergraduate Coordinator, Postgraduate Coordinator, and ultimately Head of Department. I also served as the Registration Officer of the Faculty of Agriculture and was a member of the Senate Standing Committee for four years. Between 2016 and 2018, I served as a member of the Faculty Board of Law, reflecting the University's confidence in my capacity to contribute beyond my primary discipline.

Outside the University, I served as Director of Albaniy Science International Academy, Zaria, from 2014 to 2023; Chairman of the Board of Trustees of Daarul Hadeethis Salafiyyah from 2014 to 2016; and Chairman of the Board of Directors of IAR Integrated Links from 2023 to 2024.

My contributions to scholarly publishing have also been significant. I served as Managing Editor and later Editor-in-Chief of the Nigerian Journal of Soil and Environmental Sciences. I also served as Managing Editor of the Nigerian Journal of Soil Science, the official publication of the Soil Science Society of Nigeria, and I currently serve as its Editor-in-Chief.

At the University level, I have served on numerous strategic committees. These include Chairman of the Committee for the Reconstruction of the Ahmadu Bello University Main Gate Monument, which successfully restored this important institutional landmark following its demolition; Member of the Ahmadu Bello University Research Fair Committee; Chairman of the IAR Life Fence Committee; Chairman of the Committee for the Investigation of Alleged Plagiarism by a Professor; and Chairman of the Anti-Corruption and Transparency Unit (ACTU) of the Institute for Agricultural Research.

These diverse leadership and administrative responsibilities have enriched my understanding of university governance, strengthened my commitment to institutional development, and reinforced my belief that academic excellence must be complemented by integrity, accountability, and dedicated service.

20. AWARDS, GRANTS, AND CITATIONS

2007: Volkswagen Foundation, Hanover, Germany, Fellowship for Doctoral Studies

2012: African Credibility Gold Award
2012: COMSTECH-TWAS, Joint Research Grants Programme for Young Scientist: The Academy of Science for Developing World, Italy
2013: The most Promising Young Scientist for the Year 2012/2013, Department of Soil Science, Ahmadu Bello University, Zaria
2018: Marquis Who's Who in The World; Lifetime Achievement Award
2019: Award of Excellence, Ahmadu Bello University Postgraduate Representative Council
2013: Marquis Who's Who in The World
2013: 2000 Outstanding Intellectuals of the 21st Century, International Biographical Center, Cambridge, U.K.
2013: Leading Scientist of the World: International Biographical Center, Cambridge, U.K.
2013: Top 100 Scientist: International Biographical Center, Cambridge, U.K.
2022: TETFund-UBR Research Grant, Ahmadu Bello University 2023
2024: COMCEC Project Funding (Investment & Development Bank of Turkey)
2023: The Most Cited Staff of the Year, Faculty of Agriculture, ABU, Zaria
2024: The Most Cited Staff of the Year, Faculty of Agriculture, ABU, Zaria
2024: Grant Fellow of the Year, Institute for Agricultural Research, ABU, Zaria
2024: Overall Grant Fellow of the Year, Ahmadu Bello University, Zaria
2025: The Most Cited Staff of the Year, Faculty of Agriculture, ABU, Zaria

21. MEMBERSHIP OF PROFESSIONAL BODIES/ HONORS SOCIETIES

1) Fellow, Soil Science Society of Nigeria.
2) Fellow, Pan-African Scientific Research Council.
3) Member, New York Academy of Science, U.S.A.
4) Member, Society of Chemical Industry, UK.
5) Member, International Union of Soil Science
6) Member, Nigerian Institute of Soil Science
7) Member, Soil Science Society of Nigeria.
8) Member, Agricultural Society of Nigeria.
9) Member, Academic Staff Union of Universities, A.B.U. Branch

22. COMMUNITY SERVICE

1) External Examiner to the Undergraduate Programme of the Department of Soil Science and Agric Engineering, Usmanu Danfodio University, Sokoto, 2017/18 – 2019/20 Academic Sessions.
2) N.Y.S.C. Agricultural Science Teacher at Federal Government Girls College, Bauchi. 2001 - 2002.
3) Resource Person at Quarterly Training Review Meeting, Jigawa State, 2009.
4) Chemistry Teacher Muslim Refresher Course Programme (Charity organization), Tudun Wada, Zaria, 1997 – 2009.
5) Resource Person "Dinkin Kwalba" Public Enlightenment Programme, Radio Nigeria Kaduna, Hausa service, 7th and 14th November, 2010
6) Resource Person "The Professionals" Public Enlightenment Programme, Radio Nigeria Kaduna, English service, 14th November, 2010
7) Participant in the World Ranking of Universities organized by Thomson Reuters and Times Higher Education, U.S.A; 2010, 2011, 2015, 2017 and 2024
8) Referee to Numerous Peer Reviewed National and

International Journals

9) Chemistry Teacher (Voluntary Teaching), Albaniy Science Academy, Zaria. 2010 – 2014
10) Director, Albaniy Science Int'l Academy, Zaria (Voluntary Service). 2014 – 2023
11) Chairman, Security Committee, Tukur Tukur Layout, 2019 – 2023
12) Member, Scholarship Committee of The Honorable Speaker, Federal House of Representatives
13) Director, Abdullahi Ibn Abbas Masjid and School, Tukur Tukur Layout, Zaria 2019 – 2025

23. CONCLUSION

This inaugural lecture has attempted to synthesize the major intellectual themes emerging from my research journey in soil chemistry, environmental quality, nutrient dynamics, and sustainable land management.

My overall scientific contributions can be viewed at three levels:

1. National impact: This involves strengthening soil science research, improving sustainable agriculture, informing environmental management, and training future scientists in Nigeria.

2. Regional impact: My work has provided researches applicable across Africa, particularly for soil fertility, heavy metal contamination, and land degradation.

3. Global impact: My work has contributed to internationally recognized research in soil chemistry, environmental contamination and sustainable soil management through publications, collaborations, editorial leadership, and international research partnerships.

The central message is simple but profound:

Healthy soils are indispensable for sustainable societies. The interactions among soil minerals, nutrients, contaminants, microorganisms, water, and plants determine not only agricultural productivity, but also environmental stability, ecosystem health, and human wellbeing.

From phosphorus fixation to heavy metal contamination, from biochar remediation to land evaluation, the broader scientific objective has remained consistent: generating knowledge capable of improving the sustainability of soil systems under changing environmental conditions.

As scientists, our responsibility extends beyond laboratories and publications. We must contribute solutions to the pressing challenges facing humanity.

The future of food security, environmental sustainability, and climate resilience in Africa will depend substantially on how effectively we manage our soils.

Soil may lie beneath our feet, but it must remain at the forefront of our national priorities.

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