FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

LEGUMES AND RHIZOBIA: ONE OF NATURE'S PARTNERSHIPS FOR FOOD AND NUTRITION SECURITY OF THE POOR

By

PROF. ABDULLAHI BALA

B.Agric (ABU), MSc (Reading), PhD (London)

Professor of Soil Science

INAUGURAL LECTURE SERIES 33

9TH APRIL, 2015

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

LEGUMES AND RHIZOBIA: ONE OF NATURE'S PARTNERSHIPS FOR FOOD AND NUTRITION SECURITY OF THE POOR

By

PROF. ABDULLAHI BALA
B.Agric (ABU), MSc (Reading), PhD (London)
Professor of Soil Science

INAUGURAL LECTURE SERIES 33

9TH APRIL, 2015

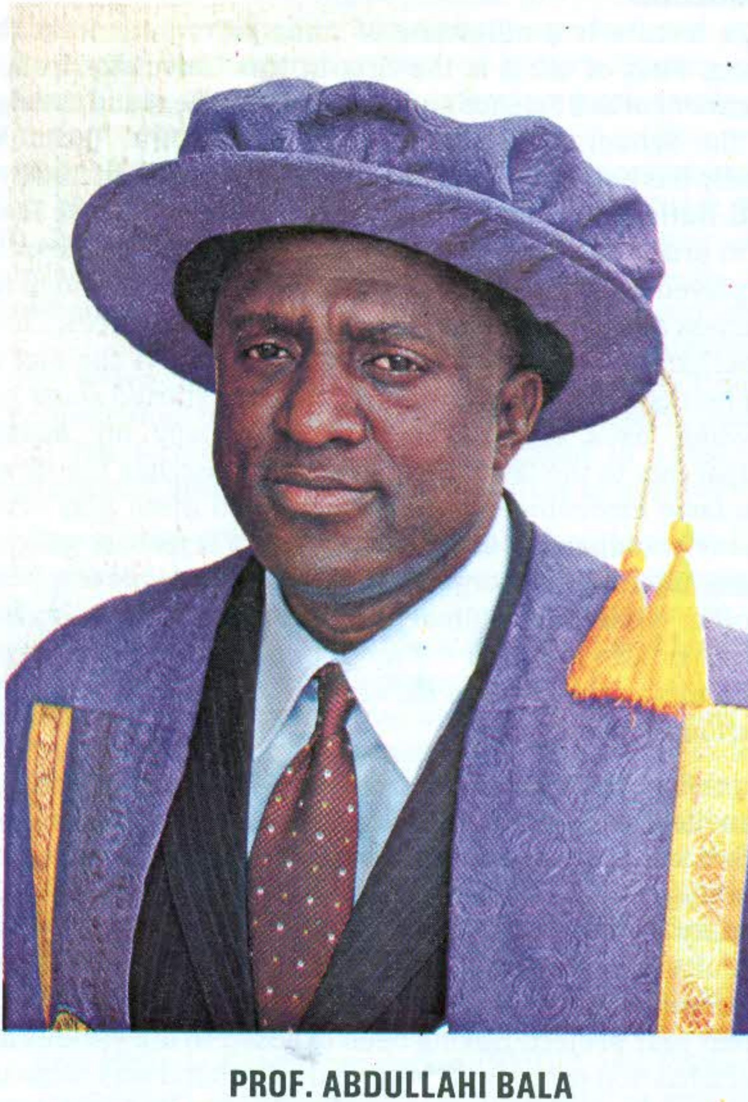
This 33rd Inaugural Lecture was delivered under the Chairmanship of:

Professor M. A. Akanji, FNSMBM
Vice-Chancellor
Federal University of Technology, Minna

Published by:
University Seminar and Colloquium Committee,
Federal University of Technology, Minna.

9TH April, 2015

Design + Print:
Global Links Communications, Nigeria
✆: 08056074844, 07036446818



PROF. ABDULLAHI BALA
B.Agric (ABU), MSc (Reading), PhD (London)
Professor of Soil Science

Introduction

Today's lecture is a milestone of some sorts in at least three respects. First of all, it is the first in this University from the Department of Soil Science and Land Management and the eighth from the School of Agriculture and Agricultural Technology. Secondly, it is being presented in 2015, the year designated by the United Nations General Assembly as the International Year of Soils in order to draw the attention of the world to the critical roles played by soil in our lives and survival on earth and to raise awareness and promote sustainability of soil resources. Thirdly, and perhaps more important to me, however, is the fact that today marks a major landmark of a journey started some years ago when, as a child, I used to accompany my maternal grandparents to the farm. I recollect with nostalgia the serenity of the farm environment and how I would often play around while my grandparents toiled. It was nature at its best with birds chirping happily and energetically hopping from one tree branch to another while small animals crawled about in the bush. Being at the farm also afforded me an opportunity to eat a range of foods, fruits and vegetables harvested by my grandparents from the various parts of the field.

It was this seminal experience that in part shaped my decision later in life to read Agriculture in the University. The decision to read Soil Science, however, was purely accidental as I knew next to nothing about a course like that before getting to the University. As fate would have it, we spent the first three years in the Faculty doing general courses and it was only in our final year that we were allowed to select a department where we would do our final year project. Having been exposed to the various areas of specialisation in the first three years, my mind was made up to go for Soil Science, rather than the Agronomy I had initially wanted to read. The rest, as the aphorism goes, is history.

Rationale for the Chosen Title

Statistics from various agencies of the United Nations estimate that nearly fifty per cent of the population in sub-Saharan Africa lives below the poverty line while about one in three, or 250 million people, are undernourished or hungry. Coming closer home, more than 70 per cent of Nigerians are poor, earning less than the equivalent of $1.25 daily and about 20 million people have inadequate access to food for their wellbeing, with nearly 11 million being malnourished. (FAO, 2010; UNDP, 2014; WHO, 2015). Paradoxically, while an estimated 70 per cent of the people living in Africa are employed directly or indirectly in the agricultural sector; the annual food import bill of the continent is about 350 billion US dollars. These are indeed depressing statistics, which suggest that there is a large mass of poor, hungry and malnourished people in Africa, and indeed Nigeria, and that most of the farmers are poor and engaged in subsistence agriculture with little resources to invest on the enterprise.

According to the World Health Organisation, poverty is the primary cause of hunger, but hunger also causes poverty due to ill health, low energy level and even mental impairment, thus diminishing peoples' ability to work and learn and leading to more hunger (WHO, 2015). Thus hunger and poverty are two sides of the same coin that entrap individuals in a vicious cycle that can only be broken by exogenous interventions that address the multi-dimensional nature of the problem. It is this scenario and the many partnerships or alliances forged over the years to help grow Africa's agriculture and improve farmers' incomes and livelihoods that have inspired the title of this inaugural lecture. Some of these partnerships include but not limited to the following:

* The Alliance for a Green Revolution in Africa (AGRA) – Created in 2006 as a strategic partnership between Bill and Melinda Gates Foundation (BMGF) and Rockefeller Foundation to dramatically improve African agriculture and to do so as rapidly as possible (agra-alliance.org).

* The New Alliance for Food Security and Nutrition – launched in 2012 by NEPAD (New Partnership for African

Development), some of its goals are to help lift 50 million people out of poverty in Africa by 2022 and achieve sustained, inclusive agriculture-led growth in Africa (new-alliance.org).

* Africa Climate-Smart Agriculture Alliance (CSA) – This aims to build the food and nutrition security of the rural poor so that farm families have access to enough nutritious food at all times, even in the face of a changing climate. Six million smallholder farmers in sub-Saharan Africa are to be empowered by 2021. (africacsa.org)

* Africa-Brazil Agricultural Innovation Marketplace – This is an initiative of the Brazilian Agricultural Research Corporation (Embrapa) and the Forum for Agricultural Research in Africa (FARA), with support from international donor agencies, including the World Bank, the United Kingdom's Department for International Development (DfID), the International Fund for Agricultural Development (IFAD) and the BMGF. The initiative aims at linking Latin American, African and Caribbean (LAC) experts and institutions to develop cooperative research projects for development (www.africa-brazil.org).

Given the plethora of past and present initiatives aimed at reducing hunger in Africa and the little progress made over time, I am tempted to draw the audience's attention to a mutually beneficial relationship between two remarkable partners – one a bacterium and the other a plant- that nature has blessed mankind with, which if properly harnessed, will go a long way in engendering food and nutrition security to the continent and indeed Nigeria. The title, therefore, serves as a metaphor for progress in the fight against hunger and poverty hinged on functional and sustainable partnerships within the Nigerian context in particular and Africa in general.

Soil and its Composition

Soil may mean different things to different people but, for a soil scientist, it is defined as ***'the unconsolidated mineral and/or organic material on the immediate surface of the Earth that serves as a natural medium for the growth of land plants'***. It is a product of the combined effects of living organisms, genetic and climatic factors (including rainfall and temperature), conditioned by topography, acting on the parent material over a period of time. The upper limit of soil is the boundary between soil and air, shallow water, or plant materials that have not begun to decompose. However, its lower boundary hugely differs, depending on the nature of soil and the interactive effects of the soil-forming factors, but soils generally transition, at the lower boundary, to a hard rock or a region of non-biological activity. Most soils do not go beyond a depth of 200 cm, which is the limit arbitrarily used for the purpose of soil classification.

Soil is chiefly composed of five components, namely minerals, organic matter, water, air and living organisms. The mineral matter, which is largely responsible for the solid matrix of the soil, constitutes about 50% by volume of soil and is made up of sand, silt and clay. The minerals, in general, provide physical support for plants and are the original source of most essential plant nutrients in the soil. The organic matter is the product of decayed remains of plants and animals and, although it constitutes less than 5% of soil volume, it supplies large portions of the nutrients essential for plant growth. Soil water resides in the pore spaces that exist between aggregates of mineral and organic matter and, although variable, may account for 20-30% of the soil volume. Water carries most of the nutrients essential for plant growth as dissolved salts in forms readily available for plant uptake. The soil air resides in the rest of the soil pores not occupied by water and has similar composition as the atmosphere, but with lower amounts of oxygen and higher concentrations of carbon dioxide and water vapour.

The living component of soil accounts for less than 1% of soil volume and is composed of a diverse community of plants and animals. These range from plant roots and large burrowing animals, such as rodents and earthworms, to organisms (microorganisms) too small to be seen with eyes unaided by using hand lens or microscopes. While the number and biomass of these organisms vary greatly, depending on prevailing environmental conditions, it is not uncommon for one teaspoonful of soil to have more individual living organisms than all of humanity on Earth (SSSA, 2015).

Soil organisms have varied roles, the totality of which has a profound effect on the chemical, physical and biological properties of soil. For instance, the burrowing activities of some of these organisms alter the physical structure of soils by creating large pores that enhance water infiltration and movement in the soil. The waste products and certain compounds produced by other organisms bind mineral particles together, modifying the pore structure and making it easier for air and water movement and plant roots penetration. The activities of soil organisms also include the physical diminution of plant remains by insects and earthworms and the chemical breakdown (decomposition) of these materials by microorganisms. The outcome of such decomposition processes is the transformation of plant nutrients, especially nitrogen, sulphur and phosphorus, into mineral forms that are available for plant uptake. Other potentially harmful compounds in the soil are degraded through decomposition and other transformation processes. However, not all activities of the organisms lead to desirable outcomes as some are involved in processes that lead to the loss of essential plant nutrients from the soil and the release of gases into the atmosphere that exacerbate global warming.

Given the interconnectedness of soil and living organisms, both plants and animals, especially in terms of their roles in soil formation and nutrient transformation, and the fact that these organisms live in and get their provisions from the soil and, at the same time, plants rely on soil to produce the food that gets into the food chain, it becomes apparent that, ***'Soils make life and life makes soils'***.

Soil and its Relevance to Human Civilisation

Without soil, life would not exist as we know it. Soil is one of the three major natural resources, together with water and air, which sustain life. It is the single most important resource base of any nation and is a non-renewable resource at least within the human timescale. The rise and fall of many ancient civilisations were linked to the productivity of their soils. For instance, the ancient civilisation of Egypt, which lasted for about 3000 years, flourished on irrigation and the rich alluvial soils of the Lower Nile valley, while the Mayan civilisation of Central America came to an end as a direct result of the mismanagement of their soils. In Mesopotamia, the Sumerians lost political power to the Babylonians when their soils became too salty for crop growth due to poor irrigation practices. The Babylonian rule also failed because eroded soil from the surrounding hills due to tree cutting and over-grazing led to the siltation of their irrigation canals.

To a soil scientist, the primary role of soil is to serve as a medium for plant growth, thus providing the basis for production of crops for food, fodder and fibre. Nearly ninety per cent of the food produced on Earth comes from soil, thus underscoring the important contribution of soil to food and nutrition security. Other ecosystem services provided by soil include the filtering of underground water, the regulation of many of the greenhouse gases (GHGs) and thus the Earth's temperature. In particular, nearly 35% of all GHGs emitted into the atmosphere since the mid-19th Century is linked to land use changes (SSSA, 2015). Such emissions can be mitigated by means of sound soil management practices that promote carbon sequestration because soil stores carbon dioxide and other GHGs in soil organic matter.

Role of Soil Scientists

The single most important constraint to agricultural productivity is soil degradation, which may be exemplified by one or more of the following: soil crusting and sealing; soil compaction and the reduction of infiltration rate, thus leading to accelerated runoff and severe erosion; decline in soil organic matter, loss of nutrients, and decrease in pH leading to acidity and nutrient imbalance. Soil Scientists have the primary responsibility of managing and protecting the soil such that it does not suffer from degradation and in such a manner that sustainable agricultural production and productivity are realised. In this regard, they conduct research, develop suitable technologies, educate and train requisite manpower and advise policy makers in decisions that meet a nation's modern agricultural, water quality, land management, and environmental challenges. In spite of these, there appears to be an awareness and policy deficit in Nigeria in terms of the status of soil as a national resource base, with the Nigerian Government policy on soil resources management being heavily skewed towards fertiliser procurement and distribution to the detriment of other programmes.

Fertiliser and Plant Nutrition

The emphasis on fertiliser supply by Government is not unconnected with the fact that most soils in Nigeria are inherently low in fertility and thus incapable of supplying adequate nutrients for optimum crop productivity without supplementation from fertiliser application. Plants, like all living organisms, need nutrition for growth and reproduction. In general, the nutrients essential for plant life are also required by animals and humans except that plants extract the nutrients directly from the soil, while man and animals must feed on plants to get their provision. Sixteen elements are universally considered as essential for plant growth; the criteria for essentiality of an element being that:

* Plants cannot complete their life cycle or set seeds in the absence of the element.
* The deficiency of an element cannot be met by supplying some other element.
* The element must be directly involved in the metabolism of a plant.

Three of the sixteen elements - carbon (C), hydrogen (H) and oxygen (O) - are taken up from the atmosphere, while the rest are extracted from the soil and are, depending on the relative quantity required by plants, grouped as primary-, secondary- or micronutrients. Nitrogen (N), phosphorus (P) and potassium (K) constitute the *primary nutrients* because they are used in the largest amounts by plants, with N being the element utilised in the greatest quantity. The *secondary nutrients*, made up of calcium (Ca), magnesium (Mg) and sulphur (S), are required in smaller quantities than the *primary nutrients*. Boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn) are utilised by plants in minute quantities and are thus grouped as *micronutrients*. Additional elements may also be essential for certain but not all crops; for instance, cobalt (Co) is required by legumes and silicon (Si) by rice. Irrespective of the quantities used by plants, the nutrient elements must not only be adequate in terms of quantity, but must also be of the right proportion with other elements. According to the ***Law of the Minimum***, espoused by Baron Justus von Liebig, a mid 19^{th} century German scientist, ***"plants will use essential elements only in proportion to each other, and the element that is in shortest supply - in proportion to the rest - will determine how well the plant uses the other nutrient elements"***.

Among the thirteen essential elements taken up by plants from soil, N is the most limiting, followed by P and K, in most Nigerian soils. This is why urea (with 46% N content) and NPK blended fertilisers are the commonest fertilisers used by farmers in the country. There is also a widespread deficiency of B and, to a lesser extent, those of Zn and Mo, especially in soils of the Nigerian savanna, which are often characterised by relatively low organic matter content. Other elements abound in relatively adequate quantities for crop production. However, agricultural intensification over long periods of time leads to nutrient mining which, if not adequately replenished and handled using suitable soil management practices, results in nutrient depletion and gradual degradation of the soil. In addition to nutrient loss through crop harvests, nutrients are commonly lost from the soil by soil erosion and leaching. Fertilisers are, therefore, very important in agriculture because they serve as food supplements to crops, supplying those essential elements that are deficient or are not found in adequate quantities in soils.

Apart from mineral fertilisers, various types of organic materials are used as alternative sources of nutrients and for enhancing the organic matter content of the soil. The advantage of soil organic matter (SOM) over fertilisers is that, added to its role in nutrient supply, SOM improves the soil structure, water and air infiltration rates, and water holding capacity as well as the soil's ability to resist sudden changes in chemical imbalance (buffering capacity). Its presence also minimises soil erosion and supplies carbon that supports the proliferation of microbes which carry out other beneficial roles in soil.

We are What We Eat

Human nutrition is to a large extent dependent on the intake of mineral elements in man's daily diet. The elements get into the food chain through plant uptake from the soil, with the plants consumed directly as vegetative matter or indirectly as products of animals that feed on the plants as fodder. In addition to the 16 essential nutrient elements, plants are also known to absorb nearly 70 other elements from the soil. The human tissue is composed of about 26 elements, made up of the 16 nutrient elements essential for plant growth as well as cobalt (Co), fluorine (F), sodium (Na), silicon (Si), chromium (Cr), vanadium (V), iodine (I), tin (Sn) and selenium (Se), which are all also found in plants (Table1). Of these, C, H, O, N, P and S account for ninety eight per cent of total composition by weight, while the remaining two per cent is constituted by the other elements. Thus, a key factor to human nutrition is plant availability of nutrient elements in the soil, which is governed by several factors, such as the nature of parent material, organic matter content, and soil pH. It, therefore, follows that low crop yields from nutrient depleted and infertile soils will often not only result in quantitative but also qualitative human malnutrition. Additionally, foods obtained from diverse farm locales provide a better chance of supplying the requisite amounts and types of essential elements for human nutrition than food sourced from restricted localities.

Nutrient depletion is not uncommon on farms across sub-Saharan Africa and, given the subsistence nature of most farm holdings, the vast majority of farmers rely on what they produce from their farms, with little inflows from other sources. This restricts their food sources and types and ultimately their nutrition and health. Given this scenario, soil nutrient depletion can easily pull down farm households into poverty traps where, due to low resource endowments, the farmer cannot invest adequate resources for proper soil management and, in consequence, obtains low and poor quality yields which result in poor family income and home nutrition and thus a malnourished family of poor health. This reduces the family's ability to work and learn and thus leads to even greater poverty and hunger.

Table 1. The composition and approximate concentrations of nutrient elements required for healthy plant and human tissues

Element	Concentration in dry matter (mg kg^{-1})	
	Plant tissue[a]	Human tissue[b]
Oxygen	480000	650000
Carbon	420000	185000
Hydrogen	60000	95000
Nitrogen	**14000**	**32000**
Potassium	10000	4000
Calcium	5000	15000
Magnesium	2000	1000
Phosphorus	2000	10000
Sulphur	1000	3000
Chlorine	100	2000
Iron	100	trace
Manganese	50	trace
Boron	20	trace
Zinc	20	trace
Copper	6	trace
Molybdenum	0.1	trace
Cobalt	trace	trace
Sodium	trace	2000
Silicon	trace	trace
Others –Fluorine, Iodine, Selenium, Tin, and Vanadium		trace

Source: [a]*http://www.fao.org/ag/AGP/AGPC/doc/publicat/FAOBUL4/FAOBUL4/B402.htm*
[b]*http://en.wikipedia.org/wiki/Composition_of_the_human_body*

It is very fitting that man obtains nourishment and sustenance from the soil because the evolution of man, at least from the perspectives of the scriptures, has its root in soil.

Your Lord said to the angels, "I am going to create a human being out of clay. When I have formed him and breathed My Spirit into him, fall down in prostration to him." (Quran 38:71-72)

And the LORD God formed man of the dust of the ground, and breathed into his nostrils the breath of life; and man became a living soul (Genesis 2:7)

It is also apt that the human body at death is buried into soil, thus providing a substrate for organic matter decomposition, nutrient release for plant uptake and the formation of humus, which is the organic component of soil. The cycle is thus completed such that man is derived from soil, sustained by soil and is finally fed to soil. Hence the epithet *'Ashes to ashes, dust to dust'*.

Fertiliser Supply and Use in Nigeria

Fertiliser procurement and distribution is an annual ritual by the various strata of government in Nigeria. Since 1999, an average of about 500,000 metric tonnes of fertilisers (mainly urea, NPK and single superphosphate) is procured by the Federal Government of Nigeria (FGN) annually and distributed to farmers at subsidised prices, resulting in an expenditure of more than one hundred billion Naira (₦100,000,000,000) during the period under review (Fig. 1).

In spite of the colossal amount of money spent, fertiliser use in the country has not gone beyond 15 kg/ha within the period under review and yields of major cereal staples have only shown weak increases (Fig. 2). This is against the background of the Abuja Declaration of 2006 made by African Heads of Government setting a minimum fertiliser use target of 50 kg/ha for member states.

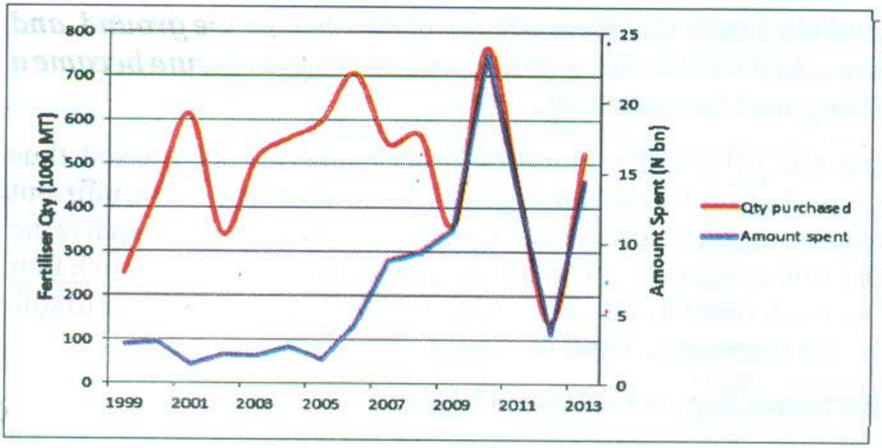


Figure 1. The approximate quantities of mineral fertiliser procured by the FGN and the resulting expenditure during the period 1999 to 2013.

Source: *FAOSTAT (2015); World Bank (2015)*

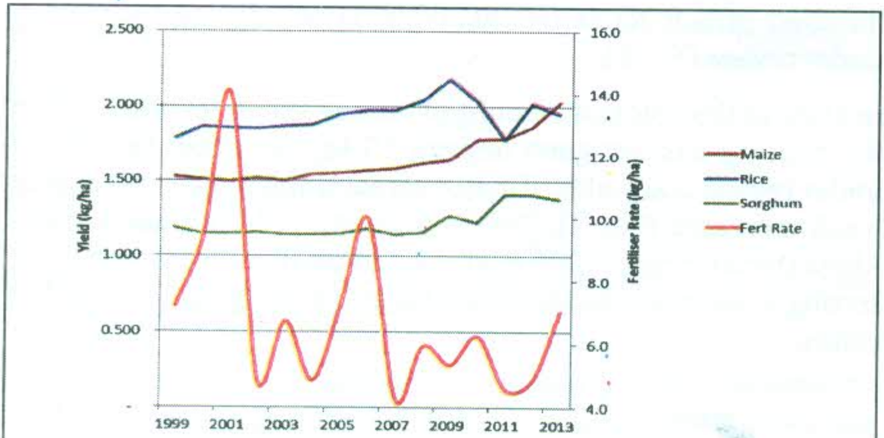


Figure 2. Fertiliser use and yields of three cereal staples in Nigeria between 1999 and 2013.

Source: NPAFS (2010); NAERLS& NPAFS (2010); NAERLS & PRSD (2013)

Several factors are responsible for the poor fertiliser culture in Nigeria but a major reason is that of inefficient distribution of the product. Fertiliser products distribution is often not synchronised with peak periods of needs and many state governments use fertiliser as a means of patronage with products distributed to ruling party cronies first before getting to the market. Additionally, most of the supply outlets are concentrated in urban areas rather than the countryside where they are most needed, thus resulting in farm gate prices being much more than the normal price of the products.

In 2012, the FGN introduced the Growth Enhancement Scheme (GES), which coordinates fertiliser distribution to farmers through the 'e-wallet' initiative. This entails registered farmers across the country getting pin numbers through SMS messages on cell phones, which they use to collect fertiliser at designated redemption centres. The initiative has widely been adjudged to have improved access by farmers to fertilisers, with calls by a segment of the population for the enactment of law by the National Assembly to make it a permanent feature of the polity. Nevertheless, the programme is still beset with challenges, not least of which are inadequate telephone network coverage, cumbersome procedure of getting approvals from the implementing body, low density coverage of agro-dealers, and the supply of fertilizer out of sync with peak demand periods (Adebo, 2014).

More worrisome, however, is the pervasive sense of 'chest-beating' and accomplishment in government circles when in essence the one bag each of urea and NPK given to farmers can at best supply no more than 35 kg N – enough for just about one acre of maize. For a government that plans to change farming into a business, what the farmers are getting is a mere *survival ration* that supports subsistence production. Ultimately, the Government must either increase the number of bags available per farmer under GES, or must take concrete steps towards encouraging complete liberalization of the fertilizer industry so that the role of Government is only that of a regulator. Although the GES is said to be private-driven, with fertiliser companies and agro-dealers being the principal implementers, Government remains the major customer and production and/or importation of fertiliser products by the companies is still largely driven by the incentives of being patronized by Government. There is little effort by the companies to link up directly with farmers who are the ultimate end users of the fertiliser products.

The Nitrogen Paradox

Nitrogen is a vital constituent of cell protoplasm and proteins and is found in all enzymes needed for plant functions. It is necessary for plant growth and reproduction and is thus the nutrient element required by plants in greatest amounts. On the other hand, it is also often the most limiting nutrient in a vast majority of soils. This is ironic in view of the fact that nitrogen accounts for nearly 80 per cent by volume of atmospheric air, with oxygen contributing about 21 per cent and trace gases, including carbon dioxide, making up the rest. However, plants cannot use N in its inert form as found in the atmosphere and must of necessity be converted to other forms, such as ammonia, for it to be readily available for plant uptake. This is where nitrogen fixation comes into play.

Table 2. Composition of atmospheric air and the use of the constituent gases by plants

Constituent gas	Proportion by volume (%)	Harnessed by plants for:
Nitrogen	78.08	Biological nitrogen fixation
Oxygen	20.95	Respiration
Carbon dioxide	0.03	Photosynthesis
Others	0.94	-

Nitrogen Fixation

Nitrogen fixation is a process, biotic or abiotic, by which atmospheric nitrogen is converted into ammonia. Biological nitrogen fixation (BNF) is carried out by a specialized group of prokaryotes (mainly bacteria) which possess the enzyme nitrogenase that is used to catalyse the conversion of atmospheric nitrogen (N_2) to ammonia (NH_3). The equation for the reactions is as follows:

$$N_2 + 8H^+ + 8e- + 16ATP = 2NH_3 + H_2 + 16ADP + 16Pi$$

This reaction requires a minimum 16 moles of adenosine triphosphate (ATP) for every mole of N_2 reduced hence this process is energy-intensive and may explain why N_2-fixation is not universal in plants (Giller, 2001). Globally, BNF accounts for as much as 193 million tonnes of N fixed annually.

The fixation of N_2 by lightning and the industrial production of ammonia using the Haber-Bosch method for the production of nitrogenous fertilisers are two examples of non-biological N_2-fixation processes. The Haber-Bosch process is based on the reaction similar to that of BNF:

$$N_2 + 3H_2 = 2NH_3$$

Unlike BNF, however, an iron-based catalyst is required for the process which is conducted at 15–25MPa of pressure and a temperature of 300–550 °C. The source of hydrogen for the reaction is methane (CH_4), which is commonly obtained from natural gas. This method of fertiliser production is associated with some environmental and health consequences given the attendant reliance on fossil fuels for the energy needed and the resulting carbon dioxide emissions and pollution from burning these fuels.

BNF can be classified into three broad categories - Free living, Associative and Symbiotic.

(i) Free living nitrogen fixation is carried out by a number of heterotrophic bacteria and cyanobacteria (blue-green algae) that live in the soil and fix nitrogen without associating with other organisms. Heterotrophic bacteria are bacteria that rely on organic carbon as source of carbon for vegetative growth. Examples of such bacteria include *Azotobacter* spp., *Beijerinckia* spp., *Clostridium* spp. and *Klebsiella* spp. These organisms obtain the energy required for the process by oxidizing organic substrates, such as leaf litter and straws, in the soil. Cyanobacteria on the other hand are Gram-negative bacteria, most of which possess chlorophyll and are, therefore, reliant on solar energy for photosynthesis to fix their carbon. Free-living microorganisms may contribute up to 20 kilograms of N_2 fixed per hectare per year.

(ii) Associative nitrogen fixation involves Gram-negative bacteria of the genera *Azospirillum*, *Herbaspirillum*, *Acetobacter*, and *Azoarcus* in loose associations with roots of some grasses, such as sugar cane, maize, rice and wheat. The microsymbionts may be found on the surface of the roots of the associate plants or may colonise the roots endophytically, that is, they live within tissues internal to the epidermis. These organisms fix appreciable amounts of nitrogen within the rhizosphere of the host plants and obtain their energy by oxidizing organic substrates obtained from the carbon lost from living and dead roots of the plants. Estimates of 5-20 kg N ha^{-1} have severally been reported for associative N_2-fixation (Giller, 2001).

(iii) Symbiotic nitrogen fixation is a partnership between N_2-fixing microorganisms and host plants. It is symbiotic in nature with the plant providing the microorganism with sugars from photosynthesis for the energy it needs for nitrogen fixation in exchange for the nitrogen fixed by the microbe. One of the most economically important groups of bacteria involved in symbiotic nitrogen fixation are the cyanobacteria, which are found in association with *Azolla*, a genus of aquatic ferns that are found floating on water surfaces. The cyanobacterial symbiont is *Anabaena azollae*, which colonizes special cavities formed at the upper surface of the *Azolla* fronds. This association has been used for centuries in Southeast Asia, mainly China and Vietnam, as a biofertiliser in rice paddies. The amount of nitrogen fixed in this system has been estimated to range from 7 kg N ha^{-1} to 50 kg N ha^{-1} per rice crop during the growing season (Giller, 2001).

The second group of bacteria that form symbiotic association with plants are members of the genus *Frankia*. This is a Gram-positive genus made up of filamentous bacteria of the order Actinomycetes. *Frankia* species symbiotically fix nitrogen on plants from at least eight families of angiosperms. The association is commonly referred to as 'Actinorhizal symbiosis'. Most of the host plants are woody shrubs and trees that are found in temperate environments, such as alder (*Alnus* spp.). The main tropical actinorhizal plants come from the family *Casuarinaceae* – primarily members of the two genera *Casuarina* and

Allocasuarina. These plants tend to thrive in nitrogen-poor environments and are commonly used in land reclamation activities. Actinorrhizal symbiosis in *Casuarina equisetifolia* trees is reported to generate about 40-60 kg N ha^{-1} yr^{-1} (Gauthier *et al.*, 1985).

The symbiotic association between legumes and a specialized group of bacteria called rhizobia is by far the most important symbiotic nitrogen-fixing association in both natural and agricultural ecosystems. This symbiosis contributes a substantial part of the global nitrogen input, estimated to be at least 70 million metric tonnes per annum (Brockwell *et al.*, 1995) and is known to fix more nitrogen per hectare than any of the other N_2-fixing systems. Estimates of N_2-fixation by grain legumes grown in the tropics range between 3 and 200 kg N ha^{-1} (Giller, 2001). Important legumes used in tropical agricultural systems include beans, cowpea, groundnut and soybean.

The Legume-Rhizobium Symbiosis: An Overview

In this association the rhizobial symbiont colonises the host plant's roots and induces the formation of nodules (Plate 1) which are invaded by the rhizobia. These nodules constitute a power house in which the rhizobia are able to reduce atmospheric nitrogen into forms which are readily available for utilisation by the host plant. In return, part of the host's photosynthate is utilised by the microsymbiont. By no means are all such associations mutual, since there are several cases where the rhizobia are able to induce and infect nodules on their hosts without actually fixing nitrogen, thus resulting in 'ineffective nodules'. In effect, the rhizobia in this case are acting as parasites.

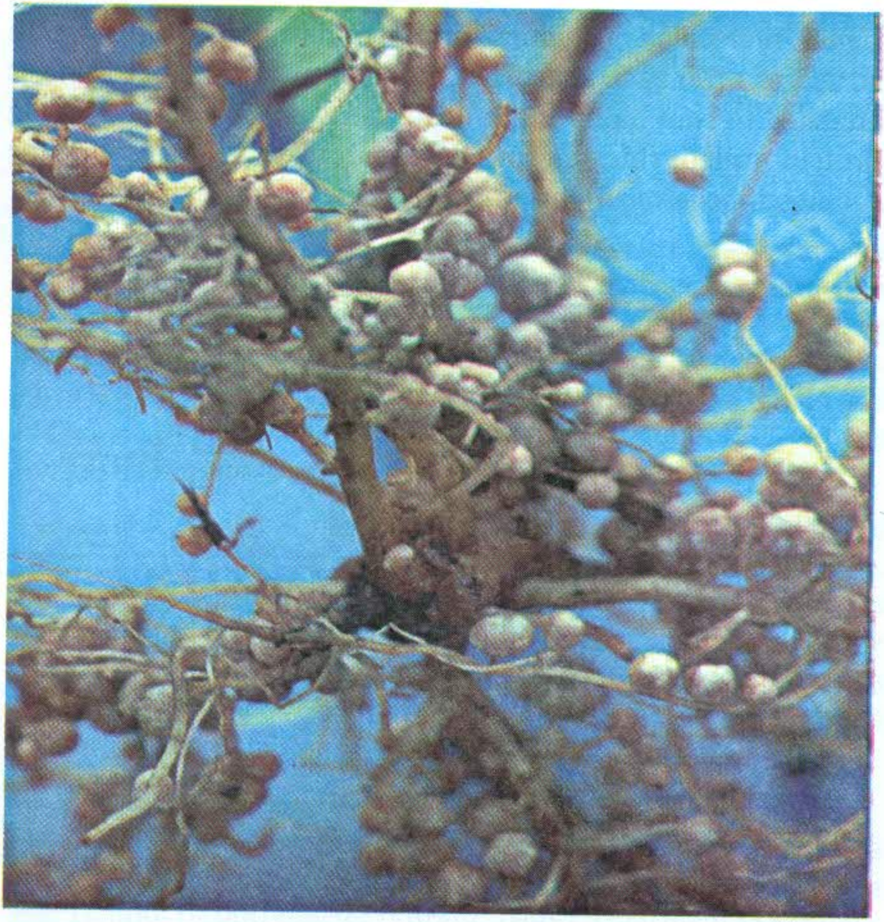


Plate 1. Root of a groundnut plant showing numerous root nodules

The nodulation process (Plate 2) is a highly specific and controlled interaction between the bacteria and host plant and involves a series of recognition events to ensure that only the right partner gains entry into the plant. The process begins when the cognate rhizobia recognise and are attracted to flavonoids and isoflavonoids released by the host legume's roots. The flavonoids, which are ketone-based metabolites, thus act as signal molecules. Legumes produce flavonoids differing in structure, with each specific to the host plant. The bacteria get attached to root hairs of the host plants using a Ca^{2+} - binding protein called rhicadhesin, the host plant's lectins and/or cellulose fibrils and fimbriae produced by the bacteria.

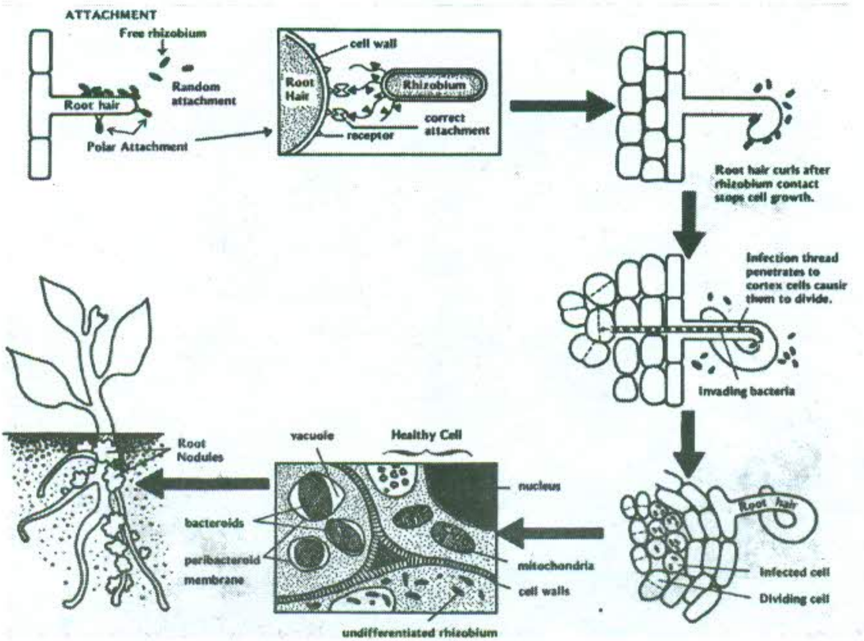


Plate 2. Diagrammatic illustration of the different stages of root nodule formation. Diagram courtesy of Slide Share, http://www.hudson.edu/custom_users/sheldonc/nutcycle.pps

The attached rhizobia release signal molecules called Nod factors, which are products of *nod* (nodulation) genes, that is, genes responsible for the nodulation of the cognate legume host. The nod factors have been identified to be lipochitin oligosaccharides and variations in their structures determine the host specificity for the microsymbiont. The presence of the nod factors in the root rhizosphere triggers a cascade of events in the plant, starting with the curling of the tip of the colonized root hair to form what is called a 'shepherd's crook'. This is followed by the invagination of the root tip, forming a tubular structure called an infection thread, which enables the rhizobia to gain entry into the plant. On reaching the root cortex, they stimulate cortical cell divisions that lead to the formation of nodules in which the rhizobia reside. The bacteria subsequently lose their cell walls and undergo a profound change in cell morphology to form large, irregularly shaped cells called bacteroids. It is in this form that the rhizobia commence to fix nitrogen for use by the host plant in return for all of the bacteria's energy needs.

The formation of nodules on legumes is not only restricted to the roots; stem nodulation among aquatic plants is not uncommon. For example, *Sesbania rostrata* and several species of the genus *Aeschynomene* exhibit both stem and root nodulation. The process leading to the development of stem nodules differs from that of root nodules, even though both may be induced by the same rhizobial symbiont.

Legumes: Taxonomy, Distribution and Nodulation

Legumes belong to the family Leguminosae, which is the third largest family of flowering plants, comprising about 750 genera and 16,000-19,000 species (Sprent, 1995). They include annuals, shrubs and trees and are identified characteristically by their possession of a seed pod that splits in two, containing the seeds. The pod may be borne aerially or underground. The group includes some of the most economically important species, such as cowpea, groundnut and soybean, which are harvested for their edible seeds. Several of the woody shrubs and tree species, such as camel foot (*Piliostigma* spp.; Hausa: Kalgo), African locust bean tree (*Parkia biglobosa*; Hausa: Dorawa), and Flame of the forest or Flamboyant tree (*Delonix regia*; Hausa: Ashakata) are found in the wild in Nigeria. Others such as siratro (*Macroptilium atropurpureum*), calopo (*Calopogonium mucunoides*), and stylo (*Stylosanthes* spp.), are exotic species commonly cultivated as pasture legumes in the country.

Legumes are divided into three sub-families, the Caesalpinoideae, the Mimosoideae and the Papilionoideae. The classification and ecology of members of the family Fabaceae are given in detail by Raven and Polhill (1981). The Caesalpinoideae contains 154 genera and about 1,900 species, which are mainly tropical trees and shrubs. Their floral morphology generally consists of 4-5 petals arranged in an apparent radial symmetry. Examples of genera in the Caesalpinoideae are *Piliostigma* spp., *Delonix regia*, and *Tamarindus indica* (Tamarind, Hausa: Tsamiya). The Mimosoideae is made up of about 50-60 genera and 2,713 species and are also woody and mainly tropical, but are also found in sub-tropical and warm temperate regions. About two thirds of the known species in the Mimosoideae fall into three genera: *Acacia*, with 1,200, *Mimosa* with 400-500 and *Inga* with 350-400. The floral morphology of this sub-family is characterised by a compound inflorescence with reduced petals. The Papilionoideae is the largest sub-family of the Leguminosae, and is comprised of some 440 genera and 13,000 species, which are largely herbaceous, but about 4,000-5,000 species are woody and largely tropical. Members of this sub-family are identified by their characteristic papilionoid (pea - like) flower. The majority of the most important grain legumes belong to this group including cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*) and soybean (*Glycine max*). Others include woody species such as gliricidia (*Gliricidia sepium*) and sesbania (*Sesbania sesban*).

Not all members of the Leguminosae are able to produce nodules. In general, nodulation among the three legume sub-families is least in the Caesalpinoideae, most common in the Papilionoideae, with the Mimosoideae being intermediate. Among the species examined, nodulation occurs in 23% of the Caesalpinoideae, 90% of the Mimosoideae and 97% of the Papilionoideae.

Rhizobia: Characteristics and Classification

The group of soil bacteria that establish symbiotic association with legumes are collectively referred to as rhizobia. They are Gram negative, aerobic and generally do not produce endospores. They are also characterised by the possession of flagella, and are thus motile. When not in symbiotic association, rhizobia could exist in free living saprophytic state. The size of rhizobial populations vary from very low and undetectable numbers, to millions per gram of soil, depending on the environmental and soil conditions. Conditions associated with low rhizobial numbers include low pH, nutrient and mineral toxicities and deficiencies, moisture stress and very high temperatures; while high populations are favoured in soils where such environmental stresses are minimal and where their homologous hosts are prevalent or are frequently grown (Giller, 2001). Rhizobia are widely distributed in both tropical and temperate environments, in both cultivated and virgin soils.

There are currently ninety nine species and thirteen genera of rhizobia recognised. The genus *Azorhizobium* contains three species, which characteristically form stem nodules especially on aquatic plants such as *Sesbania rostrata* and *S. virgata*. The genus *Bradyrhizobium* contains nine recognised species including *B. japonicum*, *B. elkanii*, *B. liaoningense*, *B. diazoefficiens*, *B. ottawaense* and *B. huanghuaihaiense*, which are all symbionts of soybeans. The old genus *Rhizobium* has now been split into three genera, *Rhizobium*, *Sinorhizobium* and *Mesorhizobium*. *Rhizobium* contains thirty species including the relatively acid tolerant *R. tropici* and *R. etli*. The genus *Mesorhizobium* is comprised of twenty one species whose members are characteristically of intermediate growth rate between *Rhizobium* and *Bradyrhizobium*. These include *M. gobiense*, isolated from wild legumes growing in Gobi Desert; and *M. metallidurans*, a metal-resistant symbiont of *Anthyllis vulneraria*. The genus *Sinorhizobium* has seventeen species including *S. fredii*, a symbiont of soybean and *S. morelense*, an antibiotic-resistant symbiont of *Leucaena leucocephala*. The genus *Burkholderia* consists of seven recognised species that include *B. acidipaludis*, a characteristically aluminium tolerant bacteria first isolated from Chinese water chestnut growing in highly acidic swamps in South East Asia. The other rhizobia genera are relatively newly classified taxa and are still evolving. These include *Phyllobacterium* and *Microvirga* each consisting of three species, and *Ochrobactrum* with two species. Others are *Methylobacterium*, *Cupriavidus*, *Devosia* and *Shinella* containing one species each.

My Contributions

My contribution to knowledge in the area of legume-rhizobium symbiosis covers the entire continuum, from the molecular level to field scale. I will now proceed to give summaries of some aspects of the studies I have conducted along with my colleagues and students.

Phenotypic Characteristics of Rhizobia

Rhizobia are usually classified according to their growth rate as fast, intermediate or slow growers and formed the basis for the phylogenetic classification of the genera *Rhizobium*, *Mesorhizobium* and *Bradyrhizobium*, respectively. Our studies showed that rhizobia in tropical soils exhibit all three categories of growth rates (Bala *et al.*, 2004). This discovery contributed to the body of evidence that gave an insight contrary to the predominantly held opinion at that time that all fast-growing rhizobia were from temperate areas, and all slow-growing rhizobia from tropical areas. It is now clear that fast-growing rhizobia are as prevalent in tropical soils as the slow-growing ones and that the fast-growers may be even more tolerant of some of the prevalent adverse tropical soil conditions such as temperature and desiccation than the slow-growing types due in part to the ability of the fast-growing rhizobia to be more quickly responsive in adapting to fluctuations in the environment than the slow growers.

Classification of rhizobia based on phenotypic properties tends to poorly correlate with groupings based on 16S rRNA sequence analysis. Given the limited capacity for recombinant DNA technology in most laboratories in developing countries, we conducted studies to standardise the phenotypic method as a simple, low-level technology protocol for routine assessment of rhizobial diversity. The study led to the identification of certain carbon substrates with different degrees of differentiation between rhizobial groups, which tended to increase the number of shared phenotypic characters that can be used for numerical analysis, thus enhancing the robustness of the phenotypic method of rhizobial classification (Bala *et al.*, 2004; Bala *et al.*, 2006). The carbon compounds found to be diagnostic of some rhizobial groups included glucose, sucrose, mannose, dulcitol, oxalate, soluble starch, polyethylene glycol and cyclodextrin.

Genetic Characteristics of Rhizobia

Phylogenetic analyses based on 16S rRNA has led to the discovery that rhizobia from tropical soils belong to all the major branches of the Rhizobiaceae, including the genera *Rhizobium*, *Mesorhizobium* and *Sinorhizobium* (Bala *et al.*, 2003). There exists within these groups large intra-species diversity as revealed by DNA sequence comparisons of the internally transcribed spacer (ITS) region between the 16S rRNA and 23S rRNA (Bala *et al.*, 2003a). Unlike the 16S rRNA that is highly conserved, the ITS region exhibits some degree of sequence and length variation, thus providing a basis for intra-species differentiation. The vast majority of rhizobial strains we studied possess a single copy of ITS fragment with sequence length of 500-1300 base pairs (bp), but a few others have two copies, indicating the presence of multiple copies of the ribosomal RNA (rRNA) operon (Bala *et al.*, 2002; Bala *et al.*, 2003a). An operon is a unit of genomic **DNA** of specific size that contains a cluster of genes, in this case rRNA genes encoding for ribosomes, under the control of a single promoter. The possession of multiple copies of the rRNA operon is thought to confer on the bacterium the ability to rapidly respond to favourable changes in growth conditions and may explain why some strains have greater saprophytic competence than others.

Ecology of Rhizobia

It is generally accepted that rhizobia co-evolved with their host legumes such that the plant's centre of diversity coincides with that of the rhizobia. However, the introduction of legumes into new areas where they had hitherto not been cultivated must have contributed to the spread of rhizobia across continents, and these introduced rhizobia become naturalised in their new environment with time. For example, *R. tropici*, a symbiont of *Phaseolus vulgaris* and *Leucaena. leucocephala*, which is common in acid soils of Brazil, has also been found in soils of Central America, Southeast Asia, and several African countries, including Nigeria (Bala *et al.*, 2003a). Conversely, our study also revealed that local rhizobia which evolved to nodulate indigenous legumes in some soils are also able to form associations with introduced leguminous species.

The survival of rhizobia in a locality and their ability to nodulate and fix nitrogen are strongly influenced by the prevailing environmental conditions, including soil particle size and soil acidity (Bala *et al.*, 2002; Bala *et al.*, 2003b). Increasing soil particle size has an adverse effect on soil rhizobial populations, especially in areas with high evapotranspiration rates and low precipitation. This effect of soil particle size is illustrated by the results of a study conducted on *Sesbania sesban*, a multipurpose agro-forestry tree, using fifty three soils sampled from three southern African soils – Malawi, Zambia and Zimbabwe ((Bala *et al.*, 2002). This plant formed nodules in only twenty per cent of the soils tested; where nodulation occurred, it was often in soils with clay contents of at least 10%. Given that a large proportion of arable lands in sub-Saharan Africa are characterised by low clay contents, the use of organic residues to enhance the organic matter contents of such soils becomes imperative . if an appreciable population of indigenous rhizobia is to be sustained in such soils.

The stress due to soil acidity is expressed as hydrogen ion activity (pH) and/or aluminium concentration (Exchange acidity). High soil exchange acidity or low soil pH often results in decreasing rhizobial numbers and intra-species diversity (Bala *et al.*, 2003a; Bala *et al.*, 2003b; Bala *et al.*, 2006). A further insight into the effect of such stresses on intra-species diversity was revealed by a study we conducted using soil dilution as a form of pedoturbation (Bala *et al.*, 2001). We observed in that study distinct shifts in the structure of rhizobial populations with increasing dilution, with new strains being sampled as others were diluted out. This maintained the level of apparent diversity of the population for several rounds of dilution before a steep decline in diversity occurred (Fig. 3). However, the changes in the population structure and the eventual decline in apparent diversity due to dilution did not adversely affect the efficiency of N_2-fixation except at the highest level of dilution when most of the strains had been diluted out.

Unlike intra-species diversity, the influence of soil acidity on inter-species diversity tends to be exerted on species abundance rather than the overall diversity of the community. Figure 4 shows changes in species dominance due to soil acidity, with acid-tolerant rhizobial types of the genus *Rhizobium* dominating the rhizobial population at low soil pH, while species of *Mesorhizobium* and *Sinorhizobium* were more prevalent at higher pH (Bala *et al.*, 2006). Just like the effect of dilution stress, the efficiency of N_2-fixation was not impaired as a result of the stress due to acidity (Bala *et al.*, 2003b). The deduction that can be made from these findings is that genetic diversity within natural populations of rhizobia confers on such populations the resilience to withstand pedoturbation in so far as N_2-fixation as a function is concerned.

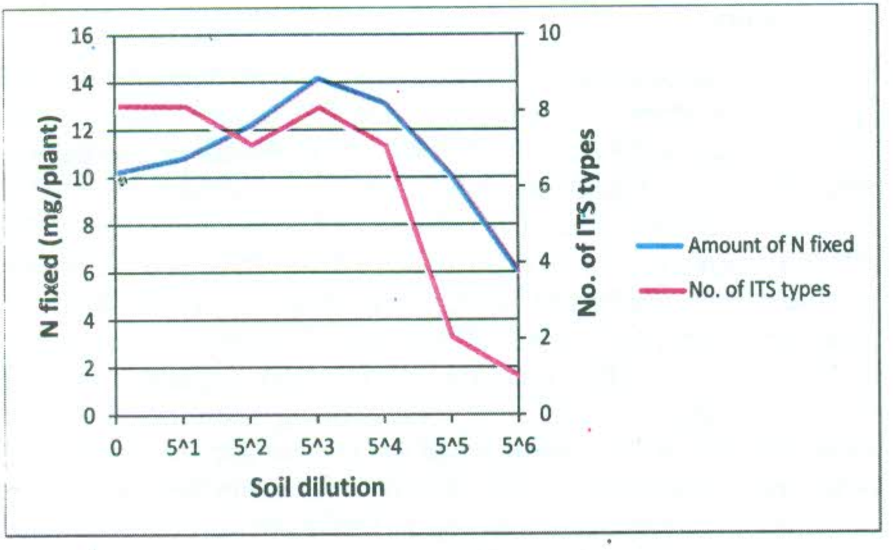


Figure 3. Changes in apparent rhizobial diversity based on ITS types and the amount of N_2 fixed in three legume hosts after inoculation with a gradient of soil dilutions. Adapted from Bala *et al.* (2001)

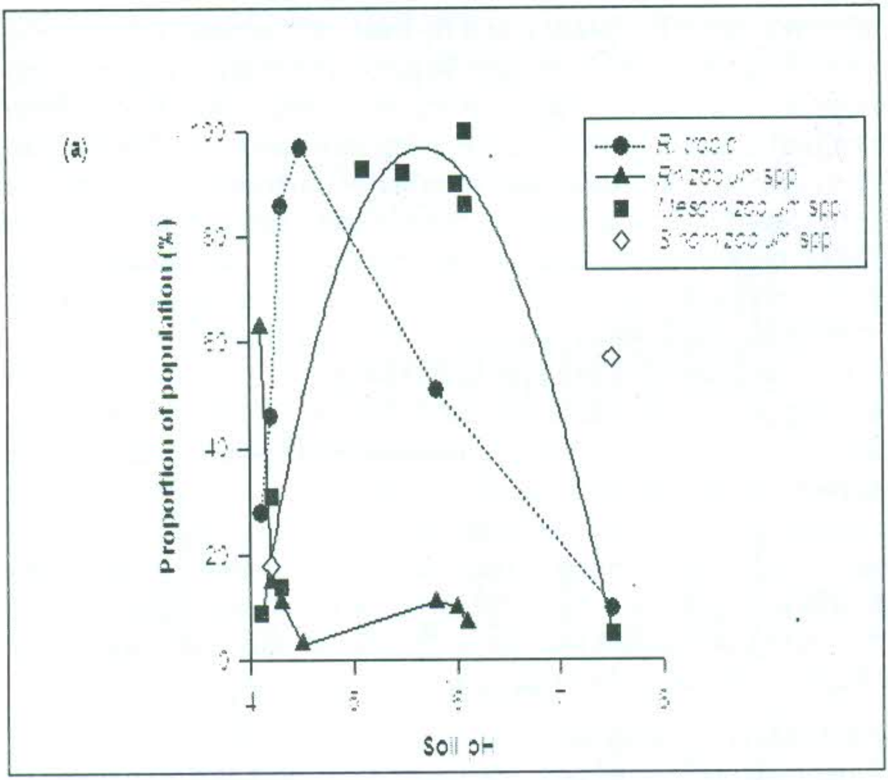


Figure 4. Relationship between the relative dominance of rhizobial types and soil pH (Bala *et al.*, 2006)

Symbiotic Relationships between Legumes and Rhizobia

The symbiosis between legumes and rhizobia involves two stages – nodulation and nitrogen fixation. Thus specificity of the symbiosis is defined in terms of infectiveness and effectiveness, respectively. Infectiveness is the ability of a rhizobial strain to form nodules with a particular legume, while effectiveness is the ability of those nodules to fix nitrogen. Given the series of recognition events and the involvement of molecular signalling between rhizobia and host legumes in the process of nodule formation, it is rather unsurprising that specificity should occur at each stage of nodulation and N_2-fixation. This may explain why some legumes never nodulate. In general, however, legumes and rhizobia vary in the range of partners they are able to form symbiotic association with. Some legume hosts and rhizobia can form symbioses with a small number of partners and, hence, are considered as being specific. Others can associate with a wide range of symbionts and are deemed to be promiscuous (or permissive). Between these extremes, there is a great variation among legumes and rhizobia in terms of their specificities in nodulation and N_2-fixation with the range of partners often overlapping (Bala and Giller, 2001; Bala *et al.*, 2003b, Bala *et al.*, 2006). Some rhizobial strains can elicit and form nodules on host plants but fail to fix N. Such nodules are considered as being ineffective and the relationship between the host and microsymbiont deemed to be parasitic. Those that are able to fix N often do so with varied degree of efficiency (Fig. 5), thus providing the basis for the selection of efficient strains for rhizobial inoculant formulation.

Rhizobial Inoculation

Rhizobial inoculation is the deliberate introduction of rhizobia to soil in order to establish nodulation and effective N_2-fixation in legumes. Usually, inoculation becomes necessary when the compatible rhizobia are absent, their population is small, or the indigenous rhizobia are ineffective or less efficient than inoculant strains. We have conducted large-scale inoculation trials on promiscuous soybeans within the Nigerian savanna that have led to on-farm yield increases of between five and sixty per cent resulting in average raise in soybean yield from less than 1000 kg/ha to nearly 2000 kg/ha. Application of phosphate fertiliser is a key to successful inoculation in the Nigerian savanna as most soils responded to the application of 17.5 kg P ha^{-1} (Fig. 6). In general, however, the magnitude of response to inoculation varies according to location, with the number of nodules occupied by inoculant strains also determined by other factors such as soil organic matter content and the population of resident rhizobia (Bala *et al.*, 2003c; Osunde *et al.* 2003b).

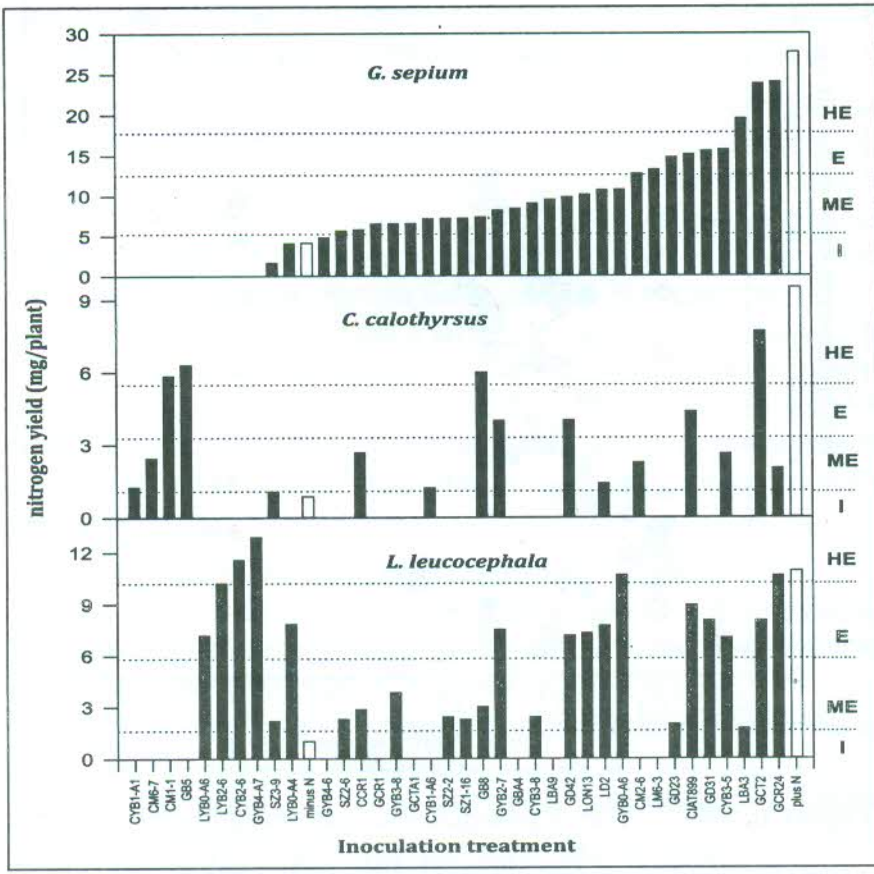


Figure 5. Total N accumulation by seedlings of tree legumes 8 weeks after inoculation with their rhizobia and those of *S. sesban*. Areas between dotted lines are the confidence intervals for ineffective (I), moderately effective (ME), effective (E) and highly effective (HE) nodulations. Open histograms indicate -N or +N controls. (Bala and Giller, 2001).

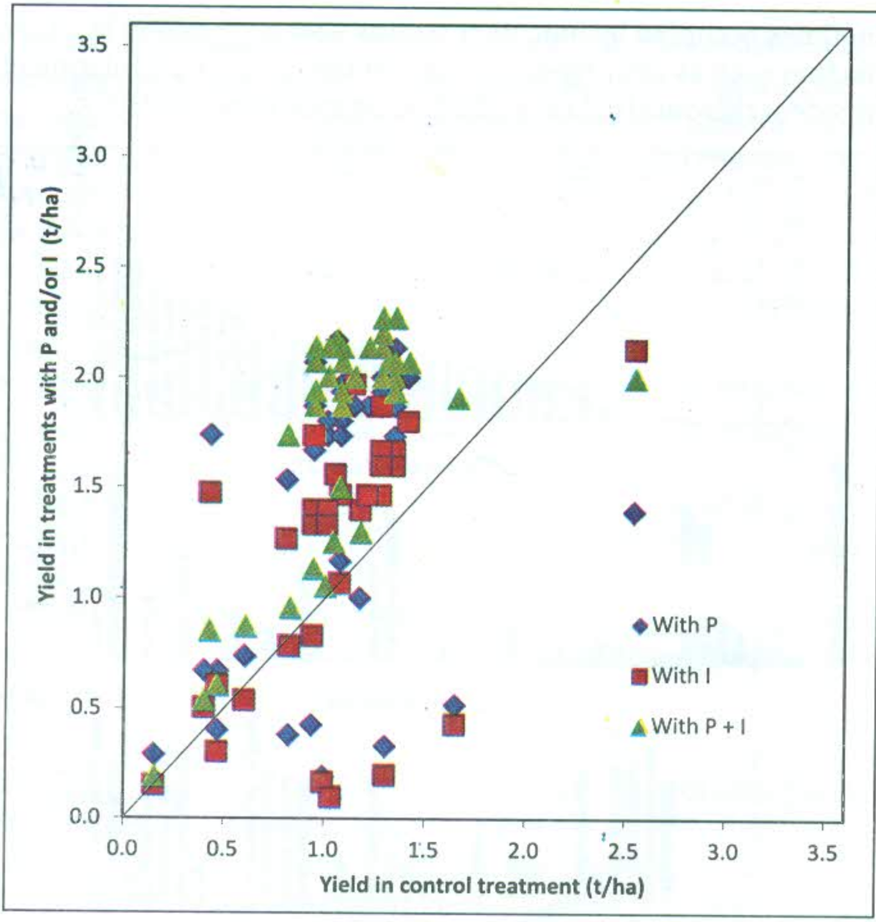


Figure 6. Grain yields of promiscuous soybeans in forty farmers' fields in the Nigerian savanna in response to the application of phosphorus (P) and/or inoculation (I) (Unpublished data).

It is generally assumed that response to inoculation is likely where the indigenous rhizobial population is less than 50 cells g^{-1} soil. However, our experience with promiscuous soybean shows that response to inoculation is possible even in some fields that have more than 1.0×10^7 cells g^{-1}, suggesting that the competitiveness of the inoculant strain is also important for inoculation to succeed. Thus, the success of inoculation will not only depend on the environment, but also the symbiotic quality (effectiveness and competitiveness) of the inoculant strains.

Rhizobial inoculation of promiscuous soybeans often causes an increase in arbuscular mycorrhizal fungi (AMF) infection of the plants' roots sometimes by as much as 50% (Bala *et al.*, 2003c; Osunde *et al.*, 2003a; Osunde *et al.*, 2003b). AMF are specialised fungi that form a symbiotic association, known as mycorrhiza, with roots of plants. Mycorrhizae enable the plant to access nutrients, especially P, from a larger volume of soil than would have been possible without the association. The increase in AMF due to rhizobial inoculation may, therefore, partly be as a result of improved growth of the inoculated plant, which in turn leads to greater demand for phosphorus and, hence, enhanced AMF infection.

Role of Legumes in Food and Nutrition Security

Food security is said to exist ***"when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life"*** (FAO, 1996). It is built on three pillars:

* ***Food availability: presence of sufficient quantities of food on a consistent basis.***
* ***Food access: having adequate resources to obtain suitable foods for a nutritious diet.***
* ***Food utilisation: appropriate use based on knowledge of basic nutrition and care.***

Nutrition security on the other hand ***"means access by all people at all times to the adequate utilization and absorption of nutrients in food, in order to be able to live a healthy and active life".***

The concept of food and nutrition security (FNS) addresses not only under-nutrition but also the so-called diseases of the rich –where increased intake of sugar, fat and sodium is resulting in increased cases of obesity and the attendant ailments that go with them. Thus FNS emphasises the importance of dietary quality as much as total energy intake.

The contribution of legumes to food and nutrition security is majorly in three key areas, namely as food, as animal feed and soil fertility improvement.

Legumes as Food

Effective symbiosis with rhizobia ensures that legume seeds and leaves are high in protein, which makes them valuable crop plants throughout the world. Grain legumes are second only to cereals in terms of their importance as food. Nutritionally, legume seeds have two to fourfold more protein than cereals (Table 3) and also provide those essential amino acids, such as lysine, that are not found in sufficient amounts in cereal crops. For instance, the protein contained in soybean, also called soy protein, is generally considered as 'complete protein', that is, a protein that contains significant amounts of all the essential amino acids, which must be ingested because the human body cannot on its own produce them. Legume seeds may also contain double to three-fold more minerals and vitamins (Table 3) as well as a greater range in the types of these nutrients than cereals.

Table 3. Nutrient composition of selected Nigerian food staples based on a serving size of 100g

Food	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrates (g)	Minerals (mg)	Vitamins (mg)
Maize	371	7.80	3.4	83.3	1037.40	4.03
Rice	370	7.94	2.92	77.24	732.49	6.71
Sorghum	329	10.62	3.46	72.09	837.03	5.08
Millet	378	11.02	4.22	72.85	611.69	5.95
Cowpea	343	23.85	2.07	59.64	2305.06	6.15
Groundnut	567	25.8	49.24	16.13	1366.85	21.76
Soybean	446	36.49	19.94	30.16	3080.59	11.02
Daily Requirement[a]	**478-2462[b]**	**46.2**	**70**	**100**	**1688.47**	**94.94**

[a]Average daily dietary requirement for average weight of 70 kg; [b]Variable values depending on age and level of physical activity.

Source: USDA (2015); British Nutrition Foundation (2015)

Out of the thousands of known species of legumes, less than thirty are cultivated extensively and those cultivated for their grains include the common ones such as peas, lentils, chickpeas, kidney beans, soybeans, groundnut and cowpeas. In Nigeria, legumes are usually a component of most cropping systems as they serve as a major source of food staples and a rich source of N in human diets (Osunde and Bala, 2000; Osunde and Bala, 2005). In addition, some species, such as soybeans and groundnuts, are important oil seed crops; others, such as winged bean and *Pachyrhizus*, produce edible tubers, while the green pods of some, such as peas, cowpea and kidney beans, are used as vegetables.

The global protein supply continues to improve due, in part, to increased levels of income and urbanization. Protein supply in the world has increased by eight percent since 1999 and is currently at about 80 g/capita/day (Fig. 7). Both the African and

Nigerian supply levels are lower than the global average but have also improved since the turn of the Millennium by about twelve and nine per cents, respectively.

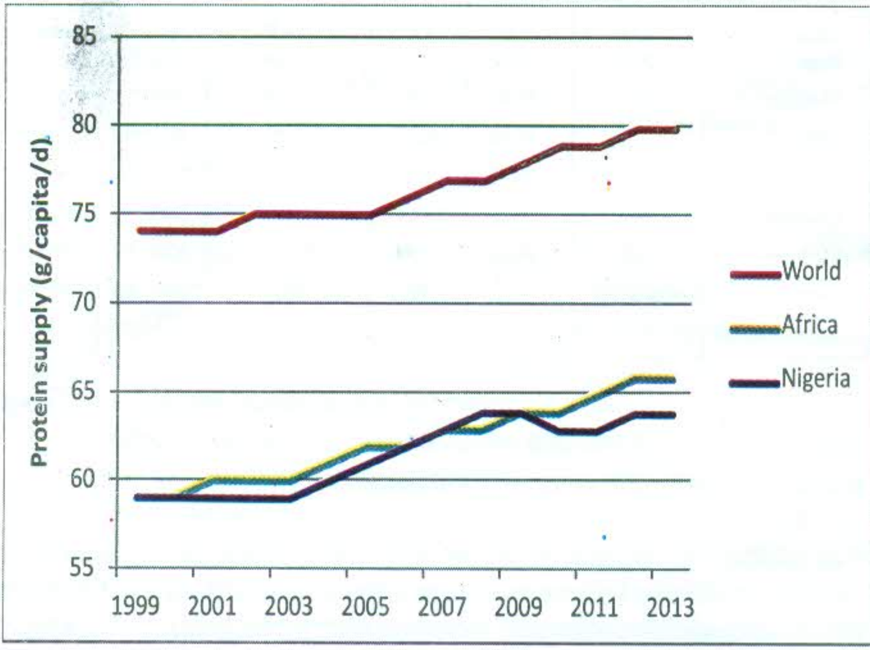


Figure 7. Global per capita protein supply between 1999 and 2013

In spite of the global increase in the consumption of animal protein, plant protein has remained the major source of dietary protein in human diet, experiencing only marginal decreases within the last one and a half decade (Fig. 8). Currently, the share of dietary protein from plants is about 60% globally, 80% in sub-Saharan Africa and 85% in Nigeria.

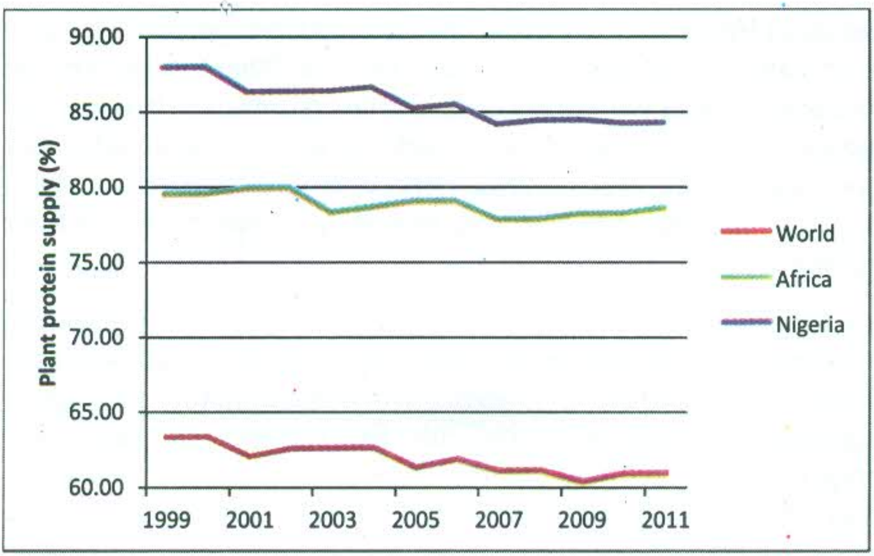


Figure 8. Contribution of plant protein to global average daily protein supply (FAOSTAT, 2015)

Legumes as Animal Feeds

Seeds of some legumes, such as groundnut and soybean are useful components of animal feed formulations. Groundnut cake is often used for protein and energy supplementation in cattle feed and its low fibre and high protein contents make it a useful ingredient for poultry feeds. Globally, soybean is an indispensable component of most feeds formulated for poultry, and other categories of livestock. The outstanding essential amino acids profile and their high digestibility make soybean meal to be an excellent component of animal feed.

Legumes are commonly included in pastures in order to improve fodder quality because of their rich N content, thus providing an additional source of protein to grazing animals especially in dry seasons when the quality of grass is poor. Examples of forage legumes used for pasture improvements in Nigeria include siratro (*Macroptilium atropurpureum*), stylo (*Stylosanthes* spp.) and calapo (*Calopogonium mucunoides*). The foliage and/or fruits of several woody shrub and tree legumes are browsed by goats and other animals especially during seasonally dry periods. In some areas, animal herders would often cut or lop off some of the high-hanging tree branches in order to feed their animals.

In Nigeria and much of West Africa, cowpea and groundnut haulms are good sources of fodder, especially for small ruminant livestock, during the dry season when good quality herbage is limited. This makes it difficult for farmers to adopt soil improvement technologies that rely on the incorporation into soil of such legume residues. However, the animal waste generated after feeding on the residues still contains appreciable amounts of N, which if added to soil will improve the N as well as organic matter levels in the soil. In a survey across Niger and Kwara States as well as the Federal Capital Territory, nearly seventy per cent of the crop farmers were reported to be keeping various categories of livestock but although the average per capita generation of farmyard manure was about 1 $t\,yr^{-1}$, less than half of this group applies the manure to their farmlands (Anyika *et al.*, 2008; Bala *et al.*, 2011). This provides both an opportunity and a challenge in getting farmers to collect and return to their farms manure generated from the consumption of legume residues.

Legumes as Enhancers of Soil Fertility and Productivity

Improving soil fertility and soil productivity enhances general agricultural productivity and improves food systems quantitatively and qualitatively, and thus contributes to global food and nutrition security. Cultivating cereals and legumes in mixtures is a widespread practice in Nigeria as the legumes serve to improve the nitrogen economy of the system, as well as control weed infestation, soil erosion and decline in soil organic carbon (Osunde and Bala, 2000; Osunde *et al.*, 2004). While there is little evidence of direct N transfer from legumes to companion crops in intercrops, the companion crops benefit from such mixtures by utilising the N that accrues from legume roots senescence and decomposition. Additionally, the companion crop may also have access to the N spared in the soil resulting from the legume meeting part of its N needs through N_2-fixation. Cereals grown after legumes often exhibit better growth than cereals after cereals because of residual benefits due to the decomposition of the legume leaf litter, roots and incorporated haulms (Bala *et al.*, 2003c; Osunde *et al.*, 2003a). We have also observed that enhanced AMF infection of legume roots due to rhizobial inoculation is often carried over to the following maize crop in rotations, which also exhibits improved AMF infection of its roots (Osunde *et al.*, 2003a; Osunde *et al.*, 2003b; Bala *et al.*, 2003c).

Some legumes are grown as green manures - crops grown specifically for use as organic manure. They are incorporated into the soil while they are still succulent and green which facilitates a rapid mineralisation of the N in the legume residue. A number of herbaceous and grain legumes including *Canavalia ensiformis*, *Mucuna cocchinensis*, *Sesbania rostrata* and *Aeschynomene indica*, have been found to be useful as green manures in upland and lowland systems (Adeboye *et al.*, 2009; Usman *et al.*, 2006; Usman *et al.*, 2013). However, the rhizobia that effectively nodulate some of these green manure legume species are either absent or exist in low numbers in many soils; hence green manure legumes are likely to benefit from inoculation using highly effective rhizobial strains.

Growing legumes in mixtures or rotation with cereals also decreases the risk of pests and diseases. For example, soybean is known to induce 'suicidal germination' in *Striga* spp., a common weed in sub-Saharan Africa, which devastates cereals (mainly sorghum, millet and maize) and to some extent legumes (cowpea and groundnut). This reduces the seed bank of the parasite in a soil and thus minimises infestation of companion or subsequent crops. In East Africa, the International Centre of Insect Physiology and Ecology (ICIPE), developed the 'Push-Pull' technology involving a legume, *Desmodium uncinatum* (silverleaf desmodium), and a grass, *Pennisetum purpureum* (Napier grass) for the biological control of stem borers and *Striga* in maize and improvement of soil fertility. Maize is intercropped with the desmodium, while the Napier grass is planted around the intercrop. While the desmodium secretes volatile chemicals that repel (push) female moths away from the maize plant, the Napier grass releases other compounds that attract (pull) the moths to lay eggs on the grass. The desmodium roots also secrete isoflavonoid chemicals that induce suicidal germination in *Striga* and at the same time contribute to N inputs in the system through N_2-fixation. This allows farmers to have three harvests – maize for their diets and good quality fodder from desmodium and Napier grass for their animals (ICIPE, 2015).

The N2Africa Project

A question that may keep recurring in the minds of members of the audience is how has all of the knowledge generated from my work been used to benefit the Nigerian, and indeed the African farmer? Actually, quite a lot of effort has been directed at making the knowledge and technologies garnered to work for the African farmer. In April 2008, I was one of 25 international scientists invited by the Bill and Melinda Gates Foundation (BMGF) for a two-day Convening on Nitrogen Fixation at the Foundation's headquarters in Seattle, USA. Soon after, one of the participants at that meeting, Professor Ken Giller of Wageningen University, The Netherlands, was invited by BMGF to form a core group of African scientists with expertise in Rhizobiology to prepare a concept note for funding. I was privileged to be part of the group and had the honour of preparing the first draft of the concept, which was presented at the 13th Congress of African Association of Biological Nitrogen Fixation in Hammamet, Tunisia in December, 2008. A special session was organised at the conference for the participants to discuss the concept. This was followed by a planning workshop in Mombasa, Kenya, attended by about 25 international scientists that led to the development of a full proposal, which was submitted to BMGF. After numerous discussions and adjustments to match the strategy of the Foundation, the project was approved and started in September 2009 (Giller *et al.*, 2014).

N2Africa is an acronym for ***'Putting Nitrogen Fixation to Work for Smallholder Farmers in Africa'*** (www.n2africa.org). It is a project that aims at increasing grain legume production and the inputs from N_2-fixation in smallholder farming systems in sub-Saharan Africa. The project focuses on four major grain legumes: common bean (*Phaseolus vulgaris* L.), cowpea (*Vigna unguiculata* (L.) Walp.), groundnut (*Arachis hypogaea* L.) and soybean (*Glycine max* (L.) Merrill) and legume forages. The project started with eight countries - Democratic Republic of Congo, Ghana, Kenya, Malawi, Mozambique, Nigeria, Rwanda and Zimbabwe - but the impact was so obvious within the first two years that additional funding was provided by the Howard G. Buffet Foundation to expand activities to Ethiopia, Uganda, Tanzania, Liberia and Sierra Leone.

We used existing knowledge and technologies developed from previous research efforts in the continent to:

1) Increase the farm area cropped with legumes;
2) Enhance legume productivity through the use of phosphorus fertilizer and good agronomic practices;
3) Introduce improved legume varieties with good pest and disease resistance, grain and nutritional quality and yield;
4) Inoculate with rhizobia where needed and select better

rhizobial strains; and

5) Link farmers to markets and add value through local processing.

At the end of the first phase of the project, over 253,000 households benefitted from the project in the eight countries that started the project, resulting in average increases of 146 kg grain ha^{-1}, 43,000 ha legume area, 17 kg N ha^{-1} $farm^{-1}$, and crop value of \$224 $farm^{-1}$ $season^{-1}$ (Woomer *et al.*, 2014). There were huge variations in attainment of targets across the various countries, with Nigeria and Kenya out-performing the other countries. The performance in Nigeria was so outstanding that we had the honour of hosting the Co-chair of BMGF, Mr Bill Gates within the first two years of project commencement, which afforded him and other management staff of BMGF the opportunity to observe first-hand project activities and to interact with some of the farmers, extension staff and other stakeholders involved with the project (Plates 3 & 4).

As a confirmation of its impact and relevance to the developmental needs of the African farmer, the N2Africa project was one of three outstanding projects that were chosen as winners of the Secure Nutrition Knowledge Platform 2013 Harvesting Nutrition Contest. Organised by the World Bank in collaboration with the Global Alliance for Improved Nutrition (GAIN) and Save the Children UK, the 'Harvesting Nutrition Celebration: A Showcase of Award-Winning Agriculture-Nutrition' award giving ceremony took place on 19 February, 2015 at the World Bank Headquarters, in Washington D C. The projects were selected for bridging the gap between nutrition, agriculture, and food security. The N2Africa project was the winner in the Most Scalable Approach category, in recognition of its effort in scaling out technologies that bring about better nutrition through promoting legume production among small-holder farmers in sub-Saharan Africa.

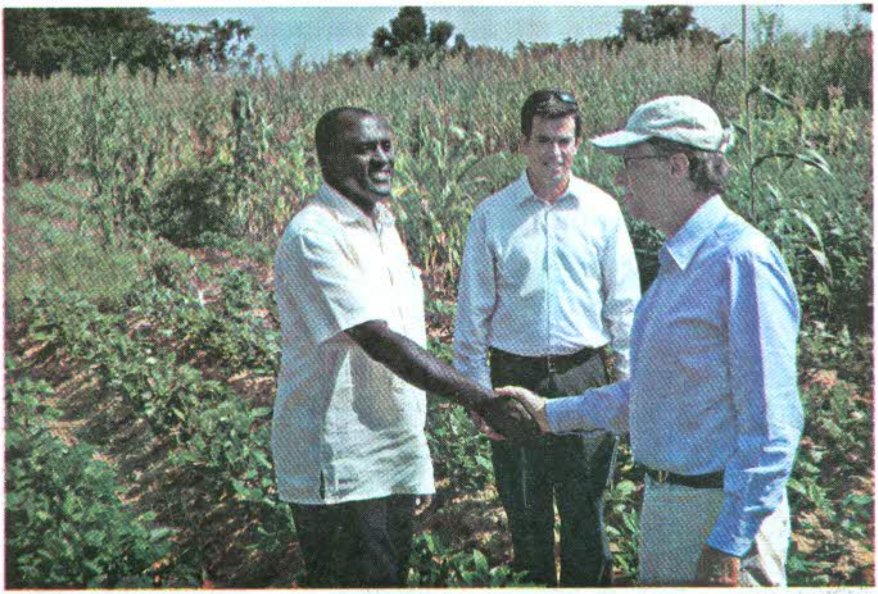


Plate 3. The lecturer, Professor Abdullahi Bala, welcoming the Co-Chair of BMGF, Mr. Bill Gates, to an inoculant technology demonstration site in Bichi LGA, Kano State.

Challenges and Limitations of BNF

Harnessing the opportunities offered by BNF in form of improved nutrition, soil fertility, farm incomes and livelihoods is constrained by a number of environmental and socio-economic and institutional factors. In the course of the implementation of the N2Africa project, we found the following to be particularly germane to the success of the project:

(1) Dearth of trained staff at all technical/academic levels in the area of Rhizobiology, which is the study and application of root nodule bacteria associated with symbiotic legumes. A striking discovery is the near absence of scientists trained to degree level in this area and the few technicians available are at advanced states of their career close to their retirements. Osunde and Bala (2000) had earlier related this shortage of skilled

manpower to brain drain and general inadequate funding of research in Nigeria. To make progress, we had to train a cadre of technicians and young scientists to be able to carry out basic tasks in laboratories and greenhouses. A total of 14 M.Sc and six PhD candidates were also selected across the eight countries for advanced degree training in Rhizobiology and allied areas.

Plate 4. Professor Abdullahi Bala demonstrating the effects of various rhizobial inoculation treatments on soybean yield to Mr. Bill Gates and other Senior Management staff of BMGF.

(2) Difficulties in accessing high quality inoculants in Africa: Although inoculation and inoculant production have been in existence in Africa since the 1930s, most inoculant production facilities do not have in place requisite quality control mechanisms to ensure good quality inoculants – products with consistently high rhizobial numbers per unit of carrier that are

free of contaminants. The use of such low quality inoculants often gives poor results, leading to the impression of non-necessity of inoculation and general disillusionment with the practice. In trying to address this problem, some existing facilities in countries such as Kenya and Zimbabwe were capacitated through equipment upgrade and manpower development to improve on the quality of their products. In Nigeria, a pilot inoculant plant has been built at the International Institute of Tropical Agriculture, Ibadan, and the products with proprietary name *Nodumax* are due to be on sale in the forth-coming cropping season.

(3) Lack of useful inoculant quality control regulations in Africa: Given the poor quality of inoculants produced within the continent, we have had cause to import inoculants for development and research works in several countries with varying degrees of difficulties. Although trans-border movements of inoculants are generally controlled through the issuance of import permits and phytosanitary certificates, there are hardly any laws that deal with inoculant manufacture or product registration. This often results in tentativeness among Government officials and decisions are regularly left to the discretion of such officers. There is, therefore, a need to push for legislation or at least modify some of the existing laws to cover rhizobial inoculant production, use and handling.

(4) Non-responsive soils: Nutrient limitations in soils of the Nigerian savanna and elsewhere in sub-Saharan Africa are widespread and these affect the efficiency of N_2-fixation in agricultural systems. For example, legumes often respond to the application of P and K (Osunde *et al.*, 2002; Bala *et al.*, 2003c; Adeboye *et al.*, 2012) as well as micronutrient fertilisers (Uzoma *et al.*, 2013a; Uzoma *et al.*, 2013b) and different legume varieties may show differential response to low P in soils (Osunde *et al.*, 2007). There are, however, some soils at some sites that have

shown striking non-responsiveness to P application and/or inoculation. These included sandy nutrient depleted soils in west Kenya, Zimbabwe and Malawi; highly weathered soils in northern Rwanda and DR Congo; and shallow nutrient depleted savanna soils of Nigeria and Ghana. Greenhouse studies have shown most of the soils to be deficient in one or more of potassium, magnesium and zinc (Woomer *et al.*, 2014). Fertiliser blends formulated to address such nutrient deficiencies have been found useful in west Kenya, while use of farmyard manure was recommended for use in Rwanda and Congo. In Nigeria, a combination of organic manure and compound fertilisers are undergoing trials.

(5) Inadequate linkage of farmers to market: A major institutional constraint that cuts across many of the African countries where we have worked in is the misalignment between supply and demand. For instance, there is a national deficit for soybean in many countries, with demand said to outstrip supply. Very often, however, we encounter farmers in rural areas complaining of lack of market for their produce. In Nigeria, the formal soybean processing sector has an installed capacity of more than 700,000 tonnes per annum, but annual soybean production is estimated at nearly 550,000 tonnes. This has led to middlemen getting supplies of soybean from as far as Chad and Cameroun due supposedly to the insufficient supply from local sources; meanwhile farmers tend to shy away from up scaling their production for fear of lack of market. Clearly, more effort is required at linking produce aggregators with soybean producers at the local level.

The other side of the coin to this problem is inadequate access to inputs by farmers, with most input distributors tending to remain in urban areas, rather than in the countryside where the bulk of the farmers reside. Inadequate access to fertilisers is a good example; in addition to poor distribution, single superphosphate fertiliser, which is the main fertiliser material suitable for legume production, is often imported in low quantities, thus causing more difficulty in access. Other agricultural inputs, such as pesticides and certified seeds pose similar challenges to efforts at boosting production of legumes in Nigeria. For instance, one of the medium term goals of the Maize and Soybean Transformation Agenda is to triple soybean production within a three-year time-frame, but this looks unachievable due in part to the lack of requisite supplies of good quality seeds. Deliberate efforts must be made by governments and input distributors to improve the gaping gap that currently exists between farmers' needs and input supplies if tangible progress is to be made in the nation's desire to improve production output. One way to do this is for Government to partner with the private sector in setting up 'one stop input outlets' in rural communities, such that a farmer can obtain all requisite inputs at one location in a timely manner.

Conclusion

We are constantly living in contact with an atmosphere that is awash with nitrogen, yet this nutrient is the most limiting in most soils and is the primary cause of low crop productivity in terms of nutrient limitations. Large sums of money are annually expended on purchasing nitrogenous fertilisers in addition to the huge environmental costs incurred due to the burning of fossil fuels in producing these fertilisers. BNF resulting from the symbiosis between legumes and rhizobia provides us with an opportunity to reduce our reliance on nitrogenous fertilisers because the legume host plant is able to meet part of its N requirement from this process and thus enables the plant to grow in N limiting environments, a feat that cereals are not capable of. Some of the fixed N contained in the legume residues, such as roots, leaf litter and haulms, becomes available, through decomposition of the residues over time, to other non-fixing crops that are in rotation or combination with the legumes.

Various parts of the legume also serve as good sources of N for food and fodder. Grain legumes provide edible seeds that are rich in nitrogen and which are processed into a wide variety of protein-rich products, thus constituting the major source of protein in the diets of the poor in most parts of sub-Saharan Africa. Additionally, grain legumes have a good market value and often serve as cash crops and sources of income to families. Many types of legumes also serve as excellent sources of feed and fodder to livestock, especially during the dry season when animal feeds are in short supply.

Based on the foregoing, legumes represent a key and direct source of highly nutritious and relatively cheap and affordable food for man as well as feed and fodder for livestock and are thus significant contributors to increased food and nutrition security of poor households. Considering their role in reducing costs of food for poor consumers and enhancing family incomes and livelihoods, they could play a key role in the overall strategy for the reduction of poverty especially in rural households. Given that agricultural productivity and improved food systems are central to achieving global food and nutrition security, and considering that one of the Millennium Development Goals (MDG 2) is to ***'Eradicate poverty and hunger'***, harnessing the legume-rhizobium symbiosis for the food and nutrition security of the poor becomes an imperative. One way of doing this is by increasing legume production output through one or combinations of land area expansion, frequency of cultivation and improved yields.

Acknowledgement

All praises and gratitude are due to Allah, the Beneficent and the Merciful, who has made me who and what I am today. I thank Him for His favours; for He has given me more than I could ever have asked for. O Allah! Your Name shall forever remain glorified.

Words cannot fully express the deep sense of awe and gratitude for the toil and sacrifices that my late parents, Alhaji Jibrin Bala and Hajiya Fatima Abdullahi Bako, had to make in ensuring that my siblings and I had a decent upbringing, as best of both Western and Islamic education as possible and a chance in life. I shall forever remain grateful to them for making me understand that not all that glitters is gold and for instilling in us the fear of God and the virtues of contentment, humility, hard work and worship. I continue to glorify Allah for your lives well spent and pray that He rewards you with Aljannat Firdaus.

My beloved wives, Talatu and Amina, you have been strong pillars of support to me and I feel blessed to have you as lifetime partners. I shall remain ever grateful to you both for your love, prayers and encouragement. You have shown immense forbearance in taking care of the home in spite of my long stays in the office and frequent travels. May Allah reward you abundantly. To my sons, Jibril, Ayman, Ibrahim and Faisal, I thank you for putting a smile on my face and for making life more meaningful. May Allah continue to bless and guide you.

In my life time, I have come across several people, too numerous to mention, who in their own different ways have contributed to who and what I am today. These include members of my immediate and extended family, my friends and well-wishers, mates and teachers in the various schools I attended, colleagues at various places of work and forums, students and other acquaintances. I am highly honoured for your being part of the tapestry of my life and am greatly indebted to you for the value you added to that life. I feel tremendously obligated to certain

people who, supported, prodded, encouraged, and even whipped me in line at critical stages of my education and career. I consider these people as my mentors, hence the need to single them out for mentioning. They include Mr. and Mrs. M. K. Pele, Prof. V. O. Chude, Prof. A. O. Osunde, Prof. K. E. Giller and the late Prof. A. M. Falaki, who was brutally murdered by some elements within the Nigeria Police in February this year. May his gentle soul rest in peace, Amen.

I am immensely grateful to the authorities of the Federal University of Technology, Minna for their support, through fellowships, leaves, and sponsorships, in furthering my education and career and for finding me worthy of serving the University in different capacities. I am particularly appreciative of the love and support as well as the camaraderie I enjoy from the members of Management and other organs of the University.

Finally, I thank members of the University Seminar and Colloquium Committee, led by Prof. (Mrs.) Z. D. Osunde, for making today a reality. I shall not forget to appreciate the presence of all of you here and the prayers and support of others who, for various reasons, are unable to be present here.

I thank you all for your kind attention!

References

Adebo, G. M. (2014). Effectiveness of e-wallet practice in grassroots agricultural services delivery in Nigeria - a case study of Kwara State Growth Enhancement Support Scheme. Journal of Experimental Biology and Agricultural Sciences 2, 410-418.

Adeboye, M. K. A., Ibrahim, P. A., Osunde, A. O. and Bala, A. (2009). Evaluation of *Sesbania rostrata* and *Aeschynomene indica* fertilised with phosphorous as pre-rice green manure in the inland valley swamps of southern Guinea savanna of Nigeria. Journal of Applied Agricultural Research 1, 119-126.

Anyika, C. C., Odofin, A. J., Tsado, P. and Bala, A. (2008). Raw materials used for production of organic fertilizer and their competing uses in Abuja (FCT), Niger and Kwara States. Journal of Research in Agriculture 5, 72-76.

Bala, A. and Giller, K. E. (2001). Symbiotic specificity of tropical tree rhizobia for host legumes. New Phytologist 149, 495-507.

Bala, A. and Giller, K. E. (2006). Relationships between rhizobial diversity and host legume nodulation and nitrogen fixation in tropical ecosystems. Nutrient Cycling in Agroecosystems 76, 319-330.

Bala, A., Murphy, P. and Giller, K.E. (2001). Genetic diversity of rhizobia from natural populations varies with the soil dilution sampled. Soil Biology and Biochemistry, 33, 841-843.

Bala, A., Murphy, P. and Giller, K. E. (2002).Occurrence and genetic diversity of rhizobia nodulating *Sesbania sesban* ing African soils. Soil Biology and Biochemistry 34, 1759-1768.

Bala, A., Murphy, P. and Giller, K. E. (2003a). Distribution and diversity of rhizobia nodulating agroforestry legumes in soils from three continents in the tropics. Molecular Ecology 12, 917-929.

Bala, A., Murphy, P. J. and Giller, K. E. (2004). Classification of tropical tree rhizobia based on phenotypic characters forms nested clusters of phylogenetic groups. West African Journal of Applied Ecology 6, 9-19.

Bala, A., Murphy, P. J., Osunde, A. O. and Giller, K. E. (2003b). Nodulation of tree legumes and the ecology of their native rhizobial populations in tropical soils. Applied Soil Ecology 22, 211-223.

Bala, A., Osunde, A. O., Muhammad, A., Okogun, J. A. and Sanginga, N. (2003c). Residual benefits of promiscuous soybean to maize in an Alfisol of Nigeria's southern Guinea savanna. Nigerian Journal of Soil Science 13, 7-20.

Bala, A., Osunde, A. O. and Odofin, A. J. (2011). Organic matter utilisation and the determinants of organic manure use by farmers in north central Nigeria. *In* Bationo, A., Waswa, B. S., Okeyo, J., Maina, F. and Kihara, J. (eds.) SI: Innovations as Key to the Green Revolution in Africa: Exploring the Scientific Facts, pp. 965-974.

British Nutrition Foundation (2015). Nutrient requirements. http://www.nutrition.org.uk/nutritionscience/nutrients/nutrient-requirements.html?start=2

Brockwell, J., Bottomley, P. J., and Thies, J. E. (1995). Manipulation of rhizobia microflora for improving legume productivity and soil fertility: A critical assessment. Plant and Soil 174, 143-180.

FAO. (1996). Rome Declaration on World Food Security and World Food Summit Plan of Action.http://www.fao.org/docrep/003/w3613e/w3613e00.htm

FAO. (2010). The State of Food Insecurity in the World 2010. http://www.fao.org/docrep/013/i1683e/i1683e.pdf

FAOSTAT. (2015). Food and Agricultural Organization of the United Nations, Statistics Division, http://faostat3.fao.org/home/E

Gauthier, D., Diem, H. G., Dommergues, Y. R. and Ganry, F. (1985). Assessment of N_2 fixation by *Casuarina equisetifolia* inoculated with *Frankia* ORS021001 using ^{15}N methods. Soil Biology and Biochemistry 17, 375–379.

Giller, K.E. (2001).Nitrogen Fixation in Tropical Cropping Systems, 2nd Edition. CABI Publishing, Wallingford, UK, 423 pp.

Giller, K. E., Franke, A. C., Abaidoo, R., Baijukya, F., Bala, A., Boahen, S., Dashiell, K., Kantengwa, S., Sanginga; J-M., Sanginga, N., Simmons, A., Turner, A., de Wolf, J., Woomer, P. and Vanlauwe, B. (2013). N2Africa: Putting nitrogen fixation to work for smallholder farmers in Africa. *In* Vanlauwe, B., van Asten, P. and Blomme, G. (eds.) Agro-Ecological Intensification of Agricultural Systems in the African Highlands. Routledge, London, pp. 156-174.

ICIPE. (2015). Push pull technology for the control of stem borers and *Striga* weed.http://www.push-pull.net/push_pull_works.htm.

NAERLS and NPAFS. (2010). Agricultural Performance Survey of 2010 wet season in Nigeria, NAERLS, Ahmadu Bello University, Zaria, 182 pp.

NAERLS and PRSD. (2013). Agricultural Performance Survey Report of 2013 Wet Season in Nigeria, NAERLS, Ahmadu Bello University, Zaria, 142 pp.

NPAFS. (2010). Report of the 2009 Agricultural Production

Survey (APS). National Programme for Agriculture and Food Security, Abuja, 86 pp.

Osunde, A. O. and Bala, A. (2001). Biological nitrogen fixation and farming systems in Nigeria: Problems and prospects. African Journal of Science and Technology 1, 11-14.

Osunde, A. O. and Bala, A. (2005). Nitrogen derived from promiscuous soybean in maize-based cropping system in the Moist savanna of Nigeria. Nigerian Journal of Soil Science 15, 109-115.

Osunde, A. O., Bala, A., Gwam, M. S., Tsado, P. A., Sanginga, N. and Okogun, J. A. (2003a). Residual benefits of promiscuous soybean to maize (*Zea mays* L.) grown on farmers' fields around Minna in the Southern Guinea savanna zone of Nigeria. Agriculture, Ecosystems and Environment 100, 209-220.

Osunde, A. O., Bala, A. and Uzoma, A. (2007). Differential response of cowpea (*Vigna unguiculata*) lines to phosphorus fertiliser in a low phosphorus soil in the Southern Guinea savanna of Nigeria. Nigerian Journal of Soil Science 17, 52-64.

Osunde, A. O., Gwam, M. S., Bala, A., Sanginga, N. and Okogun, J. A. (2003b). Responses to rhizobial inoculation by two promiscuous soybean cultivars in soils of the southern Guinea savanna zone of Nigeria. Biology and Fertility of Soils 37, 274-279.

Osunde, A.O., Tsado, P.A., Bala, A. and Sanginga, N. (2004). Productivity of a maize-promiscuous soybean intercrop as affected by fertiliser in the southern Guinea savanna zone of Nigeria. West African Journal of Applied Ecology 5, 51-61.

Raven, P. H. and Polhill, R. M. (1981). Biogeography of the Leguminosae. *In* Advances in Legume Systematics (R. M. Polhill and P. H. Raven, eds.), pp. 27-34, Vol. VI. Royal Botanic Gardens, Kew, London, UK.

SSSA. (2015). Why soil is important. www.soils.org

Sprent, J. I. (1995). Legume trees and shrubs in the tropics: N_2 fixation in perspective. Soil Biology and Biochemistry **27**, 401-407.

UNDP. (2014). UNDP 2014 Human Development Report, hdr.undp.org/en/countries/profiles/NGA. Downloaded 6th March 2015.

USDA (2015). National Nutrient Database for Standard Reference, ndb.nal.usda.gov/ndb/foods.

Usman, A., Bala, A., Tiamiyu, S. A. and Alabi, M. O. (2006). Use of legumes for maintenance of rice yield in lowland rice-based cropping systems in Nigeria. Journal of Sustainable Agriculture 29, 43-51.

Usman, A., Osunde, A. O. and Bala, A. (2013). Nitrogen contribution of some selected legumes to a sorghum based cropping system in the southern Guinea savanna of Nigeria. African Journal of Agricultural Research 8, 6446-6456.

Uzoma, A. O., Jemiyo, C. A., Bala, A., Adeboye, M. K. A., and Osunde, A. O. (2013a). The growth and yield performance of groundnut (*Arachis hypogaea*) cultivated under various fertilizer inputs on an Alfisol in the Southern Guinea savanna zone of Nigeria. Nigerian Journal of Soil Science 23 (2), 146-156.

Uzoma, A. O., Okoh, J., Bala, A., Adeboye, M. K. A., and Osunde, A. O. (2013b). The impact of various fertiliser inputs in the growth, nodulation and yield of soybean (*Glycine max*) cultivated on an Alfisol in Minna, Southern Guinea savanna. Nigerian Journal of Soil Science 23 (2), 157-167.

Weir, B. (2013).The current taxonomy of rhizobia. http://www.rhizobia.co.nz/taxonomy.

WHO. (2015). World Hunger and Poverty Facts and Statistics http://www.worldhunger.org/articles/Learn/world%20hunger%20facts%202002.htm

World Bank. (2015). The World Bank Open Data, data.worldbank.org/indicator/AG.CON.FERT.ZS/countries/NG

Woomer, P., Huising, J. and Giller, K. E. (2014). N2Africa: Final Report of the First Phase, 2009-2013, www.N2Africa.org, 138 pp.

Profile of the Inaugural Lecturer

Professor Abdullahi Bala was born on 27th March, 1967 in Suleja in Niger State. He attended Dawaki Primary School Suleja before proceeding to Federal Government College, Minna for his secondary education, graduating in 1984 with distinction. He thereafter went to Ahmadu Bello University, Zaria where he graduated with a First Class Honours in Agriculture in 1989.

Professor Bala obtained M.Sc in Soil Chemistry and Fertility from the University of Reading in 1993 and Ph.D in Microbiology in 1999 from the University of London, both in the UK.

He first got his first administrative responsibility when he was appointed class monitor within the first week of enrolment in primary school and remained so until graduation. In secondary school, he was President and Secretary of many clubs and societies; he also represented FGC, Minna in science quiz competitions and in volleyball and handball; and was a Junior House Captain and later Senior Prefect. Prof. Bala was a member of ABU Students' Union Consultative Assembly and President of the National Association of Agricultural Students.

He joined the services of the Federal University of Technology, Minna on January 10th, 1991 as Assistant Lecturer in the Department of Soil Science, and progressed steadily to the rank of Professor of Soil Science on October 1, 2010. Professor Bala has served the University as a member of numerous committees and was a member of Council from 2002 - 2004. He also served at various times as the Deputy Dean, School of Agriculture and Agricultural Technology, Head of Department of Soil Science, Director, Centre for Preliminary and Extra-Mural Studies (CPES) and Deputy Vice-Chancellor (Administration). He is currently the DVC (Academic).

Between 2004 and 2007, Professor Bala worked with the then Nigerian leader, President Olusegun Obasanjo as an Associate Policy Analyst, working extensively on contemporary policy issues especially in the Agricultural sector. He was an internationally recruited scientist (IRS) as Inoculant Delivery Specialist with the International Institute of Tropical Agriculture (IITA) between 2010 and 2012, and served as the West African Coordinator of N2Africa, a research for development project sponsored by the Bill and Melinda Gates Foundation. He is a member of several non-governmental and community based associations and had served as member, Governing Board of Suleja Community School; member, Board of Governors Diamond Development Initiatives and member, Central Working Committee, Suleja Emirate Education Foundation.

Professionally, Professor Bala's research interest covers microbially mediated nutrient transformation processes, especially biological nitrogen fixation and how these relate to soil health and crop productivity. He has supervised several undergraduate and postgraduate diploma, 12 Masters and three PhD students.

He is a member of Soil Science Society of Nigeria (SSSN), International Union of Soil Science (IUSS), African Association of Biological Nitrogen Fixation, African Network for Soil Biology and Fertility (AfNet) and the Nigerian National Soil Health Consortium.

He is a recipient of several prizes and awards including the Federal Government of Nigeria Scholarship (1980-1984), the Nigerian Tobacco Company (N.T.C.) Ltd Prize for Best Student (1986-1988), John Holt Ltd. Scholarship (1987-1989), Dean's Prize for the Best All Round Candidate for Bachelor of Agriculture Degree Course (1989), Kansas State University Prize for the Best All Round Performance throughout B. Agric Degree Course (1989), and the National Trucks Manufacturing Ltd Prize for the Best Student in Field Practical Training Programme (1989). He was also a two-term fellow of the Association of Commonwealth Universities Scholarship (1992 and 1995).

Professor Bala has numerous publications in reputable national and international journals and is happily married with children.

Global Links Communications ©: 08056074844, 07036446818