EFFECT OF NUTRIENT-RICH ALTERNATIVES ON QUALITY OF COMPOST MADE FROM MARKET WASTES

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ABSTRACT

Globally, chemical fertilizers cause serious environmental pollution and health hazards. Studies have shown that compost, a product of biodegradable organic matter, is not popular among Nigerian farmers because of its low quality. Improving compost quality is a challenge and supplementing it with natural fortifiers may be safer than opting for chemical fertilizers. This study was therefore designed to explore the effect of nutrient-rich alternatives on quality of compost made from market wastes.

This was an experimental study design, comprising compost preparation, formulation with natural fortifiers, farm plot experiments and laboratory analyses. Organically Fortified Fertilizers (OFFs) comprised: Plant-Based (PB), Animal-Based (AB), Rock-Based (RB), Organic-mixture (OM-mixture of PB, AB and RB), Synthetic/ Chemical (SC) while ordinary compost was used as control. The plot experiment was a simple plot randomised complete block design with three replicates. The main plots comprised three crops- maize (cereal), soybean (legume) and yam (tuber) while five different OFFs at three rates of applications- 2.0 tons, 2.5 tons and 3.0 tons per hectare and control formed subplots. Formulation characteristics [organic-carbon, Total Nitrogen (TN), phosphorus and potassium] were determined using spectrophotometeric and other standard methods. Germination index method was used to assess phytotoxicity of OFFs. Values obtained for phytotoxicity were compared with Thailand Agricultural Commodity and Food Standard of ≥80 for safe OFFs. Effects of OFFs on Agronomic Parameters (APs) [Number of Leaves (NL), Plant Height (PH), Stem Girth (SG), Leaf Area (LA) and crop yield] were assessed in plot experiments. Data were analysed using descriptive statistics and ANOVA at $p = 0.05$.

Chemical analysis of OFFs revealed organic-carbon (%): 33.2±0.0, 38.4±0.2, 27.7±0.1, 34.8±0.0, 28.4±0.2, 32.8±0.21; TN (%): 5.69±0.0, 5.74±0.0, 5.85±0.0, 6.05±0.0, 6.15±0.0, 3.21±0.0, phosphorus (%):0.3±0.0, 0.5±0.0, 0.2±0.0, 0.8±0.0, 0.2±0.0, 0.7±0.1 and potassium (%): 0.5±0.0, 0.7±0.0, 0.4±0.0, 1.0±0.0, 0.4±0.0, 0.9±0.0 for PB, AB, RB, OM, SC and control respectively. The control had significantly higher phosphorus and potassium, and lower TKN than any of the formulations. Values obtained for phyto-toxicity were higher than 80 with exception of SC that was toxic to soybean at 3.0 tons/Ha (74.2). Specifically, OM and RB for maize [NL (10.0±1.1; 9.2±1.0), PH (23.9±5.4cm; 22.7±3.6cm), SG (2.2±0.4cm; 2.2±0.4cm), LA (2.7±0.1cm^2;

3.4±0.7cm^2)]; AB and RB for soybean [NL (20.3±10.1; 15.3±4.5), PH (12.0±3.5cm; 10.8±5.8cm), SG (0.4±0.1cm; 0.4±0.1 cm), LA (21.0±15.7cm^2; 18.7±7.2 cm^2)] and RB for yam [PH (44.0±24.0cm); SG (0.8±0.1cm)] respectively gave the best crops' performances in APs among all the formulations and the control. Rate of application of OFFs showed no significant effects on APs. However, AB at 2.0 tons/ha followed by PB (2.5 tons/ha) gave the highest soybean yield; RB (2.0 tons/ha) gave the highest maize yield and OM (3.0 tons/ha) gave highest yam tuber yield.

Nutrient-rich materials sourced from animal, plant and rock changed the chemical composition of compost made from market wastes and yielded better agronomic performances than the synthetic fertilizer. Fortification of compost with natural materials which are readily available and environmentally friendly should be promoted among the farmers.

Keywords: Organic fertilizer formulation, Compost quality, Natural fortifiers, Agronomic parameters

Word count: 483

DEDICATION

This work is dedicated to Al-mighty God and my parents: the Late, **Alhaji Hammed Ayinde** and **Alhaja Musilimat Hammed Olohungbebe.**

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CERTIFICATION

I certify that this work was carried out by **Mr. Taiwo Babatunde Hammed** in the Department of Environmental Health Sciences, University of Ibadan, Ibadan.

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GLOSSARY OF TECHNICAL TERMS AND ABBREVIATIONS

ABBREVIATIONS AND ACRONYMS

%	Percentage
AAS	Atomic Absorption Spectrophotometer
ADP	Agricultural Development Project
AISD	Agricultural Input Services Department
ANOVA	Analysis of Variance
AOAC	Association of Analytical Chemist
C: N	Carbon to Nitrogen Ratio
Ca	Calcium
CCME	Canadian Council of Ministers of the Environment
CCREF	Composting Council Research and Education Foundation
Cd	Cadmium
CEC	Cation Exchange Capacity
CIW	Cow Intestinal Waste
Cl (Cl^-)	Chlorine (chloride)
CO_2	Carbon Dioxide
Cr	Chromium
Cu	Copper
CV	Calorific Value
DEFRA	Department of Environment Food and Rural Affairs
DM	Dry Matter
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
FCT	Federal Capital Territory
FDA	Federal Department of Agriculture
Fe	Iron
FEPA	Federal environmental Protection Agency
FFD	Federal Fertilizer Department
FGN	Federal Government of Nigeria

FIFA	Fertilizer Industry Federation Association
FMARD	Federal Ministry of Agriculture and Rural Development
FMSP	Federal Market Stabilization Program
FPDD	Fertilizer Procurement and Distribution Division
FSFC	Federal Superphosphate Fertilizer Company
FYM	Farmyard Manure
GDP	Gross Domestic Product
H (H+)	Hydrogen
HCL	Hydrochloric acid
IART	Institute of Agricultural Research and Training
IFPRI	International Food Policy Research Institute
IITA	International Institute for Tropical Agriculture
IMG	Ibadan Municipal Government
ISLGA	Ibadan Southwest Local Government Area
K (K^+)	Potassium
K_2O	Potash
Kg	Kilo-gramme
LSD	Least significant difference
MC	Moisture Content
Mg (Mg^{2+})	Magnesium
MgL^{-1}	Milligramme per litre
MMW	Mixed Market Wastes
Mn	Manganese
Mo	Molybdenum
MSW	Municipal Solid Waste
N, N_2	Nitrogen
Na (Na^+)	Sodium
NAFCON	National Fertilizer Company of Nigeria
NAFDAC	National Agency for Food and Drug Administration and Control
NCA	National Council on Agriculture
NEEDS	National Economic Empowerment and Development Strategy

NEPAD	New Partnership for African Development
NFDC	National Fertilizer Development Centre
NFTC	National Fertilizer Technical Committee
NGO	Non-Governmental Organizational
NH_4	Ammonium
Ni	Nickel
NINAAFEH	Nigeria Network for Awareness and Action for Environmental Health
MTNF	MTN Nigeria Foundation
NO_2	Nitrogen Dioxide
NO_3	Nitrate
NPK	Nitrogen Phosphorous Potassium
OC	Organic Carbon
OFF	Organically Fortified Fertilizer
P	Phosphorus
P_2O_5	Phosphate
PAH	Polycyclic Aromatic Hydrocarbon
Pb (Pb^{2+})	Lead
PCB	Polychlorinated Biphenyls
ppm	Parts per million
RCBD	Randomized Complete Block Design
S	Sulphur
SMA	States Ministries of Agriculture
SO_3	Sulphur trioxide
SOM	Soil Organic Matter
SON	Standards Organization of Nigeria
SONCAP	Standards Organization of Nigeria Conformity Assessment Program
SPSS	Statistical Package for Social Science
SSP	Single Supper Phosphate
UAN	Urea Ammonium Nitrate
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme

UNEP United Nations Environment Programme

GLOSSARY

Aerated static pile: A heap of compostable materials formed to promote the aerobic decomposition of the organic matter. Ventilation is either provided by passive or forced aeration, rather than through frequent agitation (turning).

Aerobic: Requiring oxygen for metabolic processes.

Bio solids: Organic product obtained from the physico-chemical and/or biological treatment of wastewater.

Cation exchange capacity: The ability of negatively charged particles to hold positively charged ions (cations) through an electrical attraction.

Compost: solid mature product resulting from composting.

Composting: Aerobic process in which organic materials are ground or shredded and then decomposed to humus in windrow piles or in mechanical digesters, drums, or similar enclosures under controlled conditions of environmental factors.

Contaminant: Element, compound, substance, organism, or form of energy which through its presence or concentration causes an adverse effect on the natural environment or impairs human use of the environment.

Feedstock: Starting materials to be composted.

Foreign matter: Any matter over 2 mm in dimension that results from human intervention and has organic or inorganic components such as metal, glass, synthetic polymers (for example plastic and rubber) and that may be present in the compost but excluding mineral soil, woody material and pieces of rock.

Heavy Metal: The term heavy metal refers to a group of toxic metals including arsenic, chromium, copper, lead, mercury, silver, and zinc. Heavy Metals often are present at industrial sites at which operations have included battery recycling and metal plating.

Humus: Recalcitrant, highly stable byproducts of organic matter decomposition.

In-vessel composting: Diverse group of composting methods in which composting materials are contained in a reactor vessel; the purpose is to maintain optimal conditions for composting.

Maturity: The degree of biodegradation at which composted material is not phytotoxic or exerts negligible phytotoxicity in any plant growing situation when used as directed, for example, nitrogen immobilization or anaerobioses.

Mesophilic temperature: Temperature range of 50–105^{0}F (i.e. 10-40^{o}C).

Micronutrient: plant nutrient (for example boron, copper, molybdenum, manganese, iron and zinc) required in lesser quantities than major (for example nitrogen, phosphorus and potassium) and secondary (for example calcium and magnesium) plant nutrients, having essential physiological functions in plant metabolism.

Municipal bio solids: Bio solids obtained from municipal wastewater pretreated to remove gravel and coarse solid waste.

Municipal solid waste: Solid non-hazardous refuse that originates from residential, industrial, commercial, institutional, demolition, land clearing, or construction sources.

Pathogens: Organisms, including some bacteria, viruses, fungi, and parasites, that are capable of producing an infection or disease in a susceptible human, animal, or plant host.

Phytotoxin: Chemicals harmful to plant health.

Recalcitrant: Relatively resistant to biological, chemical, and/or photo degradation.

Sharp foreign matter: Any foreign matter over a 3 mm dimension that may cause damage or injury to humans and animals during or resulting from its intended use.

Source separation: separation of wastes into specific types of material at the point of generation.

Thermophilic phase: Biological phase in the composting process characterized by the presence of micro-organisms which grow optimally in a temperature range of 45°C to 75°C.

Trace element: Chemical element present in compost at a very low concentration.

Volatile solids: Solids in water or other liquids that are lost on ignition of dry solids, generally above 500°C.

Windrow: elongated piles of triangular or trapezoidal cross-section that are turned in order to aerate and blend the material.

Yard waste: Vegetative matter resulting from gardening, horticulture, landscaping, or land clearing operations and includes materials such as tree and shrub trimmings, plant remains, grass clippings, and chipped trees.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

The modern understanding of plant nutrition dates back to the 19th century from the work of Justus von Liebig, among others. Management of soil fertility, however, has been the pre-occupation of farmers for thousands of years. Urea was first discovered in urine in 1773 by the French chemist Hilaire Rouelle. In 1828, the German chemist, Friedrich Wöhler obtained urea by treating silver isocyanate with ammonium chloride in a failed attempt to prepare ammonium cyanate (Weiner and Lowenstam, 1989). This was the first time an inorganic compound (urea) was artificially synthesized from organic starting material (urine), without the involvement of living organisms. The use of synthetic nitrogen fertilizers has increased steadily in the last 50 years, rising almost 20-fold to the current rate of 1 billion tons of nitrogen per year (Glass, 2003). Also, the use of phosphate fertilizers has increased from 9 million tons per year in 1960 to 40 million tons per year in 2000 (Vance et al., 2003).

Presently, in Nigeria and many other developing countries, synthetic fertilizers account for the largest source of nutrients such as nitrogen, phosphorus and potassium that are needed for plant growth (Saweda et al., 2010). The use of compost or other organic-based fertilizers have been employed only to a limited extent. Despite this, synthetic fertilizer application, estimated at 13 kg/ha in 2009 by the Federal Ministry of Agriculture and Rural Development, is far lower than the 200 kg/ha recommended by the United Nations Food and Agriculture Organization (FAO) (FMARD, 2010) for soil in Nigeria. The low fertilizer application is professed to be among the many reasons for low agricultural productivity in Nigeria (Saweda et al., 2010). According to Crawford and kelly (2005) during 2000/01–2002/03, the average fertilizer use in Sub-Saharan Africa (excluding South Africa), estimated at 9 kg per hectare, was much lower than elsewhere in the world (for example, 86 kg/ha in Latin America, 104 kg/ha in South Asia, and 142 kg/ha in Southeast Asia). Furthermore, it is estimated that Nigeria is experiencing deteriorating annual nutrient depletion, risking its ability to sustain the modest gains achieved from recent agricultural growth.

Historically, in Kano, Nigeria, the practice of using taki (compost from manure, household waste, street sweepings and ash) as fertilizing material by the city's peri-urban farmers has gone on for centuries (Lewcock, 1995). Mortimore (1972) also revealed that in 1969 and 1972, 1,137 and 1,447 donkeys respectively carried "taki" out of the old walled city of Kano. This represented between 140 and 1,180 tons of compost per day for peri-urban farms. It is estimated that in a 7.5 km radius, 25% of farmers' fertilizer needs were met by waste from Kano at an average application rate of between 3.25 and 5.0 tons per hectare per annum (Mortimore, 1972).

Emphasis on recycling waste in food crop cultivation shifted in the 1960s to the use of artificial fertilizers, when there was proliferation of Agricultural Development Projects (ADPs) in the country (Banfu et al., 2009). Also, with their newly gained independence, African countries vowed to modernise their economies based on the model of western, industrialized countries. Ultimately, indigenous agricultural practices such as re-use of organic waste were discouraged (Asomani-Boateng and Haight, 2003). Emphasis was placed on modern agricultural practices, including the use of chemical fertilizers. The indigenous form of agriculture was viewed as being out-of-touch with civilization. Hence, the reuse of waste in an urban area - which was actually a symbol and show-piece of modernity - was considered a taboo.

In the late 1970s, inorganic fertilizers such as urea, Single Super-phosphate (SSP) and different formulations of NPK (nitrogen, phosphorus and potassium) were heavily subsidised up to 95 per cent. The pattern of total fertilizer consumption in Nigeria has mirrored the ebb and flow of federal and state government subsidies and the almost annual changes in procurement and distribution rules. Recently, the Federal Government of Nigeria (FGN), under the Federal Market Stabilization Programme (FMSP), procures fertilizer for sale to States at a subsidy of 25 per cent. State governments then institute additional subsidies on fertilizer (Afua et al., 2009). Several States also procure fertilizers outside of the FMSP for sale to their farmers. Nevertheless, only an estimated 30 per cent of subsidised fertilizer reaches small farmers at the subsidised price. Earlier on, the price of fertilizer was usually under state control as subsidy on fertilizer was a major political issue in many Nigerian states. But after subsidy was removed in the 1990s, the price of fertilizer skyrocketed and corrupt practices prevented efficient distribution of the product on time to farmers (Trading Economics, 2014).

1.2 Statement of the Problem

The importance of agriculture to Nigeria's economy cannot be over emphasized. Farming and livestock production are the main source of livelihood for over 70 per cent of households in the country (Afua et al., 2009). In 2008, agriculture contributed 42 percent of the country's GDP (FMARD, 2010); significantly higher than the 18 percent derived from petroleum and natural gas production. However, the country's promising agricultural potential has not been realized. In all likelihood, low fertilizer use is a major factor contributing to the stagnant agricultural productivity in Nigeria (Crawford et al., 2005; Saweda et al., 2010; FMARD, 2010).

Also in many developing countries, including Nigeria, poor soil fertility, increasing cost and scarcity of chemical fertilizers are making it difficult for subsistence farmers to grow enough food to feed their families. The compost which is organic fertilizer and an alternative soil amendment is not very popular among the farmers because of its slower nutrient release potential and bulkiness. Due to low nutrient composition, large quantity of organic fertilizer must be applied to crops for effective results (Akanbi et al., 2007). The cost and problem of transporting large quantity of organic fertilizer is another major reason for its low preference among the farmers. However, over dependence on expensive inorganic fertilizers may have serious environmental health hazards (Arisha and Bardisi, 1999) such as: water pollution and increased production of greenhouse gases, leading to global climate change. Chemical fertilizers could also cause eutrophication of water bodies that can cause algal bloom and production of toxins (Williams, 2001).

At Alesinloye Market Integrated Solid Waste Recycling Complex, there was growing demand for Organo-mineral fertilizer which is organic fertilizer blended with synthesized urea and phosphorus. Apart from potential environmental health hazards associated with the use of these chemical fortifiers, they could be very expensive and scarce because they were no longer being subsidised by the Government. Many a time, the difficulty in procuring these synthetic chemical fertilizers to boost nutrient quality of compost had seriously affected the production output of the recycling complex. Even when they were available at 'black market', they were normally sold at unjustifiably high prices with a serious implication on the cost of production. Also, the quality challenges occurred along the full spectrum of the synthetic fertilizer supply chain. Adulteration, which usually involves fertilizer being mixed with products like sand and crop or weed seeds, was a major problem. Other issues like nutrient deficiency of fertilizer samples subjected to laboratory tests and underweight bags had also been confirmed across the country (Ayoola et al., 2002).

Increasing the nutrient levels in the composts and optimising its quality was a great challenge. There have been and will continue to be efforts to develop and refine methods to improve and up-grade the quality of stable and matured compost with cheap, locally and readily available organic materials to the level that could be compared to the synthetic fertilizer counterparts. According to Sridhar et al. (2001) and Adeoye et al. (2008), supplementing with natural sources of fortifiers is more environmentally friendly than opting for chemical sources (Naeem et al., 2006). Up till now, no one universally accepted and applied method for upgrading compost quality into chemical fertilizer status exists. Hence, any research into this field of operation may likely provide solution to the problems inherent in the organic fertilizer and promote its usage among the farmers.

This study was therefore designed to ameliorate problems associated with the use of organic fertilizer. Some of these problems include: potential health risks posed to workers at waste recycling companies that fortify organic fertilizer with synthetic chemicals and the end-users that apply such a fertilizer in their farms through replacement of chemical fortifiers with organic-rich materials. This will, in the long run, boost economic development and sustainability of such waste recycling companies in the country.

1.3 Rationale for the Study

Poor quality of organic fertilizer is often cited as a major constraint to its use in Nigeria. Also, the problems of fertilizer quality in Nigeria commonly mentioned range from “insufficient nutrient content” to “short weights of fertilizer in bags” and ”willful adulteration and other economic or trade crimes.” (Banfu et al., 2009). On the other hand, inorganic chemical fertilizers grossly pollute the environment and do not replace trace mineral elements in the soil which become gradually depleted by crops. A study (Lawrence, 2004) has linked mineral depletion in soil to marked fall (up to 75%) in the quantities of such mineral present in fruits and vegetables. Therefore, there was urgent need to improve the quality of organic based- fertilizers for food security and environmental protection.

To reduce all the environmental problems associated with organic based- fertilizers and improve their qualities, an extensive study of these fertilizer in the laboratory and field was required. The present study was justifiable as it focused on chemical analysis of the fertilizer products to reveal the amount of selected materials required for fortification. The study also focused on availability coefficient or nutrient supplying capacities to determine the quantity to be applied for crops on the field to reduce over-fertilization as well as other aspects such as nitrogen mineralization from compost in warmer climatic conditions over time and potential detrimental effects of fertilizers, if used inappropriately. As this study found alternative replacement for chemical fertilizers, it could not be more justifiable than now that chemical fertilizers in the country are no longer being subsidised by the Government which automatically raised their prices and made them to become out of reach for most farmers.

1.4 Significance of the Study

It is quite unfortunate that both nutrient rich organic and inorganic fertilizers are increasingly unavailable to farmers at this time when there is a continuous need to step up food production due to increase in population. This study explored and obtained required information towards the possibility of substituting synthetic chemical fertilizers which are not environmentally friendly for safer organic fertilizers that are 100% natural with well-balanced nutrients required for crop cultivation. This would not only help to preserve soil fertility but also safeguard long-term food security, while bringing down the consumption of synthetic fertilizers and pollution of water, air, food and land in the country.

Finally, the study was found significant as it aimed at how to maintain and sustain the waste recycling operations at all companies that convert organic waste to fertilizers, including the study area, Alesinloye Waste Recycling Complex, Ibadan, through application of appropriate technology. The study would also help the complex to meet the growing customers' demand for highly rich organic fertilizer; increase income generation to cater for worker's salaries; and, attain effective health risks and pollution control.

1.5 Research Questions

The following questions were intended to be answered by this study:

- What are the chemical compositions of various nutrient rich and natural organic fortifiers?
- How could these materials be processed for easy application?
- What quantity of these materials would be required for fortification?
- What are the final nutrient compositions of fertilizers fortified with these nutrient rich organic materials?
- What are the chemical compositions of synthetic fortifiers- Urea and SSP?
- What are the final nutrient compositions of fertilizers fortified with Urea and SSP?
- What are the elemental forms of N, P, K and heavy metals in the fertilizers fortified with organic and inorganic fortifiers?
- What are the nutrient release potentials of N, P, K and leaching potentials of heavy metals in the fertilizers to crops and soil on the farm?

- What are the effects of different fortified organic fertilizers on agronomic data of selected crops during rainy and dry seasons?
- What are the phyto-toxic effects of each fertilizer on the test crops?
- What are the residual effects of the fertilizers on the soil and crop yield of the test crops applied with different fertilizers?

1.6 Broad Objective

The broad objective of this study was to explore the effect of nutrient-rich alternatives on the quality of compost made from market wastes for organic waste management and environmental protection.

1.7 Specific Objectives

The specific objectives of this study were to:

i. characterise various natural and synthetic materials for their nutrients and selected heavy metals
ii. produce compost and develop formulations with the best fortifiers for crop specific use
iii. determine the mineral composition of natural and synthetic compost formulations
iv. conduct plot experiments using the compost formulations with specific test crops to determine their effects on agronomic parameters during two seasons (dry and wet seasons)
v. determine the nature of chemical binding forms of nutrients in the compost formulations
vi. assess the phytotoxic effects of compost formulations on test crops
vii. determine the residual soil nutrient levels and crop yield after harvesting

CHAPTER TWO

LITERATURE REVIEW

2.1 What is Fertilizer?

Fertilizers are broadly divided into organic fertilizers (composed of enriched organic matter -plant or animal), or inorganic fertilizers (composed of synthetic chemicals and/or minerals) (Heinrich, 2000). By legal definition, according to the Federal Ministry of Agriculture and Rural Development (2014), the term ‘fertilizer’ refers to a soil amendment that guarantees the minimum per centages of nutrients (at least the minimum per centage of nitrogen, phosphate, and potash). An “organic fertilizer” means fertilizer derived from non-synthetic organic material, including: plant and animal by-products, rock powders, seaweed, inoculants, sewage sludge, animal manures, and plant residues (Biernbaum, 2003; Benton and Janes, 2012) produced through the process of drying, cooking, composting, chopping, grinding, fermenting or other methods. Organic fertilizers and some mined inorganic fertilizers have been used for many centuries (Erisman et al., 2008), whereas chemically-synthesized inorganic fertilizers were only widely developed during the industrial revolution (Vinneras, 2002). Thus, increased understanding and use of fertilizers were important parts of the pre-industrial British Agricultural Revolution and the industrial green revolution of the 20th century.

Chemical fertilizers are made in factories by turning nitrogen gas into ammonia and by treating rock phosphate with acid while organic fertilizers are derived naturally from plants and animals and also include minerals that occur naturally (Vinneras, 2002). One major advantage of chemical fertilizers is that they quickly break down to provide specific nutritional needs to plants. However, they normally cause: rapid release of nutrients and possible unbalanced growth (Lawrence, 2004; Rowlings et al., 2013; Fernando et al., 2015), salty environment which damages plants and soil through over-fertilization; and water pollution (Vance et al., 2003; Carey et al., 2012). Compared to chemical fertilizers, organic fertilizers contain relatively low concentrations of actual nutrients and depend on soil organisms to break them down to release these nutrients. Since nutrient release by microbial activities, in general, occurs over a fairly long time period, one potential drawback is that the organic fertilizers may not release enough of their principal nutrients when the plant needs them for growth.

According to Marion (2000), organic fertilizers perform important functions which the chemical formulations do not. Organic fertilizers tend to bring the balance back to the soil and provide long-term fertility. They also impact significant physical and biological properties by: increasing water-holding capacity of the soil, enhancing soil stability, structure and texture (Composting Association, 2000; Ludwig et al., 2011), improving soil microbial activities, controlling weed and common pest growth, minimizing the dependence on expensive inorganic fertilizers, preventing soil erosion, binding toxic chemicals in soils and making them unavailable to plants, and reducing soil and water pollution.

2.2 Chemical/Synthetic Fertilizer

Inorganic fertilizer is often synthesized using Haber-Bosch process, which produces ammonia as the end product (Leigh, 2004). This ammonia is used as a feedstock for other nitrogen fertilizers, such as anhydrous ammonium nitrate and urea. These concentrated products may be diluted with water to form a concentrated liquid fertilizer such as Urea Ammonium Nitrate (UAN) solution. Ammonia can be combined with rock phosphate and potassium fertilizer in the Odda Process to produce compound fertilizer (George et al., 2002). The use of synthetic nitrogen fertilizers has increased steadily in the last 50 years, rising almost 20-fold to the current rate of 1 billion tons of nitrogen per year (Glass, 2003). The use of phosphate fertilizers has also increased from 9 million tons per year in 1960 to 40 million tons per year in 2000 (Vance et al., 2003). A maize crop yielding 6-9 tons of grain per hectare requires 30–50 kg of phosphate fertilizer to be applied; soybean requires 20–25 kg per hectare (Vance et al., 2003).

2.2.1 Nitrogen Fertilizer

There are at least eleven forms of nitrogen (N) fertilizer that are commercially available around the world (Table 2.1) (Western Fertilizer Handbook, 2002). There are often questions as to whether a grower should use one form of N-fertilizer or another. A common statement is that “a pound of N, is a pound of N” and if applied appropriately (Schimel and Bennet, 2004), all forms can perform equally well in promoting crop production. The amount of total N in the soil at any one time is mostly in the organic form (97-98%). It is contained in the organic molecules of soil humus, plant residues, soil fauna, soil microbes or animal wastes. These organic molecules are too large to be absorbed through plant root membranes and need to be decomposed and modified by soil fauna and microbes into the ionic forms NH_4^+ or NO_3^-. This whole decomposition and modification process is called mineralization, simply meaning changing organic N forms to mineral N forms (Robertson and Groffman, 2007). This is not a one-way trip for N as the ionic forms of NH_4^+ and NO_3^- can be returned to an organic form as soil microbes require and use N to decompose high carbon to nitrogen ratio containing plant residues.

2.2.1.1 Nitrogen Mineralization/Transformation in Soil

The quantity and forms of nitrogen in soils is constantly changing due to biological, chemical, and physical processes. The microbial transformation of organic nitrogen to inorganic forms is referred to as mineralization (Robertson and Groffman, 2007). Common organic nitrogen substances are; soil humus, plant leaf clippings and root tissue, and sludge and manure based fertilizers. Fungi and bacteria carry on most of the mineralization in soils. Because many different organisms can mineralize nitrogen the conditions necessary for mineralization to occur are not highly specific. Warm, wet conditions, and soil pH greater than 5.5 enhance mineralization; good soil aeration also promotes mineralization while water contents greater than field capacity tend to reduce the rate of nitrogen mineralization.

Organic nitrogen comprises over 95 percent of the nitrogen found in soil. This form of nitrogen cannot be used by plants but is gradually transformed by soil microorganisms to ammonium (NH_4^+) (Schimel and Bennet, 2004). Ammonium is not leached to a great extent. Since NH_4^+ is a positively charged ion (cation), it is attracted to and held by the negatively charged soil clay. Ammonium is available to plants. In warm, well-drained soil, ammonium transforms rapidly to nitrate (NO_3^-). Nitrate is the principle form of nitrogen used by plants (Robertson and Groffman, 2007). It leaches easily, since it is a negatively charged ion (anion) and is not attracted to soil clay.

Table 2.1. Commercially available N fertilizers

Name	Chemical Formula	Analysis % $N-P_2O_5-K_2O$
Anhydrous Ammonia	NH_3	82-0-0
Aqua Ammonia	NH_4OH,	20-0-0
Ammonium Nitrate	NH_4NO_3	34-0-0
Ammonium Nitrate-Lime	$NH_4NO_3+CaCO_3$	26-0-0
Ammonium Sulphate	$(NH_4)2SO_4$	21-0-0-24S
Calcium Nitrate	$5Ca(NO_3)_2$ NH_4NO_3 $10H_2O$	15.5-0-0-19Ca
Nitrate of Soda	$NaNO_3$	16-0-0
Urea	$CO(NH_2)_2$	46-0-0
Ammonium Nitrate solution (sol)	$NH_4NO_3 + H_2O$	20-0-0
Urea Ammonium Nitrate (UAN)sol	$NH_4NO_3 + CO(NH_2)_2 + H_20$	28-0-0/32-0-0
Calcium Ammonium Nitrate (sol)	$5Ca(NO_3)_2$ NH_4NO_3 $10H_2O + H_2O$	17-0-0-8Ca

(Source: Western Fertilizer Handbook, 2002)

The nitrate form of nitrogen is a major concern in pollution. Soil microorganisms use nitrate and ammonium nitrogen when decomposing plant residues. These forms are temporarily "tied-up" (incorporated into microbial tissue) in this process. This can be a major concern if crop residues are high in carbon relative to nitrogen. Examples are wheat straw, corn stalks and sawdust. The addition of 20 to 70 pounds of nitrogen per ton of these residues is needed to prevent this transformation.

When soil does not have sufficient air, microorganisms use the oxygen from NO_3^- in place of that in the air and rapidly convert NO_3^- to nitrogen oxide and nitrogen gases (N_2) (Galloway et al., 2003). These gases escape to the atmosphere and are not available to plants. The transformation can occur within two or three days in poorly aerated soil and can result in large loses of nitrate-type fertilizers. Soils that have a high pH (pH greater than 7.5) can lose large amounts of NH_4^+ by conversion to NH_3 gas. Solid ammonium-type fertilizers, including urea and anhydrous ammonia are usually incorporated below the surface of a moist soil to minimize these losses.

2.2.2 Commercial Phosphate Fertilizer

Rock phosphate is the raw material used in the manufacture of most commercial phosphate fertilizers in the market. In the past, ground rock phosphate itself has been used as a source of P for acidic soils (Stewar, 2002). However, due to low availability of P in this rock, high transportation costs, and small crop responses, very little rock phosphate is currently used in agriculture (George et al., 2002). The manufacture of most commercial phosphate fertilizers begins with the production of phosphoric acid. A generalized diagram showing the various steps used in the manufacture of various phosphate fertilizers is provided in Figure 2.1. Phosphoric acid is produced by either a dry or wet process. In the dry process, rock phosphate is treated in an electric furnace. This treatment produces a very pure and more expensive phosphoric acid (frequently called white or furnace acid) used primarily in the food and chemical industry. Fertilizers that use white phosphoric acid as the P source are generally more expensive because of the costly treatment process.

The wet process involves treatment of the rock phosphate with acid producing phosphoric acid (also called green or black acid) and gypsum which is removed as a by-product (EFMA, 2000). The impurities which give the acid its color have not been a problem in the production of dry fertilizers. Either treatment process (wet or dry) produces ortho-phosphoric acid—the phosphate form that is taken up by plants. The phosphoric acid produced by either the wet or the dry process is frequently heated, driving off water and producing a super phosphoric acid. The phosphate concentration in super phosphoric acid usually varies from 72 to 76%. The P in this acid is present as both orthophosphate and polyphosphate. Polyphosphates consist of a series of orthophosphates that have been chemically joined together. Upon contact with soils, polyphosphates revert back to orthophosphates.

2.2.2.1 Phosphate Fertilizer Terminology

The selection of a phosphate fertilizer can be confusing, because of the number of products in the market. According to George et al. (2002), some important terms for proper identification are:

1) **Water-soluble:** Fertilizer samples are first placed in water and the percentage of the total phosphate that dissolves is measured. This percentage is referred to as water-soluble phosphate.
2) **Citrate-soluble:** The fertilizer material that is not dissolved in water is then placed in an ammonium citrate solution. The amount of P dissolved in this solution is measured and expressed as a percentage of the total in the fertilizer material. Phosphate measured with this analytical procedure is referred to as citrate-soluble.
3) **Available:** The sum of the water-soluble and citrate-soluble phosphates is considered to be the percentage that is available to plants and is the amount guaranteed on the fertilizer label. Usually, the citrate- soluble component is less than the water-soluble component. Percentages of water-soluble and available phosphate in several common fertilizer products are shown in Table 2.2.

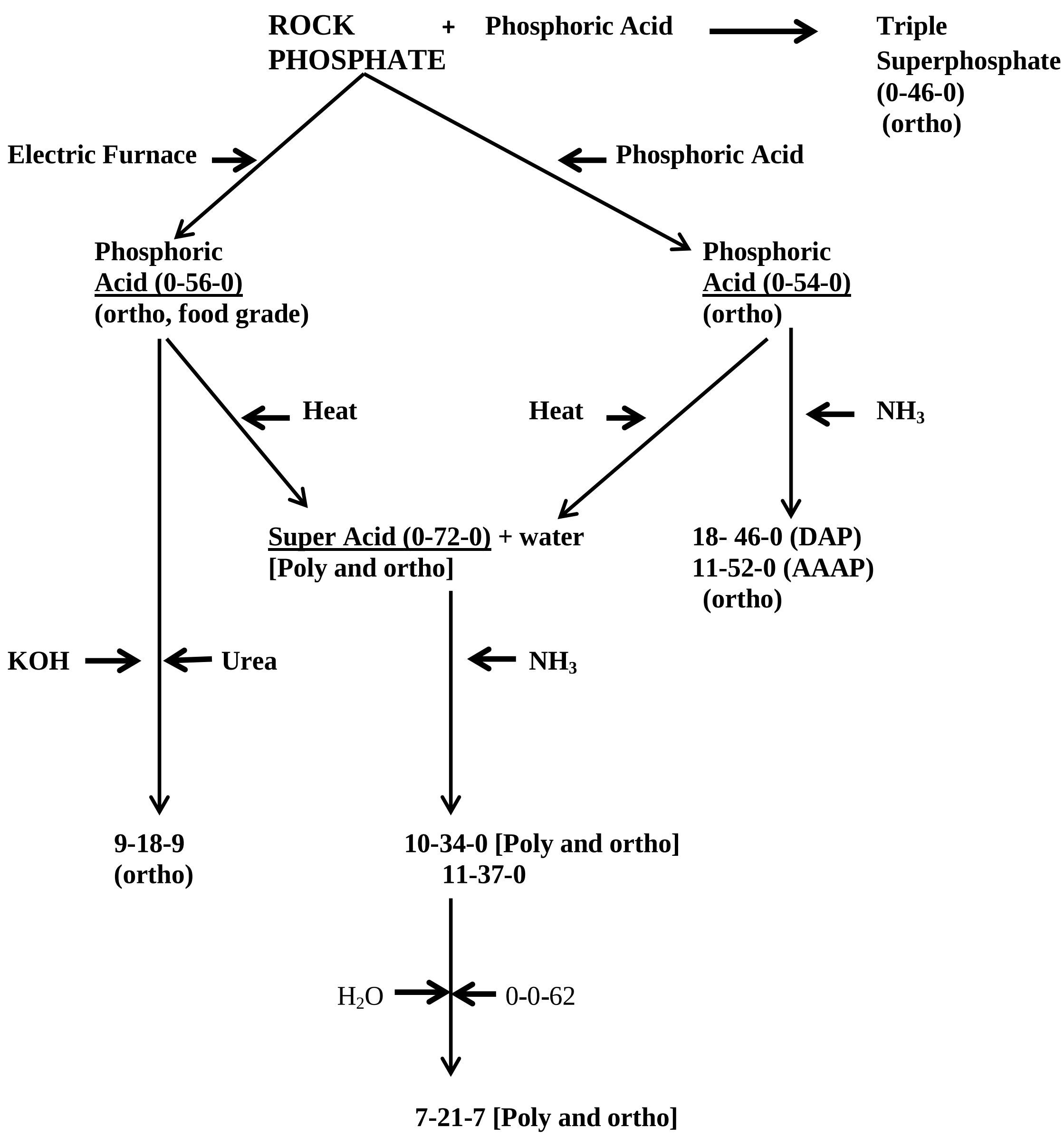

Figure 2.1. The process used in the manufacture of various phosphate fertilizers ***(Source: George et al., 2002)***

Table 2.2. Percentages of water-soluble and available phosphate in several common fertilizer sources.

		P_2O_5 (%)		
P_2O_5 Source	**N**	**Total**	**Available**	**Water Soluble***
Superphosphate (OSP)	0	21	20	85
Concentrated Superphosphate (CSP)	0	45	45	85
Monoammonium Phosphate (MAP)	11	49	48	82
Diammonium Phosphate (DAP)	18	47	46	90
Ammonium Polyphosphate (APP)	10	34	34	100
Rock Phosphate	0	34	3-8	0

*__Water-soluble data are a percent of the total P_2O_5__

(Source: George et al., 2002)

2.2.3 Problems of Inorganic Fertilizer

a) Trace mineral depletion

Many inorganic fertilizers do not replace trace mineral elements in the soil which become gradually depleted over the years by crops. This depletion was linked to a study which showed a marked fall (up to 75%) in the quantities of such minerals present in fruit and vegetables after some years of inorganic fertilizer application (Lawrence, 2004). However, another study concluded that there was no evidence of a difference in minerals of foodstuffs produced with organic and inorganic fertilizers (Dangour, 2009). Conversely, a major long-term study funded by the European Union (Lehesranta1 2007; Butler et al., 2008) found that organically-produced milk and produce were significantly higher in antioxidants (such as carotenoids and alpha-linoleic acids) than their conventionally grown counterparts.

b) Over fertilization

Over fertilization of inorganic fertilizer is a major cause of Blue Baby Syndrome (acquired methemoglobinemia). Nitrate levels above 10 mg/L (10 ppm) in groundwater caused by run-off from land excessively applied with inorganic fertilizer can cause 'blue baby syndrome', leading to hypoxia (which can lead to coma and death if not treated).

c) Soil acidification

Nitrogen-containing inorganic fertilizer can cause soil acidification when added for long period of time (Vance et al., 2003). This may lead to decreases in nutrient availability in the soil and this can be corrected by liming addition to the soil.

d) Persistent organic pollutants

Toxic persistent organic pollutants ("POPs"), such as Dioxins, polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs) have been detected in agricultural fertilizers and soil amendments (Chaney, 2012).

e) Heavy metal accumulation

The concentration of up to 100 mg/kg of cadmium in phosphate minerals increases the contamination of soil with cadmium. Uranium is another example of a contaminant often found in phosphate fertilizers (at levels from 7 to 100 pCi/g) (EPA, 2009). Eventually these heavy metals can build up to unacceptable levels and build up in vegetable. Average annual intake of uranium by adults is estimated to be about 0.5 mg (500 µg) from ingestion of food and water and 0.6 µg from breathing air (WHO, 2003).

f) Atmospheric effects

Methane emissions from crop fields (notably rice paddy fields) are increased by the application of ammonium-based fertilizers; these emissions contribute greatly to global climate change as methane is a potent greenhouse gas (Bodelier et al., 1999). Methane has a global warming potential 296 times larger than an equal mass of carbon dioxide and it also contributes to stratospheric ozone depletion (Zapata and Roy, 2004: IPCC, 2007). Apart from methane, nitrous oxide (N_2O) has become the third most important greenhouse gas after methane and carbon dioxide due to increasing use of nitrogen fertilizer, which is added at a rate of 1 billion tons per year presently (UNESCO, 2007).

Storage and application of some nitrogen fertilizers in some weather or soil conditions can cause emissions of the potent greenhouse gas—nitrous oxide (Aguilera et al., 2013). Ammonia gas (NH_3) may be emitted following application of 'inorganic' fertilizers and/or manures and slurries (Akiyama et al., 2013; Zhu et al., 2013). The use of fertilizers on a global scale emits significant quantities of greenhouse gas into the atmosphere. Emissions come about through the use of:

- animal manures and urea, which release methane, nitrous oxide, ammonia, and carbon dioxide in varying quantities depending on their form (solid or liquid) and management (collection, storage, spreading)
- fertilizers that use nitric acid or ammonium bicarbonate, the production and application of which results in emissions of nitrogen oxides, nitrous oxide, ammonia and carbon dioxide into the atmosphere.

By changing processes and procedures, it is possible to mitigate some, but not all, of these effects on anthropogenic climate change.

g) Increased pest health

Excessive nitrogen fertilizer applications can also lead to pest problems by increasing the birth rate, longevity and overall fitness of certain agricultural pests (Davis et al., 2004; Thomas, 2007; Zhao et al., 2009; Saltzman et al., 2013).

2.3 Composting of Organic Waste

The history of composting is both ancient and modern. In the ancient Rome, and possibly before, composting was recognized as a transitional force in the "life-cycle" (Biernbaum, 2003). Thus, for 2000 years, compost has been used for the maintenance of crop lands and gardens. Brito et al. (2009) describes the compost process as a biotechnology where microorganism, worms and insects participate to produce an innocuous product, chemically stable and utilisable to improve soil fertility and crop production. It is an important technique for recycling organic wastes (weed, crop residues, wastes from post-harvest processing, dung, night soil, urine, etc.) and for improving the quality and quantity of organic fertilizer. The resulting compost is a stabilised organic product produced by the biological decomposition process in such a manner that the product may be handled, stored and applied to land according to a set of directions for use.

The effectiveness of the composting process is dependent upon the environmental conditions present within the composting system i.e. oxygen, temperature, moisture, material disturbance, organic matter and the size and activity of microbial populations. A composting process that operates at optimum performance will convert organic matter into stable compost that is odour and pathogen free, and a poor breeding substrate for flies and other insects. In addition, it will significantly reduce the volume and weight of organic waste (Hammed et al., 2011) as the composting process converts much of the biodegradable component to gaseous carbon dioxide.

Composting helps to optimize nutrient management and the land application of compost can provide solution to the problems of soil organic matter decline and soil erosion (VanderGheynst et al., 2004). Compost land application completes a circle whereby nutrients and organic matter which have been removed in the harvested produce are replaced. The recycling of compost to land is considered as a way of maintaining or restoring the quality of soils. Furthermore, it may contribute to the carbon sequestration and may partially replace peat and fertilizers (Smith et al., 2001). Compost application to agricultural land needs to be carried out in a manner that ensures sustainable development. The main factor in agronomic use of compost is its nitrogen availability. High nitrogen utilization in agriculture through mineral fertilizers has been a common practice; meanwhile, increasing the nitrogen use efficiency of organic fertilizers to the status of chemical fertilizers requires further investigation (Amlinger et al., 2003).

2.3.1 Composting Process

There is an extensive literature on composting methodology (Benítez et al., 1999; Baffi et al., 2007). Misra and Roy (2014) have made a broad distinction as “Traditional” and ‘Rapid’ composting practices. ‘Traditional Methods’ adopt an approach of anaerobic decomposition, or aerobic decomposition based on passive aeration through measures like little and infrequent turnings or static aeration provisions like perforated poles/pipes. The methods take more time which may involve several months. On the other hand, ‘Rapid Methods’ make use of the treatments introduced recently to expedite the aerobic decomposition process and reduce the composting period to about four to five weeks. Besides, there are certain other recently introduced approaches like ‘Vermi-Composting’, which though bring down the process duration to a good extent as compared to the conventional methods. In addition to production of a far-superior quality product, the recent methods have a lower turn- over and longer time taken as compared to other Rapid Methods.

Traditional methods based on passive composting approach involve simply stacking the material in piles or pits to decompose over a long period with little agitation and management. The under listed methods are examples of Traditional Methods as given by Misra and Roy (2014):

I. The Indian Bangalore method
II. Passive composting of manure piles
III. Aerobic decomposition through passive aeration
IV. The Indian indore method
   - Pit method
   - Heap method
   - High temperature compost

V. Large Scale Passive Aeration
   - Windrow composting
   - Turned windrows
   - Passively aerated windrows

Indian Bangalore method relies on traditional anaerobic decomposition for a larger part of operations and requires six to eight months for the operations to complete. The method is still in use in the urban areas of the developing world, mostly for treatment of urban wastes. A method similar in approach involving anaerobic decomposition and followed in western globe with large farms, is the ‘Passive Composting or Manure Piles’. The active composting period in this process may range from one to two years. The Indian Indore method, which slightly enhances passive aeration through a few turnings, thereby permitting aerobic decomposition; reduces the time requirement and enables production in a time-span of around four months. Chinese rural composting methods, based on passive aeration approach through turnings/ aeration holes, provide output in two to three months. The methods are extensively used in developing world. Though the labour requirements for these methods are high, they are not capital intensive and do not require sophisticated infrastructure and machinery. Turned Windrows’ have been in use with the large farms especially in the developed parts of the world.

The windrows are periodically turned manually or by using a bucket loader or special turning machine. The turning operation mixes the composting materials, enhances passive aeration and provides conditions congenial for aerobic decomposition. Composting operations may take up to eight weeks. This method is very popular in Nigeria especially in the composting plants established by Professor MKC Sridhar and his team from University of Ibadan such as those in Bodija market (Sridhar and Adeoye, 2003) and Alesinloye market (Hammed et al., 2011; Hammed et al., 2012; Hammed, 2013) in Ibadan. Passively Aerated Windrows eliminate the need for turning by providing air to the materials via pipes, which serve as air ducts. Active composting period could range between ten to twelve weeks.

Rapid' composting methods which involve shredding and frequent turnings and are mostly being practiced now a day include, but not limited to, the followings:

a) The Berkley Rapid Composting Method- (involving, use of mineral nitrogen activator)
b) North Dakota State University Hot Composting- (involving, use of effective micro-organisms)
c) Effective Micro-organisms based Quick Compost Production Process- (involving, use of cellulolytic cultures)
d) Forced Aeration Aerated Static Pile
e) Controlled Systems with Forced Aeration and Accelerated Mechanical Turnings
   - In-Vessel Composting
   - Bin Composting
   - Rectangular Agitated Beds
   - Silos
   - Rotating Drums
   - Transportable Containers
f) Vermicomposting- (involving, use of Worms)

Rapid methods like Berkley Rapid Composting and North Dakota State University Hot Composting involve accelerated aerobic decomposition through measures like chopping of raw materials to small size; use of mineral compounds like ammonium sulphate, chicken manure, urine; and turning of the material on daily basis. While chopping without much machinery support may be possible at smaller scales, mechanization may be necessary at large scale applications. Also, whereas Berkley Rapid Composting methods claim an active composting period of two to three weeks only, 'North Dakota State University Hot Composting' may take four to six weeks (Misra and Roy, 2014).

2.3.2 Materials for Composting

The materials that are put into your compost pile have a major impact on how well the composting process works and the quality of the final compost (Gardens, 2010; University of Illinois Bulletin, 2014; Carmen, 2015). A list of some commonly available materials is included in Table 2.3. Compostable materials that need special handling are mentioned in Table 2.4 and materials that should be avoided are shown in Table 2.5. As materials are being collected for composting, it may not be easy to determine if materials are higher in carbon or nitrogen. Tables showing carbon to nitrogen ratios for particular materials are helpful, but they usually only show a limited number of materials. Materials of animal origin (such as feathers, blood meal) are typically higher in nitrogen. Drier, older, or woody vegetable and plant tissues are usually higher in carbon. Table 2.4 provides information on carbon to nitrogen ratios. The presence of a carbon, nitrogen, or oxygen in the C/N column indicates whether a material's effect on compost would be carbonaceous (C), nitrogenous (N), or other (O).

There are a number of compostable materials that require special handling before they are put into a backyard pile. Some of the materials listed below may require extra preparation or they may need to be added in layers or small quantities. Other materials listed may cause difficulties with the composting process or negatively affect the final product (University of Illinois Bulletin, 2014,). The comments are intended to help in deciding whether to include these particular materials in a composting pile. In an extensive survey of organic manurial materials available for use locally, Omueti et al. (2000) revealed that stalks of various crops (corn, guinea corn, sorghum) rice husks, wheat straws, vegetable peelings, banana leaves, excreta from poultry, cows piggery sheep and goats, wastes from breweries and other industries which possess organically rich materials were being used in various parts of the country, but the potential of these organic manures in Nigeria are not explored to the fullest extent.

Table 2.3. List of commonly available compostable materials

Material	C/N	Material	C/N
Bedding, herbivorous	C & N	Hair	N
Blood meal	N	Hay	C
Bone meal	N	Lake weeds	N
Coffee grounds	N	Leaves	C
Crushed egg shells	O, alkalizer	Lint	N
Feathers	N	Manure	N
Fruit	N	Paper(non-recyclable)	C
Fruit peels and rinds	N	Peanut shells	C
Garden debris, dried	C	Straw	C
Garden debris, fresh	C & N	Pumpkins	N
Grass clippings, dried	C	Vegetable scraps	N
Grass clippings, fresh	N	Tea grounds and leaves	N

Source: University of Illinois Bulletin (2014)

Table 2.4. Compostable materials requiring special handling

Material	C/N	Comment
Cardboard (non-recyclable)	C	Slow to decompose. Shred into small pieces. If desired, put in water and add a drop of detergent to further speed decomposition.
Corn cobs and stalks	C	Slow to decompose. Run through shredder or chop into very small pieces, mix with nitrogen rich material.
Diseased plants	C	Diseases may be hard to eliminate. Sun-bake plants in plastic bag until thoroughly dried, or leave in hot pile (55°-60°C) at least one week, or burn and put ashes in pile, or omit from pile.
Grass clippings with chemicals	C	Pesticides and herbicides are a concern, degradability ranges from one to twelve months. Leave grass clippings on the lawn (best) or add to pile if material composts for at least 12 months or wait 2-3 weeks before using clippings from lawn after chemicals applied. Do not use clippings as garden mulch for at least 2-3 weeks (or after chemical application).
Hedge trimmings	C or N	Slow to decompose. Thin layers of hedge trimmings can be used occasionally for roughage; chop twigs and branches into small pieces.
Lime	O, Alkalizer	Changes pile chemistry, causes nitrogen loss, and too much lime hurts bacteria and other microorganisms. Omit from pile or use very sparingly in thin layers if pile is going anaerobic (do not mix with manure).
Nut shells - walnut, pecan	C	Slow to decompose. Pulverize with shredder.
Peat moss	O, low in nutrients	Highly moisture absorbent, slow to decompose. Mix thoroughly with other materials, add in small quantities. If possible, soak peat moss in warm water before adding to pile.

Pine Cones	C	Slow to decompose. Shred or chop into very small pieces.
Pine needles	C	Slow to decompose. Mix thoroughly with other materials, add in small quantities.
Rhubarb leaves	N	Contains oxalic acid which lowers pH and inhibits microbial activity. Add in very small quantities, mix thoroughly with other materials or omit from pile.
Sawdust	C	Slow to decompose, can negatively affect aeration. Work into pile in thin sprinklings, mix with nitrogen rich material.
Sod	N	Slow to decompose. Break into small clumps, mix thoroughly with other materials or cover top of the pile with roots up, grass down (better in fall), or compost separately with roots side up, water thoroughly, cover with a dark tarp.
Soil	O, Activator source	Can make finished compost heavy. Add small quantities in thin layers as soil activator or omit from pile (finished compost produces the same results and typically weighs less).
Walnut leaves	C	Contain juglone which can be toxic to plants. Add in small quantities, mix thoroughly; toxins will biodegrade in 30 to 40 days.
Weeds, pernicious	C	Rhizomatous root system hard to kill. Sun-bake in plastic bag until thoroughly dried or omit from pile.
Weeds, other	N	Weed seeds hard to kill. Best to use when green and no seed heads present or leave in hot pile (55-60°C) at least one week.
Wood ashes	O, Alkalizer, potash	Changes pile chemistry, can cause nutrient imbalance. Use very sparingly in thin layers; do not use on top of pile or omit from pile.
Wood chips	C	Slow to decompose. Shred or chop into very small pieces; mix with nitrogen rich material.

Source: University of Illinois Bulletin (2014)

Table 2.5. Materials to avoid in compost pile

Material	Comment
Bones	Very slow to decompose; can attract pests.
Cat litter	May contain pathogens harmful to humans; may also contain chemicals to perfume litter.
Charcoal and briquettes	Contain sulfur oxides and other chemicals that are toxic to soil and plants.
Cooked food waste	May contain fats which attract animals; slow to decompose.
Dairy products	May smell, take a long time to decompose, and attract pests (butter, cheese, mayonnaise, salad dressing, milk, yogurt, sour cream).
Dishwater	May contain grease, perfume, and sodium.
Fatty, oily, greasy foods	Slow to decompose; will putrefy and smell bad; can attract pests.
Fish scraps	Can attract pests; smells bad during decomposition.
Meat	Can attract pests; smells bad during decomposition.
Paper, glossy colored	May contain inks that could contribute toxins to the pile.
Peanut butter	Can attract pests; slow to decompose.
Pet wastes, human excrement	May contain pathogenic bacteria, viruses, and parasites that require prolonged high temperatures to be destroyed.
Sludge (biosolids)	Requires special handling and high temperatures to kill disease organisms and get rid of toxic metals; do not use unless product is sold in compliance with government regulations.

Source: University of Illinois Bulletin (2014)

2.3.3 Factors Affecting the Composting Process

The composting process depends upon different factors like carbon: nutrients ratios (C: N), moisture content, free air space, temperature, pH, particles size, and activity of microorganisms.

1) Carbon: Nutrients ratios (C: N)

Organic material provides food for organisms in the form of carbon and nitrogen. Bacteria use carbon for energy and protein to grow and reproduce. Carbon and nitrogen levels vary with each organic material. Carbon-rich materials tend to be dry and brown such as leaves, straw, and wood chips. Nitrogen materials tend to be wet and green such as fresh grass clippings and food waste. A tip for estimating an organic material's carbon/nitrogen content is to remember that fresh, juicy materials are usually higher in nitrogen and will decompose more quickly than older, drier, and woodier tissues that are high in carbon.

A C: N ratio ranging between 25:1 and 30:1 is the optimum combination for rapid decomposition (Metcalf and Eddy, 2003; Sridhar et al, 2003; Parvaresh et al., 2004). However, some researchers have successfully carried out composting at lower C: N ratios: 15 (Huang et al., 2004), 18 (Gou et al., 2012), 19.6 (Kumar et al., 2010) and 20 (Zhu, 2006). If ratio is more than 30:1 carbon, heat production drops and decomposition slow down. A pile of leaves or wood chips may remain stagnant for a year or more without much apparent decay. When there is too much nitrogen, composting pile will likely release the excess as smelly ammonia gas. Too much nitrogen can also cause a rise in the pH level which is toxic to some microorganisms. The C: N ratio does not need to be exact. It is difficult to determine an exact C: N ratio without knowing the moisture content of the materials being used. Blending materials to achieve a satisfactory C: N ratio is part of the art of composting. A simple rule of thumb is to develop a volume-based recipe using from one-fourth to one-half high-nitrogen materials (Cornell Waste Management Institute, 1996).

2) Moisture content

Moisture content is very important during composting and may easily become the limiting factor if not monitored. Moisture content of 40 to 60 % has been found optimum for good composting process (Spencer and Alix, 2006; Reddy, 2011). While dry compost is easier to manipulate and store without causing a nuisance, a moist mixture is necessary to sustain the biological decomposition vital to the composting process. Only after composting has been completed, drying could be considered as a necessary prerequisite to storage or sale (Roger et al., 1991).

Decomposer organisms need water to live. Microbial activity occurs most rapidly in thin water films on the surface of organic materials. Microorganisms can only utilise organic molecules that are dissolved in water. The optimum moisture content for a compost pile should range from 40 to 60 percent. If there is less than 40 percent moisture, bacteria slow down and may become dormant. If there is more than 60 percent, water will force air out of pile pore spaces, suffocating the aerobic bacteria. Anaerobic bacteria will take over, resulting in unpleasant odors. The ideal percentage of moisture will depend on the organic material's structure. Straw and corn stalks will need more moisture than leaves, while food waste or grass clippings are not likely to need additional moisture. Since it is difficult to measure moisture, a general rule of thumb is to wet and mix materials so they are about as moist as a wrung-out sponge. Material should feel damp to the touch, with just a drop or two of liquid expelled when squeezed in your hand.

If a compost pile is too dry, it should be watered as the pile is being turned or with a trickling hose. Certain materials such as dead leaves, hay, straw, and sawdust should be gradually moistened until they glisten. These types of materials have a tendency to shed water or adsorb it only on the surface. If a pile is saturated with water, it should be turned so that materials are restacked. It may also help to add dry, carbon rich materials.

3) Aeration

Composting systems are distinguished on the basis of oxygen usage (aerobic and anaerobic). Aerobic decomposition, in contrast to anaerobic types, is quicker, progresses at higher temperatures and does not produce foul odour. While anaerobic decomposition may be conducted with minimal operator attention and the operation may be sealed from the environment. However, most modern composting operations attempt to maintain an aerobic environment (Roger et al., 1991). Mixing the compost pile at intervals aerates it, but it is difficult to determine the exact periods to turn the pile. Consequently, aeration usually conducted in excess is not harmful to the composting process, except that an optimum temperature is harder to maintain and excessive evapotranspiration may cause moisture to become a limiting factor. An optimum oxygen level from 10 to 30 % has been reported by Gaur (1997).

Aeration is critical in composting because it supplies oxygen, and removes carbon dioxide, excess heat and moisture from the compost (Solano et al., 2001). Static pile composts can be aerated by one of the three methods: natural, passive and forced. Passive aeration systems are more economical than active aeration systems in terms of initial capital investment, operation, maintenance, and operator training costs (Yu et al., 2006). It has a higher process rate than natural aeration system and result in similar compost quality as forced aeration system (Solano et al., 2001). In passive aeration composting, open-ended perforated pipes are placed inside the compost pile. Airflow into the pile is achieved through natural convection developed by temperature differences within the pile. Passive aeration composting studies have shown the feasibility and effects of using horizontal perforated pipes (Solano et al., 2001; Zhu et al., 2004) and vertical perforated pipes (Sylla et al., 2006) for composting.

The horizontal pipe has perforations spread along the pipe length at the same level at the bottom of the pile. It is characterized by low composting rates, marked temperature differences between the top and bottom in the pile as a result of low air diffusion, and is limited to small-scale composting applications. The vertical pipe has perforations spread along the pipe length at different levels inside the pile. It was an improvement over the horizontal pipe system as it resulted in more effective air delivery into the composting pile, insignificant temperature difference among levels within the pile, and increased composting rates.

4) Temperature

Temperature is an excellent indicator of how much oxygen is being used by the microorganisms in a composting pile (Walker, 2004) and its variations at different locations within the pile can be used to assert the local aeration conditions (Tiquia and Tam, 2000). It has also been established that aeration demand is highest during the thermophilic phase (Tiquia, 2002). High temperature maintained during the composting process serves to promote efficiency and effectiveness of compost by accelerating the process and by destroying pathogenic microorganisms. As the microorganisms work to decompose the compost, they give off heat which in turn increases pile temperatures. Temperatures between 32ºC and 60ºC indicate rapid decomposition. Lower temperatures signal a slowing in the composting process. High temperatures greater than 60ºC reduce the activity of most organisms (Shilev et al., 2007).

Outside air temperatures can impact the decomposition process. Warmer outside temperatures in the dry season, and early fall stimulate bacteria and speed up decomposition. Low temperatures in the rainy season can slow or temporarily stop the composting process (Biswarup, 2015). As air temperatures warm up in the spring, microbial activity will resume. During winter months, compost piles can be covered with a tarp to help retain heat longer, but it is not necessary. The most accurate readings will come from a compost thermometer or temperature probe. Another method for monitoring temperature is to stick fist into the pile. One can also place a metal pipe or iron bar in the middle of the pile, periodically pulling it out and feeling it. If the bar or the interior of the pile feels uncomfortably warm or hot during the first few weeks of composting, everything is fine. If the temperature inside the pile is the same as the outside that is an indication that the composting process is slow.

5) pH

No specific pH is required for composting process as different organic wastes suitable for composting have a range of pH from 5 to 12 (Gaur, 1997). However, compost products usually have a near neutral or slightly alkaline pH with a high buffering capacity. Generally, the increase in pH during composting could be linked to the biodegradation of the organic acids, mineralisation of organic compounds and the consequent release of volatile NH_3 (Paredes et al., 2000; Said-Pullicino et al., 2007). The pH of between 8.0 and 9.0 attained during the composting process indicated a successful and fully developed process (Sundberg et al., 2004).

6) Particle size

Particle size affects the rate of organic matter breakdown. The more the "surface area" available, the easier it is for microorganisms to work, because activity occurs at the interface of particle surfaces and air. Microorganisms are able to digest more, generate more heat, and multiply faster with smaller pieces of material. Although it may not be required, reducing materials into smaller pieces will definitely speed decomposition. Organic materials can be chopped, shredded, split, bruised, or punctured to increase their surface area. The optimum particle size ranges between 25 and 75mm.

7) Role of microorganisms in composting

Composting is an aerobic biological process; a diverse consortium of microorganisms acting concurrently controls this process. The most active players in composting are bacteria, actinomycetes, fungi, and protozoa (Ryckeboer et al., 2003). These microorganisms are naturally present in most organic materials, including food waste, soil, leaves, grass clippings, and other organics. Composting is also dependent upon a succession of microbial activities, whereby the environment created by one group of microorganisms ultimately promotes the activity of successor groups. To accelerate the process of composting, Singh and Sharma (2003) inoculated various kinds of wastes (mixed solid waste, municipal solid waste and horticultural waste) with different microbes.

Different types of microorganisms are active at different phases in the composting pile (Carmen, 2015). According to Vargas-Garcia et al. (2010), the total number of microorganisms does not significantly change during composting. Bacteria have the most significant effect on decomposition; they are the first to become established in the pile, processing readily decomposable substrates (e.g., proteins, carbohydrates, and sugars) faster than any other group. Nitrogen-fixing bacteria are also present in the compost pile, which will fix atmospheric N for incorporation into cellular mass. Commercial products are available that claim to speed the composting process via the introduction of selected strains of bacteria. Some researchers (Xi et al., 2005; Vargas-Garcia et al., 2006; Espiritu, 2011) reported that microbial inoculation during composting could degrade difficult biodegradable substrates like lignin. However, according to other researchers, inoculating compost piles has not been found to bring about completion any more rapidly (Rynk et al., 1992; EPA, 1994).

Fungi play an important role in composting as the pile dries, since fungi can tolerate low-moisture environments better than bacteria. Some fungi also have lower nitrogen requirements than bacteria and are, therefore, able to decompose lignin and cellulose materials, which bacteria cannot. Because fungi are numerous in composting, concern has arisen over the growth of genera such as *Aspergillus*, which pose a potential health hazard.

Rotifers, nematodes, mites, springtails, sowbugs, beetles, and earthworms reduce the size of the compost feedstock by foraging, moving within the pile, or breaking up particles of the feedstock. These actions physically break down the materials, creating greater surface area and sites for microbes to attach and metabolize (EPA, 1994). In later stages, other organisms including Actinomycetes, Centipedes, Millipedes, Fungi, Sowbugs, Spiders and Earthworms assist in the process. The composting process is carried out by three classes of microbes:

- ✓ Psychrophiles - low temperature microbes e.g *Enterobacter sp*. (Carmen, 2015)
- ✓ Mesophiles -medium temperature microbes e.g *Bacillus sp.* and *Esscherichia sp*. (Taiwo and Oso, 2004)
- ✓ Thermophiles - high temperature microbes e.g *Bacillus s.p* and *Clostridium sp.* (Insam and De Bertoldi, 2007).

The bacteria and fungi important in decomposing feedstock can be classified by optimal temperature regime as mesophilic or thermophilic. Mesophilic microorganisms experience most rapid growth at temperatures between 25^{o}C and 45^{o}C. These are dominant within the pile early in the process when temperatures are near ambient. The mesophiles use oxygen within the interstices (pores) to oxidize carbon and thus acquire energy. End products of the reactions include carbon dioxide (CO_2) and water. Heat is also generated as chemical bonds in the substrate are broken during metabolism.

2.3.4 Maturity/Stability of Compost

- Characteristics of mature and stable compost include bio-stabilization and humus formation. Guidelines for compost maturity are necessary as unstable/immature product has the potential to cause adverse effects on plants when applied in large amounts or attract vectors, such as flies, and to cause odours (Canadian Council of Ministers of the Environment, 2005; Campitelli and Ceppi, 2008). Compost should be mature and stable at the time of sale and distribution. To be considered mature and stable, compost needs to be cured for a minimum of 21 days and meet one of the following three requirements (William, 2000):

a) the respiration rate is less than, or equal to, 400 milligrams of oxygen per kilogram of volatile solids (or organic matter) per hour; or,

b) the carbon dioxide evolution rate is less than, or equal to, 4 milligrams of carbon in the form of carbon dioxide per gram of organic matter per day; or,

c) the temperature rise of the compost above ambient temperature is less than 8 °C .

In addition, organism content shall meet the following:

d) Fecal coliforms < 1000 most probable number (MPN)/g of total solids calculated on a dry weight basis, and

e) No *Salmonella* sp. with a detection level of < 3 MPN/4g total solids calculated on a dry weight basis.

In a study, Tontti et al. (2011) examined a mixture of bio-waste and anaerobically digested sewage sludge (bio-sludge) and cattle manure for their maturity and hygiene quality. Number of faecal coliforms, enterococci, clostridia and *Salmonella* in field soil was determined two weeks and 16 weeks after compost applications. The highest number of enterococci was 5.2 $\log_{10}$ CFU g^{-1}, found in manure compost in the first year, while the highest number of clostridia was found in bio-sludge compost, averaging 4.0 $\log_{10}$ CFU g^{-1} over both years. Municipal compost batches chosen showed variable maturity during field application, and the need to evaluate compost maturity with multiple variables was confirmed.

Abril et al. (2011) evaluated the abundance of microbial functional groups involved in compost maturity to propose a valid tool for measuring the quality standards of compost fertility from a microbial perspective. They concluded that because the results were heterogeneous, proposing a microbial population as universal indicator of the degree of compost fertility was very difficult. However, the microbial community structure might be used as a maturity index. Also, Benitez et al. (1999) did not find correlation between organic matter stabilization and microbial activity. The lack of consistency among studies may be attributed to the fact that biological indicators of maturity include general parameters (biomass, respiration, enzymatic activity, and taxonomic and functional aspects of C degradation).

Production of a less stable product will lower composting costs as a consequence of less frequent turning and less water addition. The lower costs will also help to offset the cost of production of compost pellets. Two consequent benefits are a somewhat higher nitrogen content (including ammonia, an immediately available nitrogen source), and a drier product. The dry pellets contain greater nutrient density in terms of kg N, P, or K per kg of product (as delivered and used,) Both of these properties are beneficial to the manufacturing (screening) and selling of the pellets.

An additional benefit of semi composted material is the production of a less stable, more biodegradable product. Two characteristics that result from the more biodegradable product are the potential for odor generation in the product and more readily available nutrients, especially nitrogen. The more biodegradable product carries all the organic matter that is important to good soil tilth, but it will release its nitrogen more rapidly than a very well stabilized, well composted product. A researcher has shown that young (less stabile) compost will result in better crop yields than the mature (more stable) compost with weed and pest control potential due to its phyto-toxicity (William, 2000). Thus, there are good reasons to not produce an overly stabilized compost product that will be used in the manufacturing of pellets.

2.3.5 Compost Quality

Fertilizer quality is notified in terms of physical and chemical characteristics. The physical parameters include moisture content and particle size (Canadian Council of Ministers of the Environment, 2005). The chemical parameters refer to the amount and form of nutrients, and to various impurities that may be toxic to plants above a critical limit, e.g. biuret in urea (Johannes, 2000). Compost contains all macro- and micronutrients essential for plant growth. However, not all nutrients are readily available in mineral forms for plant uptake. Considerable amounts of nitrogen and phosphorus are organically bound in the compost and are released only once the organic matter is mineralised through microbial activity. The level of readily available mineral nitrogen contained in compost and the degree of nitrogen release due to the mineralization process following compost application are of particular interest (Johannes, 2000). Fertilizers typically provide, in varying proportions (Sae-Lee et al., 2012):

- the three primary macronutrients: nitrogen, phosphorus, and potassium
- the three secondary macronutrients such as calcium(Ca), sulfur (S), magnesium (Mg)
- the micronutrients or trace minerals: boron (B), chlorine (Cl), manganese (Mn), iron (Fe), zinc (Zn), copper (Cu), molybdenum (Mo) and selenium (Se) (Saco et al., 2013)

The macronutrients are consumed in larger quantities and are present in plant tissue in quantities from 0.2% to 4.0% (on a dry matter weight basis). Micronutrients are consumed in smaller quantities and are present in plant tissue in quantities measured in parts per million (ppm), ranging from 5 to 200 ppm, or less than 0.02% dry weight. Hence, macronutrient fertilizers are labeled with an NPK analysis and also "N-P-K-S" (FIFA, 2008). Compost quality is also based on impurities such as: trace elements, foreign matters and organic contaminants for product safety:

i. Trace elements

Trace elements, for example, mercury, cadmium, lead, may be present in raw materials from which compost products are produced. Excessive accumulation in soils over the long term may result in toxicity to plants, animals and humans. However, copper, cobalt, molybdenum and zinc (and possibly nickel and selenium) are plant micronutrients, and their presence may be useful in compost. Also arsenic, cobalt, chromium, copper, molybdenum, nickel, selenium, and zinc are micronutrients required by animals and humans (Webber and Singh, 1995). Cadmium, mercury and lead are of no known value to either plants or animals. Compost applied repeatedly in large quantities to land without monitoring trace element concentrations could theoretically cause adverse effects on human health or the environment over the long term.

ii. Foreign matter in compost

Foreign matter reduces the quality of good compost. As most compost feedstock and products contain foreign matter, source separation of plastics, glass, batteries and other pollutants is very important to protect human health and improve attraction of the final product.

iii. Organic contaminants in compost

Organic chemicals enter waste streams from a variety of industrial and domestic sources. While many degrade or volatilize during waste collection, treatment (including composting) and storage, some of these organic chemicals persist. Some compost feedstock may contain trace amounts of persistent or bio-accumulating organic contaminants, such as dioxins, furans, pesticides, Polychlorinated Biphenyls (PCB), Polycyclic Aromatic Hydrocarbons (PAH) or herbicides (e.g. clopyralid) (Groeneveld and Hébert, 2004).

2.3.6 Compost Standards/Guidelines in Selected Countries

There is no simple way to give a summary concerning compost quality standards as they exist in the world, and how they arose (William, 2000). Recently, several European countries have adopted specific standards and many other countries, including Nigeria, are in the process of doing so. Tables 2.6- 2.12 presents a variety of established and published standards in Nigeria and some selected countries of the world.

Table 2.6. National Minimum Quality Standards for Compost

S/N	Parameters	National Standard
1	Odour	**Odourless**
2	Colour	**Variable**
3	Texture	**Variable**
4	Pathogens	**None**
5	Moisture content	**15 to 25%**
6	pH	**6.5 to 7.5**
7	Total Organic Carbon	**At least 20%**
8	C : N Ratio	**10 to 15**
9	Nitrogen (N)	**1.0 to 4.0%**
10	Phosphorus (P)	**1.5 to 3.0%**
11	Potassium (K)	**1.0 to 1.5%**
12	Non-biodegradable materials (glass, metal, plastic, stones, slugs etc	**Free**

Source:* *Federal Ministry of Agriculture and Rural Development (FMARD) (2007)

Table 2.7. Compost quality standard in Thailand

S/N	Property	Compost Quality Standard
1	pH	**5.5-8.5**
2	Conductivity (mS/cm)	**≤ 3.5**
3	N (%,w/w)	**≥ 1.0**
4	P (%,w/w)	**≥ 0.5**
5	K (%,w/w)	**≥ 0.5**
6	C/N	**≤ 20**
7	Germination index (%)	**≥ 80**
8	Cd (mg/kg)	**≤ 5.0**
9	Cr (mg/kg)	**≤ 300**
10	Cu (mg/kg)	**≤ 500**
11	Pb (mg/kg)≤	**≤ 500**

Source: Thai Agricultural Commodity and Food Standards (TACFS, 2005)

Table 2.8. Heavy metal standards in Germany

Elements	**[a] Max. Conc. Recommended (mg/kg)**	**[b] German Standard (mg/kg)**
Pb	**75**	**150**
Cu	**50**	**150**
Zn	**200**	**500**
Cr	**75**	**150**
Ni	**30**	**50**
Cd	**0.75**	**3**
Hg	**0.5**	**3**

Sources: BodSch (2000) [a]; Kraus and Grammel (2000) [b]

Table 2.9. Heavy metal standard in Danish composts (mg/kg of dry matter)

S/N	Heavy metal	Limit Values
1	Pb	**120 (80 for private gardens)**
2	Cd	**0.8**
3	Hg	**1.2**
4	Ni	**30**

Source: Nielsen and Küger (1992)

Table 2.10. California quality standard for finished compost

Indicator	Quality Standard for Finished Compost	
Visual	All material is dark brown (black indicates possible burning). Parent material is no longer visible. Structure is mixture of fine and medium size particle and humus crumbs.	
Physical	Moisture: 30-40%, Fine Texture (all below 1/8" mesh)	
Odor	Smells like rich humus from the forest floor; no ammonia or anaerobic odor.	
Nutrient	Carbon: Nitrogen Ratio	<17:1
	Total Organic Matter	20-35%
	Total Nitrogen	1.0-2.0%
	Nitrate Nitrogen	250-350 $mgkg^{-1}$
	Nitrite Nitrogen	0 $mgkg^{-1}$
	Sulfide	0 $mgkg^{-1}$
	Ammonium	0 or trace
	pH	6.5-8.5
	Cation Exchange Capacity (CEC)	>60 $Cmolkg^{-1}$
	Humic Acid Content	5-15%
	ERGS Reading	5,000-15,000 mS/cm
Microbiological	Heterotrophic Plate Count	1×10^{8} - 1×10^{10} CFU/gdw
	Anaerobic Plate Count	Aerobes: Anaerobes at 10:1 or greater
	Yeasts and Molds	1×10^{3} - 1×10^{5} CFU/gdw
	Actinomycetes	1×10^{6} - 1×10^{8} CFU/gdw
	Pseudomonads	1×10^{3} - 1×10^{6} CFU/gdw
	Nitrogen-Fixing Bacteria	1×10^{3} - 1×10^{6} CFU/gdw
	Compost Maturity	>50% on Maturity Index at dilution rate appropriate for compost application.
	Compost Stability	<100 mg O^{2}/Kg compost dry solids-hour
	E. coli	< 3 E. coli/g
	Fecal Coliforms	<1000 MPN/g of dry solids
	Salmonella	< 3 MPN/4g total solids

Source: CalRecycle (2010)

Table 2.11. Canadian Council of Ministers of the Environment heavy metal standards in compost (mg/kg of dry weight)

S/N	Trace Elements	Concentration
1	Arsenic (As)	**13**
2	Cobalt (Co)	**34**
3	Chromium (Cr)	**210**
4	Copper (Cu)	**400**
5	Molybdenum (Mo)	**5**
6	Nickel (Ni)	**62**
7	Selenium (Se)	**2**
8	Zinc (Zn)	**700**
	Others	
9	Cadmium (Cd)	**3**
10	Mercury (Hg)	**0.8**
11	Lead (Pb)	**150**

Source: Canadian Council of Ministers of the Environment (2005)

Table 2.12. Australian Fertilizer Description and Labeling

S/N	Nutrient	Concentration (%)
	Solid Fertilizer	
1	N, P, K, S, Ca, Mg, Si	0.5
2	Fe	0.1
3	Cu, Mn, Zn	0.05
4	B	0.02
5	Mo, Co, Se	0.001
	Liquid Fertilizers and Soluble Solids Intended only for Use in Solution	
6	N, P, K, S, Si	0.1
7	Ca, Mg	0.1
8	B, Cu, Fe, Mn, Zn	0.005
9	Co, Se, Mo	0.001

Source: Australian National Code of Practice for Fertilizer Description and Labeling (2011)

2.3.7 Nutrient Binding Form

In fertilizer analysis, in addition to estimating total nutrient content, it is necessary to estimate the forms of nutrients and other associated compounds in order to assess their quality properly (Johannes, 2000). Virtually all potassium supplied with compost can be used immediately by plants. The situation is more complex with nitrogen of which only a small proportion is directly available to plants initially and the remainder being mineralized and released only over time (3 – 4 years) (Motsara and Roy, 2008). As given by the Canadian Council of Ministers of the Environment (2005), the form(s) in which nutrients are present and the percentage of each must be stated on the label as detailed in Table 2.13. The low availability of phosphate in the soil is one of the most serious constraints on tropical agriculture (Wakelin et al., 2004; Oberson et al., 2006). Phosphorus is immobile in the soil system and hardly 15-20% of the applied phosphate is utilized by a crop to which it is applied while the rest remains in a fixed state in soil (Osorio and Habte, 2009: Batti and Yamar, 2010; Hitesh et al., 2015) being influenced by various physic-chemical and biological mechanisms (Raju et al., 2005).

2.3.8 Organic Fertilizer Application

According to Wagen et al. (2002), many researches have been done on the use of nitrogen fertilizer but less attention is given to sources and methods of nitrogen fertilizer application to crops. Different products may be applied in various ways. Some may be tilled in (worked into the soil with a machine or hand tool), others may be applied as a foliar spray (mixed with a surfactant and sprayed in a fine mist on the leaf surface while temperature could be below 27 ºC), and some may be injected into a drip or overhead irrigation system (fertigation with a siphon mixer) (Federal Ministry of Agriculture and Rural Development, 2014). Organic products require the activity of soil microorganisms before nutrients are available for plant uptake and other environmental factors (Borghi, 2000; Blankenau et al., 2002). Microorganism activity is generally dependent on soil temperatures greater than 10 ºC in the presence of sufficient soil moisture. Dry and/or cold soil conditions will delay the release of nutrients from these organic sources (L ◌́ opez-Bellido et al., 2004). This period refers to how long these products are available if applied to the soil. In order to get expected results from the use of agrochemicals, it has to be applied in correct form, with correct dosage and methods (Reza-Bagheri et al., 2011).

Table 2.13. Nutrient forms in organic fertilizer

Nutrient	Forms to be shown
Nitrogen	N as nitrate
	N as ammonium
	N as urea
	N in any other form (form to be stated)
	N Total
Phosphorus	P as water soluble
	P as citrate soluble
	P as citrate insoluble
	P Total
Potassium	K as chloride
	K as nitrate
	K as phosphate
	K as sulphate
	K as carbonate
	K as thiosulphate
	K in any other form (form to be stated)
	K Total
Calcium	Ca as carbonate
	Ca as hydroxide
	Ca as oxide
	Ca as sulphate
	Ca as nitrate
	Ca as chloride
	Ca as superphosphate (or phosphate)
	Ca as silicate
	Ca in any other form (form to be stated)
	Ca Total

Magnesium	Mg as carbonate
	Mg as hydroxide
	Mg as oxide
	Mg as silicate
	Mg as sulphate
	Mg as nitrate
	Mg as chloride
	Mg in any other form (form to be stated)
	Mg as total
Sulphur	S as sulphate
	S as elemental
	S in any other form (form to be stated)
	S as total

Source: Canadian Council of Ministers of the Environment (2005)

Akanbi et al. (2007) reported that compost could be formulated into liquid form (of higher nutrient contents instead of in bulky heavy form. This reduces quantity required per unit area of land, makes handling and application easier and improved the chances of adoption of composting technology by the Peasant farmers in Nigeria. In view of the importance of nitrogenous fertilizer in plant production vis-à-vis its effects on the environment, strategies that optimize on its benefits while reducing environmental impacts should be sought. In a study, Hammed (2013) tested the effect of locally fabricated pelletizing machine on the chemical and microbial composition of organic fertilizer; he concluded that pelletizing improved the quality of the fertilizer due to the significant reduction of heavy metals and microbial contents. Table 2.14 shows the application rates and procedures of both compost and organo-mineral fertilizers for some common crops, based on field experiences.

2.3.9 Effect of Compost on Soil Properties

Compost not only acts as a source of nutrients but also provides benefit of improving soil characteristics. An appropriate rate of compost application changes the physical, chemical and biological properties of soil. Hanay et al. (2004) reported that aggregate stability of clay loam soil increased by 16 and 33 % while water holding capacity increased by 2.3 and 5.7 % by the application of 100 and 150 t ha^{-1} compost respectively. Rong et al. (2001) conducted a plot trial to investigate the effects of combined inorganic and organic fertilizer application to red upland soil. Results showed that combined application of inorganic and organic fertilizer decreased soil bulk density and increased soil moisture.

Eghball (2002) reported that application of organic materials influenced chemical properties of soil; soil pH was maintained near the original soil pH level when N-based manure or compost was applied; and, increased Cation Exchange Capacity (CEC) in response to compost applications improved nutrient retention in soil (Preusch et al., 2002). Manure application in excess of crop requirements can cause a significant buildup of P and N in soil. Residual effects of N and P based compost application on corn grain yield and N uptake lasted for at least one growing season but on soil properties, it can last for several years, since only a fraction of N and other nutrients in compost become available in the first year after application (Eghball, 2002).

Table 2.14. Application rate and procedure of organic and organo-mineral fertilizer for some crops

S/N	Crop	Rate	Procedure
		Organo-mineral Fertilizer	
1	Maize and other arable crops.	2.5 tons/Ha or 2 table spoons per plant.	Apply 2 wks after planting, 5cm deep and 8cm away from plant.
2	Cassava	2.0 tons/Ha or 1¾ table spoons per plant	Apply 6 wks after planting as above
3	Yam	2.0 tons/Ha or 2 table spoons per plant.	Apply as ring (Buried) at vine initiation.
4	Vegetables	3.0 tons/Ha	Broadcast and worked into the soil
5	Cocoa and other tree crops	5.0 tons/Ha or 4 table spoon per plant. Apply ½ at transplanting (1st year) and the second half in the 3rd year.	Buried as spot application.
6	Oil palm	5 tons/Ha or 4 table spoons per plant. Apply 2 ½ tons post nursery and second application in the 2nd year.	As above
		Organic Fertilizer	
Normal practice of 5 to 10 tons per Ha applied at 5cm deep and 5cm away from plant will not do any harm to soil or crop.			

Source: unpublished field work

Eghball et al. (2004) reported that nitrogen based compost application increased soil P levels which contribute to crop uptake for up to 10 years without additional P application. According to Ghosh et al. (2010), application of cattle manure resulted in a 22% increase in soil-exchangeable K over levels found in control. Organic amendments application also resulted in a significant increase in exchangeable Na concentration. Some of the organic wastes, viz. cotton gin trash (10 t ha^{-1}), cattle manure (10 t ha^{-1}), biosolids (10 t ha^{-1}) and composted chicken manure (3 t ha^{-1}) have value as a source of nutrients to soil.

2.3.10 Health and Safety Guidance for Small Scale Composting

A possible concern with composting is the potential for the presence of human pathogens (disease causing organisms). When composting involves multiple households, pathogen reduction occurs in larger compost piles (3'x3'x3'minimum) due to self-heating, if properly managed. In small compost piles, raised temperatures are often not achieved, and the potential for the survival of pathogens increases (Cornell, 2004).

Bio-aerosols are airborne particles of microbial, plant or animal origin and may be called organic dust. They can include live or dead bacteria, fungi, viruses, allergens, bacterial endotoxins (components of cell membranes of gram-negative bacteria), antigens (molecules that can induce an immune response), toxins (toxins produced by microorganisms), mycotoxins (toxins produced by fungi), glucans (components of cell walls of many molds), pollen, plant fibers, etc. Many bio-aerosols are released or produced by the composting process (Bunger et al., 2006; Ellen, 2007). Microorganisms are frequently absorbed onto dust particles and will be transported along with the dust. Many bio-aerosols are known to cause symptoms and/or illness, including a wide range of adverse health effects and infection: muscosal membrane irritation, skin diseases, conjunctivitis and markers showing immune system response (Bunger et al., 2006). Herr et al. (2004) reported an association between residential bio-aerosol pollution and irritative airway complaints as well as excessive fatigue and shivering (which symptoms are reported at workplaces handling such materials).

In another related literature, Muller et al. (2006) reported that short-term exposure of healthy young subjects to organic dust at composting facilities led to mild but measurable effect in eliciting acute systemic alterations; Pagans et al. (2006) indicated that VOC emissions from lab-scale composting of various organic wastes showed maximum emissions early in the composting process; and, Wouters et al. (2006) monitored worker exposure in composting facilities that processed: 3 residential organic wastes - indoors; 6 green waste - outdoors; 4 mixed residential organic wastes and green waste – indoors. They concluded that endotoxin and dust levels at residential organic waste and mixed composting facilities were higher than green waste and endotoxins at such facilities often exceed Dutch occupational standards.

2.4 Constraints to Fertilizer Use in Nigeria

Low fertilizer use has been identified as a major challenge that must be overcome in order to increase Nigeria's agricultural productivity. However, there are several factors that contribute to low fertilizer use that are not addressed by direct price subsidies. Banful et al. (2010) found that the primary constraint to fertilizer use in Nigeria is absence of the product at the time that it is needed, rather than affordability problems or farmers' lack of knowledge about its importance. Second, the most often-cited primary challenge for both male and female farmers is limited access to credit. The other often-cited challenges are high prices of inputs other than fertilizer and an inadequate fertilizer supply.

In the early 2000s (between 2002 and 2005), all the nitrogen phosphorous potassium (NPK) fertilizer used in Nigeria was imported in the absence of any domestic production as the result of the closure of the only fertilizer industry, the National Fertilizer Company of Nigeria (NAFCON) for repairs. During this period, the Federal Market Stabilization Program (FMSP) remained an integral part of fertilizer policy in Nigeria and accounted for 43 percent of total capital spending in agriculture from 2001 through 2005 (Mogues et al., 2008), thereby supplying the budgetary resources needed for fertilizer imports. In addition, overvalued currency for most of the post-1980 period made it unprofitable to generate domestic production. Domestic sources of organic manure were limited by a livestock industry that is largely mobile and separated from crop agriculture, making biomass sources uncompetitive with imported synthetic fertilizer, while agro-forestry technologies were not widespread.

2.5 Institutions for Fertilizer Quality Regulation in Nigeria

Despite a multifaceted fertilizer quality regulatory process, fertilizer quality remains a challenge in Nigeria. Fake, adulterated, and misbranded fertilizers, as well as underweight bags of fertilizer are prevalent in the market (Ayoola et al. 2002; Chude, 2006; FGN, 2006). There are numerous fertilizer regulatory activities that concurrently existing in Nigeria. The Standards Organization of Nigeria (SON), National Agency for Food and Drug Administration and Control (NAFDAC), Federal Fertilizer Department (FFD) of the Federal Ministry of Agriculture and Rural Development (FMARD), States Ministries of Agriculture (SMAs) and Agricultural Research Institutes under the National University System are key agencies mandated to participate in fertilizer regulation (IFPRI, 2010).

The SON, created in 1971, is a statutory body with a core mandate to produce and periodically review standards relating to products, measurements, and material processes in Nigeria. It promotes standards developed at national and regional levels and is meant to certify industrial products. It also monitors product quality. Currently, it has two programs: Standards Organization of Nigeria Conformity Assessment Program (SONCAP) and Mandatory Conformity Assessment Program (MANCAP). The MANCAP focuses on quality assurance verification and compliance, and operates once fertilizer gets into the country, or for locally-produced fertilizer; the local SON offices issue MANCAP National Industrial Standards NIS Logo Certification to those in compliance. NAFDAC was established in 1993 with the mandate to regulate and control quality standards of foods, drugs, and chemicals imported or manufactured locally and distributed in Nigeria. It was meant to regulate and control quality standards made by SON, serving as a quality regulator and control agency for the importation, local production, and marketing of fertilizers. In addition to NAFDAC and SON, the Federal Fertilizer Department (FFD), now called the Agricultural Input Services Department (AISD), is also charged with ensuring that both locally produced and imported fertilizers meet required quality standards.

2.6 National Fertilizer Policy for Nigeria

The policy on fertilizer has existed in bits and pieces inside the grey literature such as government files over the time since the establishment of a Ministry for Agriculture at the Federal level in 1967 followed by the creation of the first professional Department in the Ministry (Federal Department of Agriculture, FDA) in 1970 (Federal Ministry of Agriculture and Rural Development, 2014). The promotion of fertilizer and other green revolution technologies has then become a deliberate government policy. The institutional policy on fertilizer involved the subsequent establishment of the erstwhile Fertilizer Procurement and Distribution Division (FPDD), which was established in the FDA in an effort to coordinate the activities of the states in the importation of fertilizer. For many years, FPDD served as the central agency for fertilizer importation and for the delivery to designated points in the country, until liberalisation of the sub-sector began in 1995 following which the division was re-designated as Federal Fertilizer Department in 2001 (Federal Ministry of Agriculture and Rural Development, 2014).

During this period (1976-1995), the main statute in force was the National Fertilizer Board Act of 1977 which provided for the establishment of “a body corporate to be charged with the responsibility for purchasing and distributing fertilizer to State Governments at such subsidised prices as may be determined by the Federal Government”. In addition, there is the Fertilizer (Control) Decree of 1992 which has provisions to punish any person who, without permission of the appropriate authority, deals in, sells or distributes fertilizer in a place not designated for the purpose of sale or distribution of fertilizer.

The production policy became operational in the early 1970s, when the Federal Government established the Federal Superphosphate Fertilizer Company (FSFC) at Kaduna (1973) as the first manufacturing company of phosphatic products, which became operational in 1976. Afterwards the National Fertilizer Company (NAFCON) was also established in 1981 but started production in 1987, for the manufacture of nitrogenous compounds for domestic use and for exports. In addition, the first in the series of local blending plants were established at Kaduna, Mina, and Kano, which grew in number and capacity. Also, their added value was in terms of producing different formulations to broaden the range of products suitable for application in different areas and for different crops. Lately both FSFC and NAFCON were privatized under the continuing reform policy of the Federal Government.

2.7 Maize: A Staple Food in Nigeria

Maize is one of most widely distributed crops of the world. It is cultivated in tropics, sub-tropics and temperate regions of the world. Tremendous choice is available as regards to varieties of maize that matures in 85 days to more than 200 days with variability in grain colour and texture. As regards to area and production, maize ranks third in world production (380 MT from 120 MT) following wheat (440 MT from 240 MT) and rice (420 MT from 140 MT) (Corn, 2008). This represents 24% of the total cereal production as compared to 27 % for wheat and 25% for rice. Because of its worldwide distribution and relatively lower price, maize has wider range of uses. It is used directly for human consumption, in industrially processing foods, as live-stock feed and in industrially nonfood products such as starches, acids and alcohols.

Maize oil is widely used as a cooking medium and for manufacturing of hydrogenated oil. The oil has the quality of reducing cholesterol in the human blood like sunflower oil. The fat content of the oil is about 80%. Maize acts as a source in the manufacture of starch, syrup, dextrose, oil, gelatin, lactic acid. Corn flour is used as a thickening agent in the preparation of many edibles like soups, sauces and custard powder. Corn syrup is used as an agent in confectionary units. Corn sugar (dextrose) is used in pharmaceutical formulations is s sweetening agent in soft drinks etc. corn gel on account of its moisture retention character is used as a bonding agent for ice-cream cones, as a dry Dustin agent for baking products.

Various studies have shown the importance of organic nutrient sources in improving maize yields: Kinhada (2003) conducted study to test whether composted manure would improve growth and yield of maize. It was observed that dry matter yield, N uptake and final grain yield were significantly higher in farm yard organic waste composted with tithonia or lantana than the control or farm yard organic waste composted alone. In Eastern Ethiopia, Asfaw et al., (1998) reported significant increases in the grain yields of maize grown on a *Typic ustorthent* and a *Typic pellustert* in the Alemaya area due to crop residues application. Heluf (2002) reported an increment of 0.47

t/ha in grain yield of maize on Vertisols of Hirna valley in western Hararghe zone of the same country during the first year due to application of farmyard manure compared to no manure application.

In addition, integrated use of organic sources with mineral fertilizers, crop residues in combination with freshly applied and residual NP fertilizers increased maize grain yields by 1.31 and 0.54 t/ha, respectively, on Inceptisols of Alemaya region (Heluf et al., 1999). The experiment conducted by Mucheru-Muna et al. (2007) in Meru South District, Kenya to investigate the effects of different soil incorporated organic manure made from *Tithonia diversifolia*, *Calliandra calothyrsus*, *Leucaena leucocephala* and mineral fertilizer inputs on maize yield, and over seven seasons. On average, tithonia treatments (with or without half recommended rate of mineral fertilizer) gave the highest grain yield (5.5 and 5.4 Mg/ha respectively) while the control treatment gave the lowest yield (1.5 Mg/ha). In a similar work carried out by Uyovbisere and Elemo (2002) to determine the effects of organic matter, neem and locust bean on maize. Results obtained over the three seasons were consistent, and revealed that neem was superior to locust bean by a factor of 2, but were all inferior to the recommended fertilizer rate (with a maximum yield of 3.75 t/ha).

Also, Kwabiah et al. (2003) conducted a field experiment in Western Kenya to compare the effects of organic and inorganic fertilizers on maize (Zea mays L.) yield. Leaf biomass and small twigs of *T. diversifolia*, *C. megalocarpus*, *L. camara*, *S. spectabilis*, *C. calothyrsus*, and *S. sesban*, were applied at 5 Mg/ ha. Effects of *T. diversifolia* and *C. megalocarpus* on maize yield were similar to the effects of 50 kg P/ha + 120 kg N/ha, as inorganic fertilizer. Nevens and Reheul (2003) studied the effects of compost on maize on a sandy loam soil. Organic wastes of vegetable, fruit and gardens were collected and composted, a yearly application of 22.5 Mg/ha of compost along with 42 Mg/ha of cattle slurry resulted in economically optimum dry matter yields with a substantial saving of mineral fertilizer. Datta et al. (2001) evaluated the manurial value of different coir dust based composts in terms of dry matter production and nutrient uptake of maize. Application of compost yielded significantly higher biomass of maize.

2.8 Yam Production

Yam (*Dioscorea* spp) is important for food security in West Africa which produces more than 90% of the worldwide production (FAO, 2009). Besides their importance as food source, yam also plays a significant role in the socio-cultural lives of people in some producing regions like the celebrated new yam festival in West Africa (Osunde and Orhevba, 2009) and wedding ceremonies in Oceania (O'Sullivan, 2008). Yam also provides cash income for a wide range of smallholders, including many women as producers, processors and traders (Assiedu, 2003). Therefore, improving yam productivity can increase food production and farmers' income in the producing areas, particularly in West Africa.

The decline in yam yields associated with loss of soil fertility has led to the conclusion that yam requires high level of nutrient for growth (O'Sullivan and Ernest, 2008). Nitrogen (N) and potassium (K) are largely stored in the tubers (Diby, 2005; O'Sullivan and Ernest, 2008) while the calcium (Ca) is mainly accumulated in the leaves and returns to the soil with dead leaves (Diby, 2005). Recently, the application of inorganic fertilizer (NPKCa) to yam had no effect on the fresh tuber yield but; it increased significantly the shoot growth (Diby et al., 2009). Hgaza et al. (2010) carried out a study on the response of *Dioscorea alata* to NPK-Ca fertilization as affected by differences in weather conditions in two growing seasons and concluded that fertilization has significantly increased the tuber yield of both years.

2.9 Soybean Cultivation in Nigeria

Soybean has been described in various ways. Some call it the "miracle bean" or the "golden bean" because it is a cheap, protein-rich grain. It contains 40 per cent high quality protein, 20 percent edible vegetable oil, and a good balance of amino acids (AMREC, 2007). It has therefore, tremendous potential to improve the nutritional status and welfare of resource-poor people particularly in a developing country like Nigeria. Soybean can also contribute to enhanced sustainability of intensified cropping systems by improving soil fertility through nitrogen fixation, permitting a longer duration of ground cover in the cropping sequence, and providing useful crop residues for feeding livestock (AMREC, 2007). However, soybean is a relatively new crop in

Africa. Until recently, it was seen as being appropriate only for large-scale commercial farming where the crop can be utilised industrially and for formulation of livestock feed.

Soybean cultivation in Nigeria has expanded as a result of its nutritive and economic importance and diverse domestic usage. It is also a prime source of vegetable oil in the international market. Soybean has an average protein content of 40% and is more protein-rich than any of the common vegetable or animal food sources found in Nigeria. Soybean seeds also contain about 20% oil on a dry matter basis, and this is 85% unsaturated and cholesterol-free (Dugje et al., 2009). The followings are benefits of growing soybean in Nigeria:

- It is good for food—soy-milk, soy-cheese, dadawa, Tom Brown (infant weaning food)
- It is the source of an excellent vegetable oil
- It is used in industry
- It improves soil fertility and controls the parasitic weed
- Soybean cake is an excellent livestock feed, especially for poultry

Soybean growth is influenced by climate and soil characteristics. Soybean performs well in the Southern and Northern Guinea savannas of Nigeria where rainfall is more than 700 mm. However, short-duration varieties can thrive in the much drier Sudan savanna when sown early and with an even distribution of rainfall throughout the growing period. The time for planting soybean depends upon temperature and day length (Dugje et al., 2009). Soybean is a short-day plant and flowers in response to shortening days. In Nigeria, soybean cultivation starts in May/June with land clearing and harvesting normally occurs in late October through November every year. The crop is harvested 3 -4 months after planting, depending on the time of sowing and seed variety (Michael, 2011). It can be grown on a wide range of soils with pH ranging from 4.5 to 8.5. Soybean should not be planted in sandy, gravelly, or shallow soils to avoid drought stress. Also, it should not be grown in waterlogged soils or soils with surfaces that can crust, as this will lead to poor seedling emergence.

Nigeria's soybean output is forecast to increase to 510,000 MT in 2011/12, up from 480,000 MT in 2010/11 (Michael, 2011). The increase in output is attributed to favorable weather in Nigeria's soybeans production belt. Compared to the erratic pattern in 2010, rainfall was favorable both in terms of volume and distribution in 2011. Also, acreage increased because of the prevailing attractive prices. Despite this steady increase, domestic output continues to lag behind rising demand. Higher production is constrained by low yield levels resulting from the high cost of seeds and scarcity of super-phosphate fertilizers.

CHAPTER THREE

METHODOLOGY

3.1 Description of the Study Area

Ibadan (Yoruba: Ìbàdàn or fully Ìlú Ẹ̀bá-Ọ̀dàn, the town at the junction of the savannah and the forest) is the capital city of Oyo State and the third largest metropolitan area in Nigeria by population after Lagos and Kano, according to the 2006 Nigerian census. It is located in south-western Nigeria, 128 km inland Northeast of Lagos and 530 km Southwest of Abuja, the Federal Capital Territory and is a prominent transit point between the coastal region and the areas to the North. In addition, about 36.25 sqkm (34.9% of the land area) is devoted to land use (such as residential area, public buildings and facilities, markets, industrial and commercial areas as well as educational institutions amenities and open spaces. The remaining 63.75 sqkm is devoted to non-urban uses such as fallow land, forest reserves, farmland and water environment (Areola, 1992).

Ibadan had been the centre of administration of the old Western Region since the days of the British colonial rule, and parts of the city's ancient protective walls still stand to this day. The principal inhabitants of the city are Yoruba people. Ibadan experiences two seasons- rainy and dry seasons. The rainy season runs from April through October, with temperature ranges from 23.1ºC to 27ºC and rainfall that ranges from 0.0 to 338.8 mm in 2005. The dry season extends from November through March. Ibadan Southwest Local Government Area (ISLGA), where the study took place, was carved out of the defunct Ibadan Municipal Government (IMG) in 1991. The Administrative Headquarter is located at Oluyole Estate. It covers a landmass of 133.5 square kilometers with a population density of 2,401 persons per square kilometer. The 2010 estimated population for the ISLGA was projected at 320,536 people, using a growth rate of 3.2% from 2006 census.

The ISLGA is bounded by Ibadan North West and Ido Local Government Areas to the North, Oluyole Local Government in the south, Ido Local Government Area in west and Ibadan North and South East in the East. Ibadan Southwest Local Government Area is a home for small, medium and large scale industries. Majority of the large scale industries are located in the Oluyole Estate, Ibadan. Among them are Yale Foods Nigerian Limited, Caps Feed Nigeria Limited, Niger Hygiene, 7up Bottling Company etc. Also, Alesinloye market with a Solid Waste Recycling Facility which formed the site for this study is located in the ISLGA (Figure 3.1). The market is one of the most popular markets in Ibadan. It has 3 major sections which include: Fancy, Paint and Food Stuff (Plate 3.1), and Plastic and sections. It also has about 500 shops, a big central car park, a police station, an abattoir (Plate 3.2), a maternity centre, a bank, a big fire station and good road network (Figure 3.1).

In a bid to sanitize and hence improve the quality of the environment, a Non-Governmental Organization known as Nigeria Network for Awareness and Action for Environmental Health (NINAAFEH) in conjunction with MTN Nigeria Foundation (MTNF) executed an environmental health project in the market. The project comprised rehabilitation of existing wells, bore holes and toilets, and also an establishment of solid waste recycling facility. The recycling complex is tailored towards an operation "Waste to Wealth" in which all organic wastes generated in the market are converted to organic fertilizer while plastic and nylon wastes are recycled into useful materials like pellets and chips for plastic industries. The recycling complex is situated next to the market abattoir where an average of 30 cows was slaughtered daily. Types of waste generated in the abattoir included animal blood, cow dung, cow intestinal waste, bone horn and hoof.

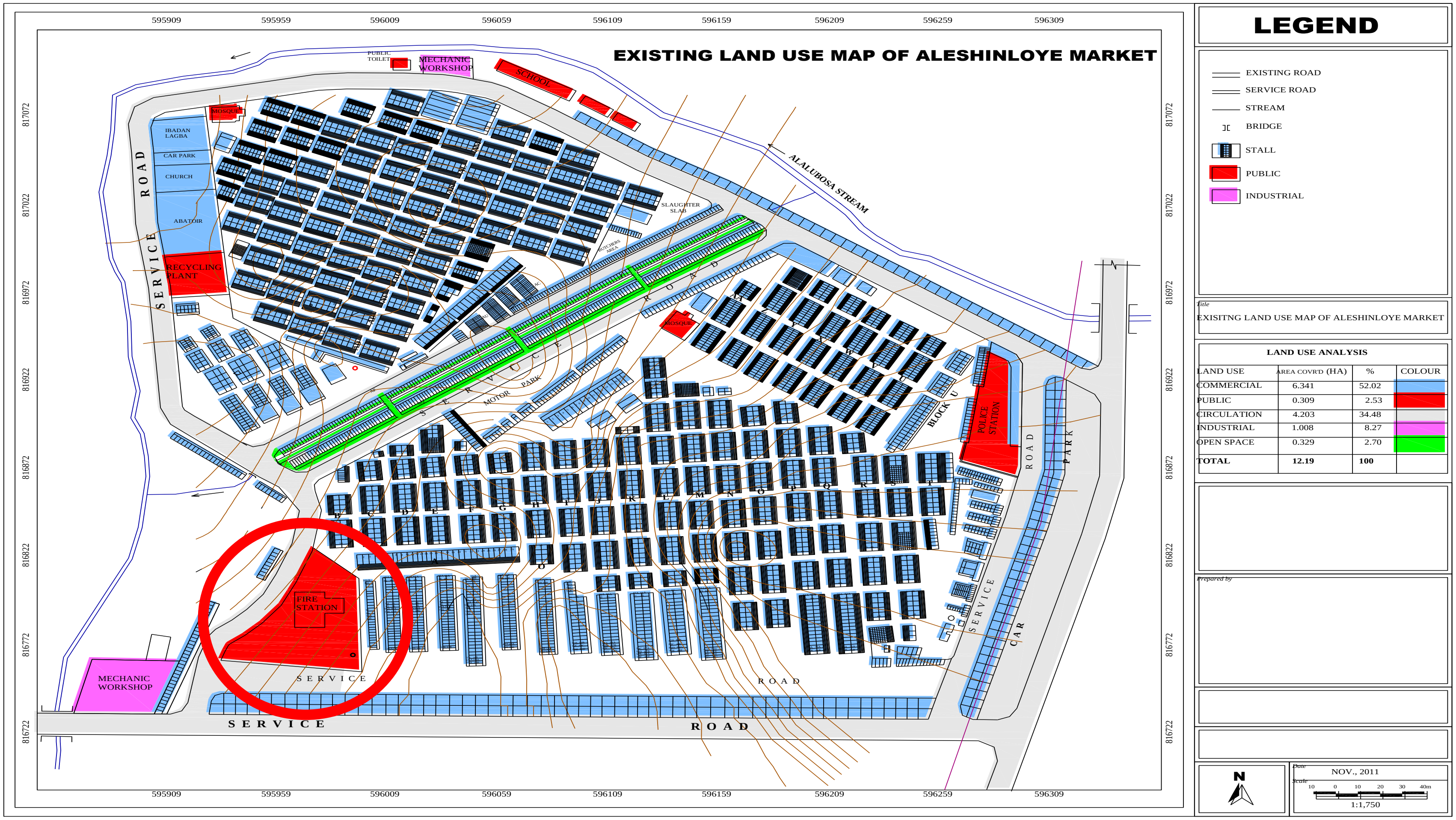

Figure 3.1. Land use map of Alesinloye market showing the waste recycling complex in red circle insert- top left hand corner comprises shops at fancy section; small portion at the centre is plastic section while the largest population of shop is located at food and paint section, including the recycling complex.

A- Market abattoir

B- Food and paint section

Plate 3.1. Sections of the market (A and B)

A- Waste segregation

B- Drying of compost

Plate 3.2. Composting operation at Alesinloye Market Waste Recycling Complex (A and B)

3.1.1 Composting Operations at Alesinloye Waste Recycling Complex

Alesinloye Waste Recycling Complex, Alesinloye Market, Ibadan was established in the year 2006 by a Non- Governmental Organization known as Nigeria Network for Awareness and Action for Environmental Health (NINAAFEH) and MTN Foundation. The following sequence of operations was performed at complex: Mixed Market Wastes (MMW) and Cow Intestinal Waste (CIW) were delivered at the receiving shed and sorting of the mixed market wastes was done manually by labourers who picked non-biodegradable wastes such as plastics, nylon, metals from the wastes-stream. Also, some large size particles found in the wastes such as leaves, paper, cartons were reduced manually by cutting into smaller sizes with cutlass or mechanically by using shredding machine in order to ensure better composting (Figure 3.2). Mixing of the wastes was done through field approach (Nadine, 2001) by combining 3 head pans of sorted market wastes with one head pans of CIW. This translated to an initial C-N ratio of 30:1 which was within the range of 20: 1 to 35: 1 recommended for rapid composting (Rynk et al., 1992; Metcalf and Eddy Inc., 2003). Water was sprinkled on the combined wastes and they were thoroughly mixed together. The mixed wastes were then piled up inside the concrete chambers constructed (windrows). Thereafter, the heap was moistened periodically with water through manual wetting, turned every five days to ensure proper aeration, left for maturation for thirty days and stored for a further period of two weeks for complete stabilization (Figure 3.2). The plant had daily production capacity of 6 tons of organic fertilizer.

The changes in pH and temperature of the compost were monitored at periodic intervals during the maturation period. The compost was dried inside rotary drier to reduce moisture content before it was sent to the mechanical production line for further processing. The mechanical operations included: sieving to remove non-biodegradable such as plastics, metals, gravel and so on; grinding of compost to a homogeneous small particle size; fortifying with Urea and Single Supper Phosphate (SSP) to improve compost quality; and, packaging into 50 kg bags.

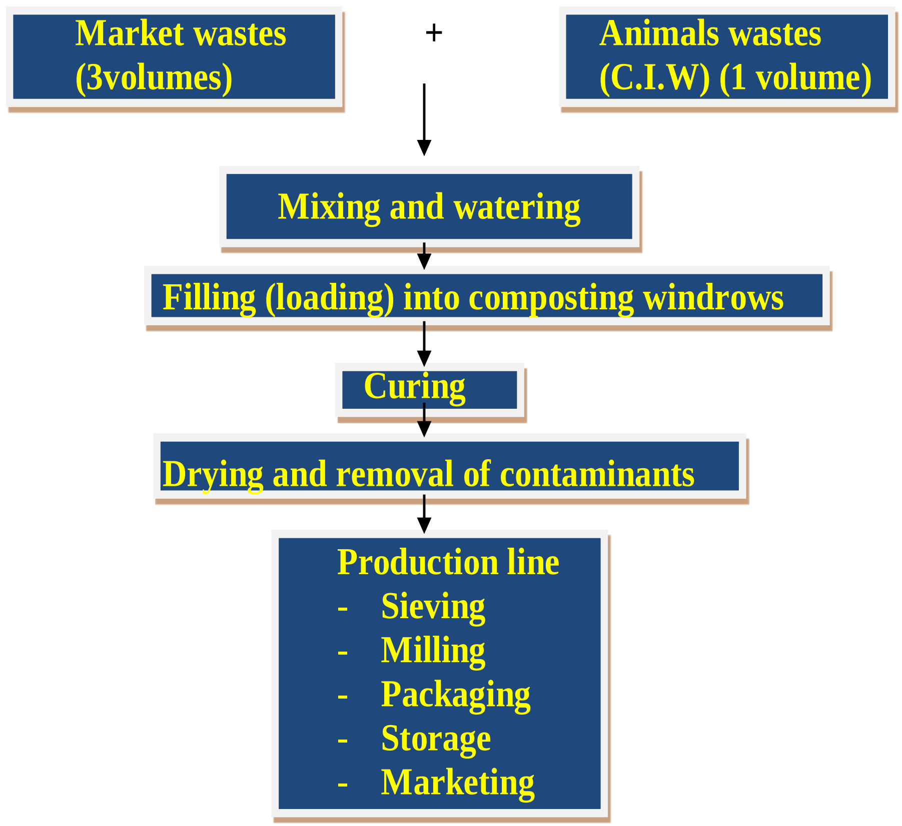

Figure 3.2. Flow Diagram for composting operation

3.2 Study Design and Scope

The study design was experimental, comprising compost treatment, farm plot experiments and laboratory analyses. It was limited in scope to the Alesinloye Market Integrated Waste Recycling Facility.

The field was located behind the factory at Alesinloye market area. The plot experiments design was simple Randomized Complete Block Design (RCBD) with three replications. The main plots were for three crops selected for the study- Maize (cereal), Soybean (Legume) and Yam (tuber) while five different organic fertilizer formulations at three levels of applications- 2.0 tons, 2.5 tons and 3.0 tons per hectare and control plot, applied with ordinary compost without formulation formed subplots. This translated to 0.20, 0.25, and 0.50 Kg per plant respectively (i.e. one 50 Kg bag was used for 250, 200 and 100 plant stands respectively). In the maize and soybean subplots, each of the treatments and control plot was designed in 3 × 3 factorial design with three replications. For yam, 2 x 3 factorial was used (Figures 3.3- 3.5). All the plots were labeled according to the type of compost formulation applied viz:

Control	-	C
Plant- based fertilizer	-	PB
Animal/ Human -based fertilizer	-	AB
Rock- based fertilizer	-	RB
Organic- based fertilizer	-	OM (Mixture of PB, AB, and RB)
Synthetic chemical fertilizer	-	SC

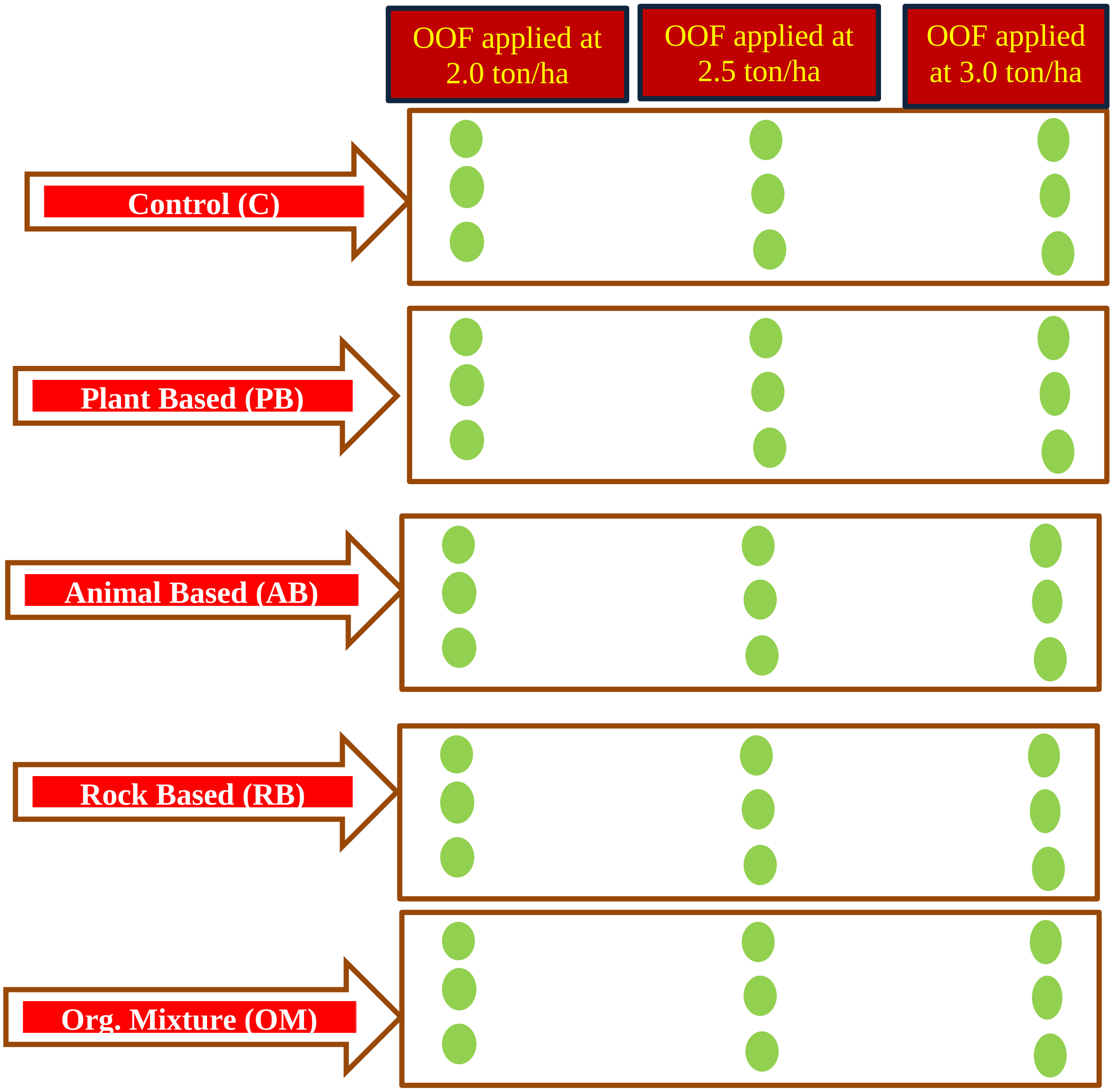

Figure 3.3. Plot design for maize farm plot experiment
(Seeds planted in each box along the columns represent replicates)

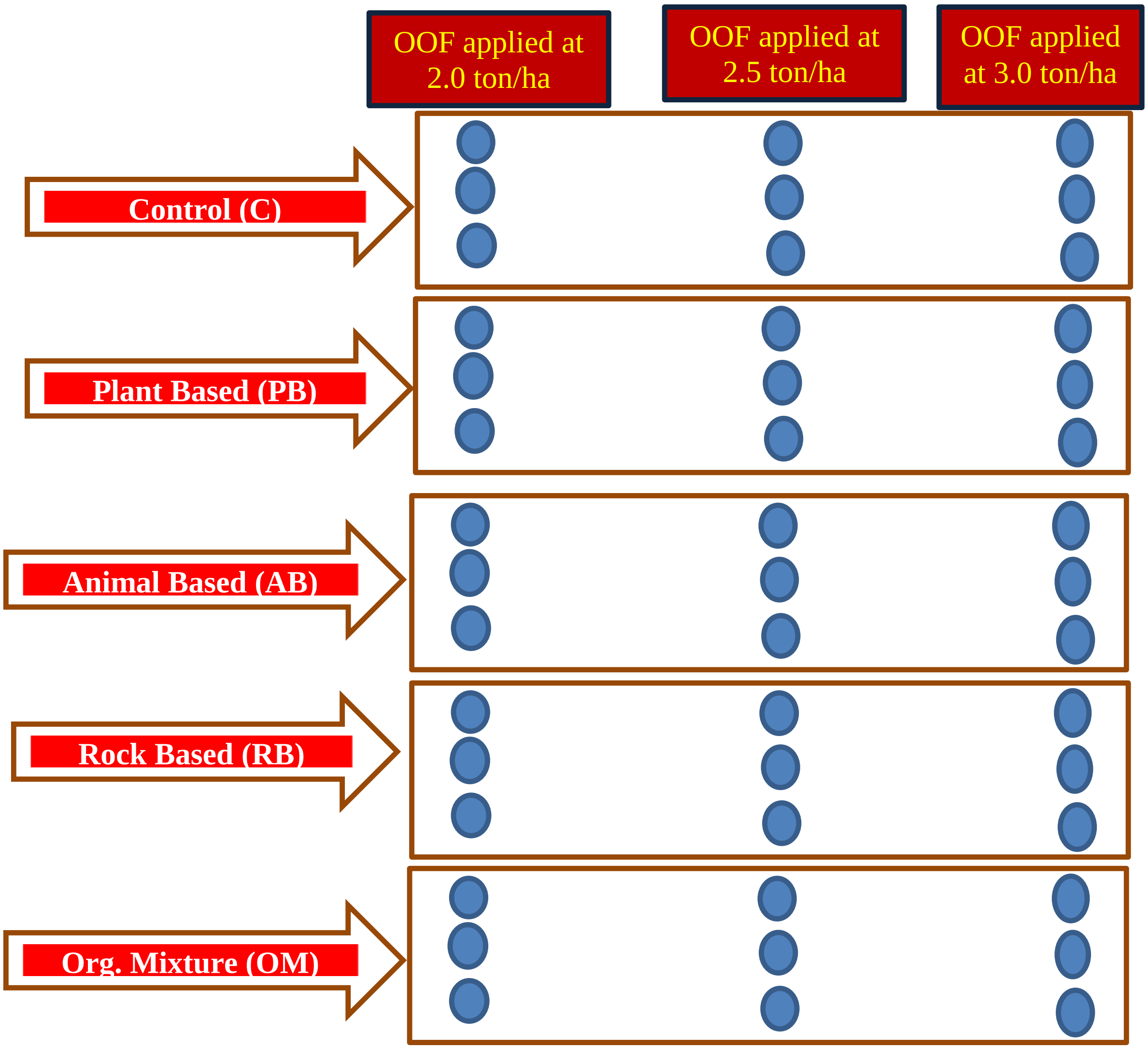

Figure 3.4. Plot design for soybean farm plot experiment
(Seeds planted in each box along the columns represent replicates)

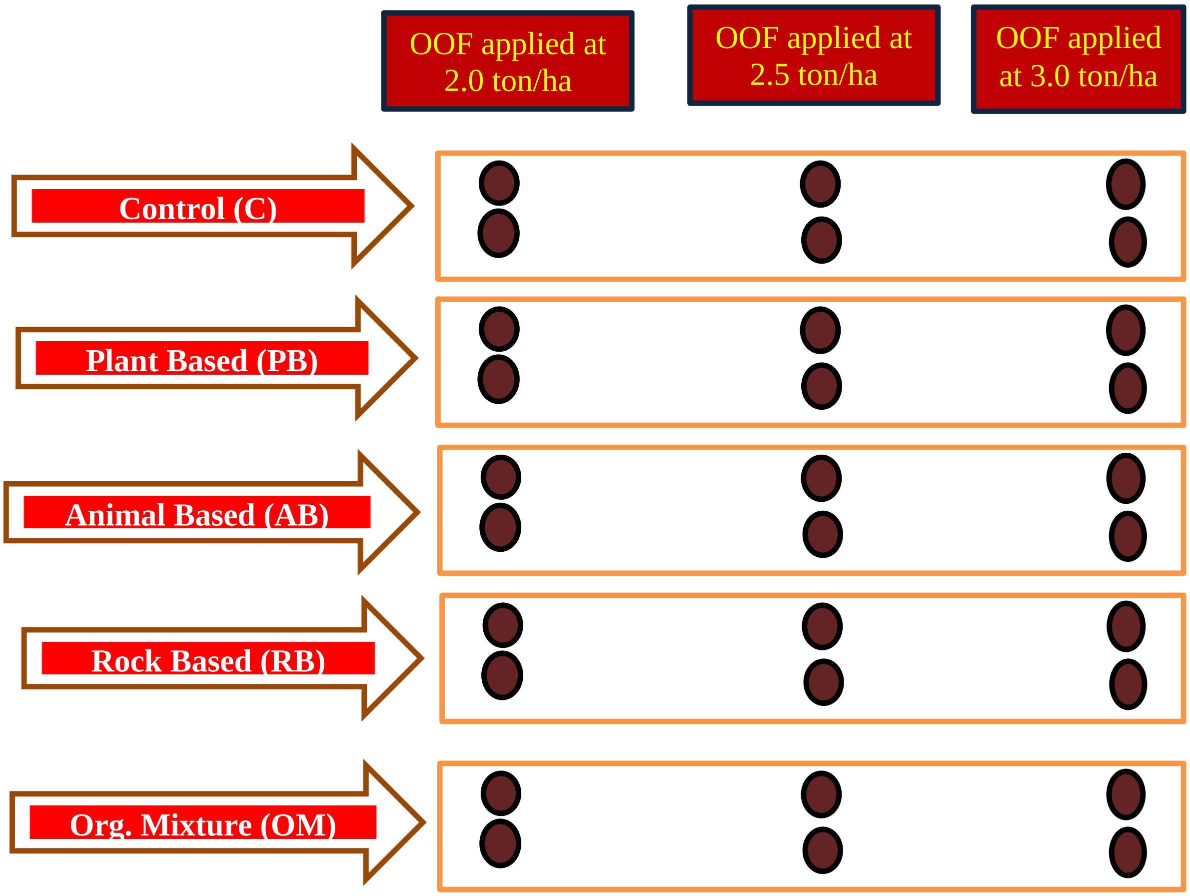

Figure 3.5. Plot design for yam farm plot experiment
(Seeds planted in each box along the columns represent replicates)

3.3 Materials for Laboratory Analyses

The test materials for laboratory analyses included both organic and inorganic materials. The organic materials were sub-divided into: Plant- based (PB), Animal/Human-based (AB), and Rock- based (RB). The Synthetic Chemicals (SC) were Urea and Single Super-phosphate (SSP), used in producing organo-mineral fertilizer at the Alesinloye Waste Recycling Complex. Urea was produced by AFCOTT Nig. LTD, Lagos; it contained 45% N per 50Kg bag. The SSP was produced by Fertilizer and Chemical LTD., Kaduna for the Federal Fertilizer Dept., Federal Ministry of Agriculture and Rural Development and contained 18% P_2O_5.

Plant- based included: Cotton Seed Meal (CSM), Palm Kernel Shell (PKS), Neem Seed (NS), and Palm Kernel Residue (PKR). All these were sourced from neighbourhood in Ibadan. **Animal-based** included: Chicken Feathers (CF), Hoof Meal (HM), Horn Meal (HM), Human Hair, and Bone Meal (BM). Human hair was collected from the market at barbing salons; chicken feather were collected from fowl sellers' shops behind the recycling premises; and, the rest were sourced from Alesinloye market abattoir beside the complex.

Rock- based included: Rock Phosphate (RP). This was sourced from Agronomy Department, University of Ibadan.

Test crops- Maize (***Zea mays*** **L -** cereals) with commercial name 'Oba Super 2' was produced by Premier Seed Nigeria Limited, Chikaji Industrial Estate, Zaria. With yield capacity of 5 to 7 tons per hectare and germination rate of 90%; Soybean (***Glycine max***; TX 114 - legume) was sourced from the Generic Laboratory of International Institute for Tropical Agriculture (IITA); and, Yam (***Dioscorea rotundata*** Poir - tuber) was sourced from Oje market, Ibadan.

3.4 Data Collection Methods

Data were collected using different methods:

3.4.1 Laboratory measurements

Laboratory measurements were used to appraise the quality of raw organic wastes, organic fortifiers, chemical fortifiers, soil samples before and after planting for residual values, and physico-chemical analysis of Organically Fortified Fertilizers (OFFs) produced, using standard analytical methods as described by the America Public Health Association (APHA, 2005). The following physico-chemical parameters were determined: moisture content, pH, total organic-carbon, total nitrogen, C: N ratio, total phosphorus, lead, chromium, nickel, zinc, and cadmium. The methods were also used to identify different forms of N, P, K in the fortified fertilizers.

3.4.2 Direct observation

Participatory observation checklist to monitor process of compost production and fortification in the factory; farm practices and operations; and, monitoring and taking records of planted crop agronomic parameters (growth and yield data). The agronomic parameters include: number of leaves, by counting; plant height (in centimeters), using metric rule; stem girth (in centimeters), using metric rule, and biomass (in g), using beam balance. It was also used to assess phytotoxic effects of the fertilizers.

3.5 Data Collection Procedures

3.5.1 Sampling Method

Quartering sampling method was used to collect samples of all test materials for the study.

The following procedures were observed for sampling of materials:

- **i.** In each case, ten grab samples from different parts of the materials and soil samples were taken and pulled together to form a heap that represented the entire materials. The heap was then spread on a clean cloth material and divided equally into eight quadrants. Then, the opposite quadrant was left out and the procedure was repeated till the required sample size was obtained. The final sample was put inside a polythene bag and labeled properly. The samples were taken in duplicates to ensure accuracy and precision in analyses.
- **ii.** Only one material each from both proteinous and carbonaceous source with the highest level of nutrients was selected from the three groups of various nutrient rich organic materials (plant-base, animal-based and rock-based) for compost fortification. In cases where two or more materials met this criterion, selection of one of them was done by lottery (ballot) method.

3.5.2 Procedures for Chemical Analysis of Samples

Chemical analyses of the selected organic and inorganic materials viz: N, P, C, C-N ratio, Ca, Mg and Na as well as some selected heavy metals like Lead (Pb), Chromium (Cr), Nickel (Ni), Zinc (Zn), Mn, Fe and Cadmium (Cd) were carried out to ascertain the quality of the compost materials and OFFs. The phyto-toxic effects of each fertilizer on the test crops (maize and soybean), binding forms of N and P in the OFFs were also determined (Figure 3.6). Prior to laboratory analyses, pH of samples were measured with the aid of a pH digital meter (Rapidest made by Luser Leaf Products Inc., China). Also, moisture content and dry matter content were determined using AOAC Official Method (2005) as follows:

3.5.2.1 Moisture content and dry matter content determination

Apparatus: oven, crucibles, desiccator and balance

Reagents: Silica gel, grease

Procedure: 2g of the sample was weighed into a previously weighed crucible. The crucible plus sample taken was then transferred into the oven set at 100 ^{0}C to dry to a constant weight for 24 hours. At the end of the 24 hours, the crucible plus sample was removed from the oven and transferred to the dessicator, cooled for ten minutes and weighed.

The weight of empty crucible = $\mathbf{W_0}$

Weight of crucible plus sample = $\mathbf{W_1}$

Weight of crucible plus oven-dried sample = $\mathbf{W_3}$

$$\%\ \boldsymbol{Dry\ Matter\ (DM)} = \frac{\boldsymbol{W_3 - W_0 \times 100}}{\boldsymbol{W_1 - W_0}}$$

$$\%\ \boldsymbol{Moisture} = \frac{\boldsymbol{W_1 - W_3 \times 100}}{\boldsymbol{W_1 - W_0}}$$

Note- % Moisture = 100 - % DM

3.5.3 Method of Sample Pre-Treatment

The raw organic waste sample taken was air dried, milled and digested for the purpose of phosphorus and heavy metal determination.

3.5.3.1 Digestion procedure for phosphorus determination

About 0.2 g of the powdered organic material of each sample was digested with nitric, and perchloric: sulphuric acid mixture in the ratio of 5:1:1 in a 100 ml conical flask (APHA, 2005). The mixture was heated on a hot plate for about one hour until 1ml of clear solution was left in the flask. Large quantity of brownish fume with choking smell was given off. It was allowed to cool and distilled water was added to the clear solution to make it up to 100 ml. The solution was filtered through an ash less filter paper (Whatman No.3) into a volumetric flask.

3.5.3.2 Digestion method for heavy metals

One gram of sample was placed in a 250 ml digestion tube and 10 ml of concentrated HNO_3 was added. The sample was heated for 45 min at 90 ^oC, and then the temperature was increased to 150 ^oC at which the sample was boiled for at least 8 h until a clear solution was obtained. Concentrated HNO_3 was added to the sample (5 ml was added at least three times) and digestion occurred until the volume reduced to about 1 ml. The interior wall of the tube was washed down with a little distilled water and the tube was swirled throughout the digestion to keep the wall clean and prevent the loss of the sample. After cooling, 5 ml of 1% HNO_3 was added to the sample. The solution was filtered with Whatman No. 42 filter paper and < 0.45 μ millipore filter paper. It was then transferred to a 25 ml volumetric flask by adding distilled water. Various metals were read, using Atomic Absorption Spectrophotometer (AAS, Buck 200 model).

Calculations

For micronutrient cations in the samples including:

$$\text{Zn, Fe, Pb, Ni, Cu and Mn (ppm)} = \text{(ppm in extract - blank)} \times \frac{A}{\text{Wt}}$$

Where: A = Total volume of the extract (mL)

W = Weigth of dry sample (g)

Figure 3.6. Level of laboratory measurement

3.5.3.3 Phosphorus Determination

Determination of total phosphorus in the raw organic waste was carried out spectrophotometrically, using the Mo (molybdo-vanadate) blue colour method of Murphy and Riley (1962).

Procedure

The following reagents were prepared and used: Ammonium molybdate; antimony potassium tartrate; 2.5MH_2SO_4 (148 ml conc. H_2SO_4 diluted to 1 litre); potassium hydrogen phosphate (KH_2PO_4); ascorbic acid; P- Nitrophenol (0.25 % wt/vol); 5MNaOH and 5MHCl. From ammonium molybdate, 12g was taken and dissolved in 250ml of distilled water. Also, 0.2908 g of antimony potassium tartrate was dissolved in 100 ml of distilled water. The two dissolved reagents were added to 1000 ml of 2.5M H_2SO_4 and mixed thoroughly before being made up to 2 litres. Then, the mixture was labeled as **A** and stored in pyrex glass vessel in dark cool temperature. At the time of analysis, 1.056 g of ascorbic acid was dissolved in 200 ml of the reagent **A** above. It was then mixed thoroughly and labeled as **B**. From the digested sample, 5 ml was pipetted into 50 ml volumetric flask and then made up to 40 ml with distilled water. To this solution was added 8 ml of reagent **B** and the mixture was thoroughly mixed. The absorbance of the coloured solution was matched against a reagent blank at 882 nm, after staying for 30 mins.

Preparation of Standard Curve

From dry KH_2PO_4 , 0.2194 Kg, was taken, dissolved in distilled water in 50 ml flask and then made up to mark. This standard P stock solution contained 100 µgP/ml. From the stock solution above, 5 ml was taken and diluted to 100 ml in 100 ml volumetric flask. This solution contained 5µg P/ml. Then from the diluted solution above, 2 ml, 4 ml, 6 ml, 8 ml, and 10 ml was pipetted separately into 50 ml flask each and the volume was made up to 35 ml with distilled water. To each of these diluted samples, 8ml of reagent **B** was added and mixed thoroughly before the volume was made up to the mark (50 ml) with distilled water. These solution contained 0.2, 0.4, 0.6, 0.8, and 1.0 µg P/ml respectively.

Total Phosphorus in the sample was calculated as follows:

$$\boldsymbol{Total\ P\ (mg/kg) = \frac{AB \times DF \times 50\ ml}{Weight\ of\ sample}}$$

Where AB = Absorbance at 882 nm

50 = Final volume of solution

DF = Dilution factor

3.5.3.4 Total Carbon Determination

Total carbon content of the raw organic waste was determined according to Walkey Black wet oxidation method (Walkley and Black, 1934).

Procedure

Standard 0. 167*M* $K_2Cr_2O_7$ was prepared by dissolving 49.04 g of dried $K_2Cr_2O_7$ in water and diluting to 1 L. Ferroin indicator was prepared by dissolving 3.71 g of o-phenanthroline and 1.74 g of $FeSO_4{\bullet}7H_2O$ slowly in 250 mL of water. Also, 0.5 *M* Fe^{2+} solution was prepared by dissolving 196.1 g of $Fe(NH_4)_2(SO_4){\bullet}6H_2O$ in 800 mL of water containing that contained 20 mL of concentrated H_2SO_4 and diluting to 1 L. Thereafter, 2.00 g dried fertilizer (ground to <60 mesh) was transferred to a 500-mL Erlenmeyer flask and 10 mL of 0.167 *M* $K_2Cr_2O_7$ was added by means of a pipette. Also, 20 mL of concentrated H_2SO_4 was added by means of dispenser; the solution was swirled gently to mix and then allowed to stand for 30 minutes. The flasks was placed on an insulation pad during this time to avoid rapid heat loss.

The suspension was diluted with 200 mL of water to provide a clearer suspension for viewing the endpoint. Using a suitable dispenser, 10 mL of 85 % H_3PO_4 and 0.2 g of NaF were added to complex Fe^{3+} which would interfere with the titration endpoint. Ten 10 drops of ferroin indicator was added just prior to titration to avoid deactivation by adsorption onto clay surfaces. The final solution was titrated with 0.5 *M* Fe^{2+} to a burgundy endpoint. The color of the solution at the beginning was yellow-orange to dark green, depending on the amount of unreacted $Cr_2O_7^{2-}$ remaining, which shifted to a turbid gray before the endpoint and then changed sharply to a wine red at the endpoint. A reagent blank was run using the above procedure without fertilizer. The blank was used to standardise the Fe^{2+} solution. Then the %C in the sample was calculated thus:

$$\%\, \boldsymbol{Organic\ Carbon} = \frac{(\boldsymbol{B-S}) \times \boldsymbol{M\ of\ Fe^{2+}} \times \mathbf{12}\ \boldsymbol{X}\ \mathbf{0.77} \times \mathbf{100}}{\boldsymbol{Weight\ of\ sample} \times \mathbf{4000}}$$

Where B = mL of $Fe2+$ solution used to titrate blank

S = mL of $Fe2+$ solution used to titrate sample

12/4000 = milli-equivalent weight of C in g.

0.77 = constant

3.5.3.5 Total Kjeldahl Nitrogen Determination

Total Nitrogen in the organic waste was determined, using regular Macro- Kjeldahl method (Kjeldahl, 1883).

<u>Procedure</u>

The following reagents were used: catalyst mixture (K_2SO_4-Se), 100: 1 w/ w ratio; concentrated H_2SO_4; Ethylene Diamine-tetra-acetic Acid Disodium Salt (EDTA); 10 N NaOH; saturated boric acid solution (H_3BO_3); 0.01 N H_2SO_4 and standard stock solution: 1.2 g NH^{4+}-N per L.

Digestion

One gram of well mixed and finely ground sample was dried at 60°C in an oven (overnight), and then cooled in a desiccator. From this, 0.25 g was weighed and transferred into a 100 mL digestion tube. A few pumice boiling granules and 3 g catalyst mixture were added, using a calibrated spoon. Also, 10 mL conc. H_2SO_4 was added with the aid of dispenser and the solution was stirred with vortex tube stirrer until it mixed well. The tube was placed in a block-digester set at 100 °C for 20 minutes. Thereafter, all material adhering to the neck of the tube was washed down with the same concentrated sulfuric acid. The tube was thoroughly agitated before it was put back on the block-digester set at 380° C for 2 hours. After the digestion was complete, tube was removed, cooled, and brought to 100 mL volume with distilled water. Each batch of samples for digestion contained at least one reagent blank (no fertilizer), and one chemical standard (containing 0.1 g EDTAstandard digest), and one standard fertilizer sample (internal reference).

Distillation

Distillation and titration apparatus was set and steamed out for 10 minutes. Prior to distillation, the digestion tube was shaken to thoroughly mix its contents and10 mL aliquot was pipetted into a 100 mL distillation flask. Then, 10 mL of 10 N NaOH was added and the flask was connected to distillation unit to begin distillation. Distillate (35 mL) was collected in the collecting dish before the distillation flask was removed. An empty 100 mL distillation flask was then connected to the distillation unit. Water was drained from the condenser jacket and the apparatus was steamed out for 90 seconds before connecting the next sample. The distillate was titrated to pH 5.0 with standardised 0.01 N H_2SO_4 using an auto-titrator and titration volume of acid was recorded. Each batch of distillations included a distillation of 10 mL ammonium-N standard with 0.2 g of MgO and 10 mL distilled water with 0.2 g of MgO. Recovery of ammonium-N standards was 98% and recovery of EDTA, corrected for reagent blank, was 97%.

Calculations

Percentage recovery of Ammonium-N standard:

$$\% \boldsymbol{Recovery} = \frac{(\boldsymbol{V} - \boldsymbol{B}) \times \boldsymbol{N} \times \mathbf{14.01} \times \mathbf{100}}{\boldsymbol{C} \times \boldsymbol{D}}$$

Percentage Nitrogen in Fertilizer:

$$\% \boldsymbol{N} = \frac{(\boldsymbol{V} - \boldsymbol{B1}) \times \boldsymbol{N} \times \mathbf{14.01} \times \mathbf{100}}{\boldsymbol{Wt} \times \mathbf{1000}}$$

Where: V = Volume of 0.01 N H_2SO_4 titrated for the sample (mL).

B = Distillate blank titration volume (mL)

N = Normality of H_2SO_4 solution.

C = Volume of NH_4-N standard solution (mL)

D = Concentration of NH_4-N standard solution (□g/mL)

14.01= Atomic weight of N.

B1 = Digested blank titration volume (mL)

Wt = Weight of dry plant (g)

3.5.3.6 Potassium Determination

Potassium content of raw samples was determined according to Mehlich 3 procedure (Mehlich 1984)

Reagents

1. Extracting Solution (1 M NH_4OAc at pH 7.0)

Approximately 500 mL of distilled water was poured into the mixing vessel and 57 mL of glacial acetic acid (99.5 percent) was added. Then, 69 mL of concentrated ammonium hydroxide was mixed with it in a fume hood. The volume was made to about 900 mL with distilled water and the pH was adjusted to 7.0 with 3 M NH_4OH. After cooling to room temperature, brig the solution was brought to a volume of 1 L.

2. Extracting Solution (Mehlich-3)

Reagent for Mehlich-3 included: 0.2 N Ch_3COOH (acetic acid, glacial: 99.5 percent, fw 60.04, 17.4 N), 0.25 N $NH4NO_3$ (ammonium nitrate: fw 80.05), 0.015 N NH_4F (ammonium fluoride: fw 37.4), 0.013 N HNO_3 (nitric acid: 68 to 70 percent, fw 63.02, 15.5 N), and 0.001 M EDTA [$(HOOCH_2)_2NCH_2NCCH_2COOH)_2$, ethylenediaminetretraacetic acid: fw 292.24]. The following steps were carried out in preparation of the solution:

a. Add 8 L of distilled water to a 10 L carboy.

b. Dissolve 200 g of ammonium nitrate in the distilled water.

c. Add 40 mL NH_4F-EDTA stock solution and mix.

d. Add 11.5 mL acetic acid.

e. Add 8.2 mL of nitric acid.

f. Add distilled water to bring volume to 10 L.

3. Standards

Stock solution (1,000 ppm K) was prepared by dissolving 1.9073 g oven dry, reagent grade KCl in 1 M NH_4OAc at pH 7.0. The solution was brought to volume of 1,000 mL with the extracting solution followed by thorough mixing. A 100 ppm standard was prepared by diluting 100 mL of the 1,000 ppm K stock solution to 1 L with extracting solution. Pipette 10, 20, 30, 40 and 50 mL of the 100 ppm K solution into 100 mL volumetric flasks and bringing each to volume with extracting solution. These solutions contained 10, 20, 30, 40 and 50 ppm K, respectively. The extracting solution served as the 0 ppm standard.

Procedure

Two grams of material was scooped into an extraction flask. Then, 20 mL of extracting solution was added to the extraction flask. The solution was shaken for 5 minutes on the shaker at 200 epm. The suspension was filtered through Whatman No. 2. Atomic adsorption spectrometer was set up for K determination. The standard curve was determined using the standards to obtain the concentrations of K in the extracts.

Calculation

$$\boldsymbol{Potassium\ (mg/kg) = \frac{A \times DF \times 50\,ml}{B}}$$

Where A = Concentration in diluted extract from the graph (mg/kg)

B = Oven-dry weight of sample (g)

DF = Dilution Factor

$$\boldsymbol{Potassium(me/100g) = \frac{Potassiium\ (mg/kg)}{E}}$$

Where E = Equivalent weight of potassium x 10. (i.e. E for K = 391.0)

3.5.4 Determination of Binding Forms of N, P, and K

The binding form of **Phosphate** in terms of: (i) water soluble or water-insoluble; (ii) neutral ammonium citrate soluble or insoluble; (iii) citric acid soluble or insoluble; and (iv) acid soluble; and **Nitrogen (N)** in terms of: NH_4-N (ammoniacal), NO_3-N (nitrate), urea-N (amide) and organic N were determined in accordance with the methods of Motsara and Roy (2008).

3.5.5 Seed Germination Toxicity Test

The procedure used in previous studies for effect of leachate samples on *O. sativa* L. (Walter et al., 2006; Prechthai et al. 2008) was modified to achieve toxic effect of formulation on maize and soybean. The seeds were first treated as shown in the Table 3.1. Five seeds of either maize or soybean, as the case may be, were put into petri dish containing 10 g of each fertilizer formulation (OFF) and control (compost) (Plate 3.3). The samples were incubated at 25±1 ^{0}C for 96 h. The germination and root elongation rates of the crops were measured at the end of incubation period. The Relative Seed Germination (RSG), Relative Root Growth (RRG) and Germination Index (GI) were calculated using the following equations:

$$\boldsymbol{Relative\ seed\ germination\ (RSG) = \frac{Ss \times 100}{Sc}}$$

$$\boldsymbol{Relative\ root\ growth\ (RRG) = \frac{Rs \times 100}{Rc}}$$

$$\boldsymbol{Germination\ index\ (GI) = \frac{RSG \times RRG}{100}}$$

Where:

Number of seed germinated in sample = Ss

Number of seed germinated in control = Sc

Average root length in sample (cm) = Rs

Average root length in control (cm) = Rc

Three attempts were made. First the seeds (maize and soybean) were planted inside the extract of each compost formulation diluted in ratio 1:5 with distilled water and none of the seed germinated. The second attempt involved 1:10 dilution and no germination was noticed as well. Thereafter, the fertilizer was diluted with ordinary compost (control) instead of distilled water. Values obtained were compared with Thai Agricultural Commodity and Food Standard of ≥ 80 (TACFS, 2005).

Table 3.1. Seed germination test condition

S/N	Requirement	Condition
1	Test species	Maize and Soybean
2	Seed pretreatment	10% hypochlorite for 20 min and rinse with deionized water for 10 times
3	Temperature	25±1 ^{o}C
4	Light	Dark
5	Container and supporting media	100mm×10mm Petri dish, Whatman filter paper No. 1
6	Number of seed per dish	5
7	Number of sample concentration	1
8	Number of replication	4
9	Control group	Ordinary compost used in fortification
10	Test duration	96 h
11	Toxicity end point	Germination rate and root length

Plate 3.3. Seed toxicity experiment

3.5.6 Factory Operations

Compost was produced following the process of fertilizer production in the complex, including mechanical milling, sorting and mixing (Figure 3.2). For the purpose of this study, intervention was made at the point of mixing/fortification in the organic fertilizer plant, the same composting procedures and materials were adopted for both organic and organo-mineral fertilizer production. The quantities of each fortifier and compost produced were determined with the aid of a top loading portable Camry scale (Plate 3.4).

3.5.6.1 Estimation for Fortification

Synthetic fertilizer

Initial N and P composition in the compost were: P = 1.0 % and N = 1.0% and final compositions in the formulation was set at: P = 2.5 % and N = 3.5 %, in accordance with the national quality standard of organic fertilizer (FMARD, 2007). Also to avoid wastage, 1.5 kg of each formulation was prepared as follow:

i. **Chemical based (SC)**

For nitrogen fortification: $\mathbf{C_1W_1 = C_2W_2}$

Where C_1 = 45 %N, W_2 = 1.5 kg, C_2 = 2.5 %N, W_1 =?

$45 \times W1 = 2.5 \times 1.5$

$$W_1 = \frac{2.5 \times 1.5}{45}$$

= 0.08 kg (i.e 83.3 g) of urea

For phosphorus fortification: $\mathbf{C_1W_1 = C_2W_2}$

Where C_1 = 18 %P, W_2 = 1.5 kg, C_2 = 1. 5%P, W_1 =?

18 x W_1 = 1.5 X 1.5

$$W_1 = \frac{1.5 \times 1.5}{18}$$

= 0.125 kg (i.e 125g) of SSP

SC formulation = 83.3 g Urea + 125 g Phosphorus + 1,291.7 g Compost

ii. **Plant Based (PB)**

For nitrogen fortification: $C_1W_1 = C_2W_2$

Where C_1 = 9.6 %N, W_2 = 1.5 kg, C_2 = 2.5 %N, W_1 =?

9.6 x W_1 = 2.5 x 1.5

$W_1 = \frac{2.5 \times 1.5}{9.6}$ = 0.391 kg (i.e 391 g) of neem

For phosphorus fortification: $C_1W_1 = C_2W_2$

Where C_1 = 12 %P, W_2 = 1.5 kg, C_2 = 1.5 %P, W_1 =?

12 x W_1 = 1.5 x 1.5

$W_1 = \frac{1.5 \times 1.5}{12}$ = 0.1875 kg (i.e 187.5 g) of cotton seed

PB formulation = 391 g Neem + 187.5 g Cotton seed + 921.5 g Compost

iii. Animal Based (AB)

For nitrogen fortification: $C_1W_1 = C_2W_2$

Where C_1 = 8.5 %N, W_2 = 1.5 kg, C_2 = 2.5 %N, W_1 =?

8.5 x W_1 = 2.5 x 1.5

$W_1 = \frac{2.5 \times 1.5}{8.5}$ = 0.441 kg (i.e 441 g) of blood

For phosphorus fortification: $C_1W_1 = C_2W_2$

Where C_1 = 22 %P, W_2 = 1.5 kg, C_2 = 1.5 %P, W_1 =?

22 x W_1 = 1.5 x1.5

$W_1 = \frac{1.5 \times 1.5}{22}$ = 0.170 kg (i.e 170.5 g) of bone

AB formulation = 441 g Blood + 170.5 g Bone + 888.5 g Compost

iv. **Rocked Based (RB)**

For nitrogen fortification: $\mathbf{C_1W_1 = C_2W_2}$

Where C_1 = 9.4 %N, W_2 = 1.5 kg, C_2 = 2.5 %N, W_1 =?

9.4 x W_1 = 2.5 x 1.5

$W_1 = \frac{2.5 \times 1.5}{9.4}$ = 0.399 kg (i.e 399 g) of hair

For phosphorus fortification: $\mathbf{C_1W_1 = C_2W_2}$

Where C_1 = 17 %P, W_2 = 1.5 kg, C_2 = 1.5 %P, W_1 =?

17 x W_1 = 1.5 x 1.5

$W_1 = \frac{1.5 \times 1.5}{17}$ = 0.132 kg (i.e.132 g) of phosphate rock

AB formulation = 399 g Hair + 132 g Phosphate Rock + 969 g Compost

v. **Organic Mixture (OM)**

For nitrogen fortification: $\mathbf{C_1W_1 = C_2W_2}$

C_1 = 9.6 %N, W_2 = 1.5 kg, C_2 = 2.5 %N, W_1 =?

9.6 x W_1 = 2.5 x 1.5

$W_1 = \frac{2.5 \times 1.5}{9.6}$ = 0.390 kg (i.e 390 g) of OM

For phosphorus fortification: $\mathbf{C_1W_1 = C_2W_2}$

C_1 = 27 %P, W_2 = 1.5 kg, C_2 = 1.5 %, W_1 =?

27 x W_1 = 1.5 x 1.5

$W_1 = \frac{1.5 \times 1.5}{27}$ = 0.138 kg (i.e 138 g)

OM formulation = 390 g + 138 g + 972 g Compost

For this fertilizer, the total amount was divided equally among all the samples: neem, bone, horn, cotton, fish etc.

3.5.6.2 Fertilizer Quantity Determination

Size of beds constructed for each crop- maize, soybean or yam was 1 m x 1 m = 1 sqm. For the maize and soybean, 9 seeds were planted per a bed. In the case of yam, only four yam tubers could be planted due to bigger size of a tuber.

Estimation for 2.0 tons/ha

1 ha = 10,000 sqm

2.0 ton/ha = 2.0 ton/10^4 = 2000 kg/10^4 m

i.e. 1sqm (size of the bed) = 2000 kg/10^4 m = 0.2 kg

For maize and soybean, a bed (1 m^2) was planted with 9 seeds and each plant was applied with 22 g (0.2 kg/9 = 0.022 kg = 22 g).

For yam, a bed (1 m^2) is planted with 4 seeds, each plant was applied with 0.2 kg/4 = 0.05 kg = 50 g.

3.6.5.3 Residual Nutrient level and Leaching Potential of OFFs

$$\textit{Residual Nutrient} = \frac{\textit{Soil nutrient after harvesting - Soil background nutrient level}}{\textit{Initial nutrient composition of fertilizers (OOFs)}} \times 100$$

Plate 3.4. Preparation of compost formulation by the investigator

3.5.7 Field Operation (Farm Plot Experiments)

Experimental farm layout

A 30 x 30 m^2 of land was cleared along Jericho Alesinloye road for farm trials. The land was tilled; maize and soybean beds; and, ridge for yam were made. Before planting, soil sample was taken at depth of 0-10 cm for baseline data. A total of 72 yam tubers (each yam weight 0.55 g) were planted on the yam ridges. Thrash removed from the ground during the clearing was used as mulch. Distance of 45 cm was maintained between the crops planted. Thinning and transplanting of maize from three stands to one was carried out two weeks after planting and before fertilizer application. Yam germinated within a month after planting and fertilizer was applied at the first appearance of shoot in ring form under the mulch.

The following general farm practices were adopted during the farm trials, including pre-planting and post-planting farm operations (Plates 3.5- 3.9):

i. **Pre-planting operation**

- sourcing for test crops (maize, and soybean),
- land clearing and preparation,
- pre-planting soil sample collection for chemical background level determination,
- making plant beds of 2m × 2m in dimension.
- planting of test crops in 0.5m × 0.5m between the plant stands.

ii. **Post-planting operation**

- Treatments (fertilizer application),
- Weeding,
- Irrigation (the same source of water was used),
- pest and rodent control,
- General monitoring,
- Post-planting soil sample collection,
- Harvesting,
- Plant sample collection and preparation.

Fertilizer application to maize and soybean was done, using ring method- 3cm deep and 5cm away from stem two weeks after germination. Soil samples for residual effect, nutrient release capacity (mineralization potential) and nutrient forms determination were collected at depth of 10 cm into the soil and 5 cm away from the base of crops at a week interval. This exercise continued for 11 weeks -maturity period for the crops. Grab samples were collected from each replicate which were then pooled together to form composite samples. Agronomic data were observed viz. number of leaves, by counting; plant height, leave area, and stem girth (in centimeters) by metric rule; and crop yield by weighing scale. Maize leaf area was calculated thus: L x B x 0.745 (Agboola, 1990). Plant height was measured as the distance from the base of the plant to the height of the first tassel branch and ear height as the distance to the node bearing the upper ear (Badu-Apraku et al., 2010).

Plate 3.5. Plant height being measured during farm plot experiment

Plate 3.6. Experimental plots for maize and soybean plots at maturity

Plate 3.7. Experimental plots for yam at maturity

Plate 3.8. Maize grown on RB organically fortified fertilizer

Plate 3.9. Harvesting of yam: a- Crop yield determination; b- yam harvested at different rates

3.6 Meteorological data in Ibadan for 2012

Part of data collected in this study included effects of seasonal variation on agronomic performance of crops applied with different fertilizers. To this effect, meteorological data in Ibadan in 2012 were collected. Figures 3.5a-d describes the climatic weather record in Ibadan during 2012. Ibadan has a tropical savanna climate. Year 2012, the period of the study, was a leap year and thus had 366 days rather than the normal 365. The hottest day of 2012 was March 16, with a high temperature of 36 °C. The hottest month of 2012 was February with an average daily high temperature of 30 °C (Figure 3.7). Also, the coldest day of 2012 was July 31, with a low temperature of 22 °C and the coldest month of 2012 was August with an average daily low temperature of 24 °C (Weather Spark, 2012). The cloudiest month of 2012 was September with 7 % of days being more cloudy than clear.

The day in 2012 with the highest precipitation observations was July 22. The month with the highest precipitation observations was July, with 6 hourly present weather reports involving some form of precipitation (Figure 3.8). The daily number of hourly observed precipitation reports during 2012, color coded according to precipitation type, and stacked in order of severity. From the bottom up, the categories are thunderstorms (orange); heavy, moderate, and light snow (dark to light blue); heavy, moderate, and light rain (dark to light green); and drizzle (lightest green). Not all categories are necessarily present in this particular graph. The bar at the top of the graph is green if any precipitation was observed that day and white otherwise. As determined by the present weather reports, the longest dry spell was from March 9 to March 19, constituting 11 consecutive days with no observed precipitation. The month with the largest fraction of days without observed precipitation was March, with 58% of days reporting no observed precipitation at all. The least humid month of 2012 was November with an average daily low humidity of 72 %, and the most humid month was February with an average daily low humidity of 87 % (Figure 3.9).

The highest sustained wind speed was 6 m/s, occurring on December 5; the highest daily mean wind speed was 5 m/s (March 15); The windiest month was July, with an average wind speed of

2 m/s. The least windy month was August, with an average wind speed of 2 m/s. The daily low and high wind speed (light gray area) and the maximum daily wind gust speed (tiny blue dashes) as shown in Figure 3.10.

3.7 Data Management and Statistical Analysis

Sample mean, confidence interval (at 95 %) and percentage composition were computed based on the data obtained from laboratory and field trials. The data was then subjected to Analysis of Variance (ANOVA) as described by Statistical Analysis System (SAS, 1997) and New Duncan's Multiple Range Test (Dunca, 1959) for means separation at 95 % level of probability for the growth and yield parameters. Again, Pearson Correlation Coefficient between the rate of fertilizer application and agronomic data was carried out, using SPSS software version 16.

3.8 Limitations of Study

The major limitation of the study was inability to include all known nutrient rich organic materials that are locally available. It might be difficult to generalize the results obtained from this study to other types of organic fertilizer such as quid fertilizer or bio fertilizer, where the microorganisms might be seriously affected. Also, it was difficult to replicate tuber crop selected (yam) within a cropping season since it usually take almost a year for maturity.

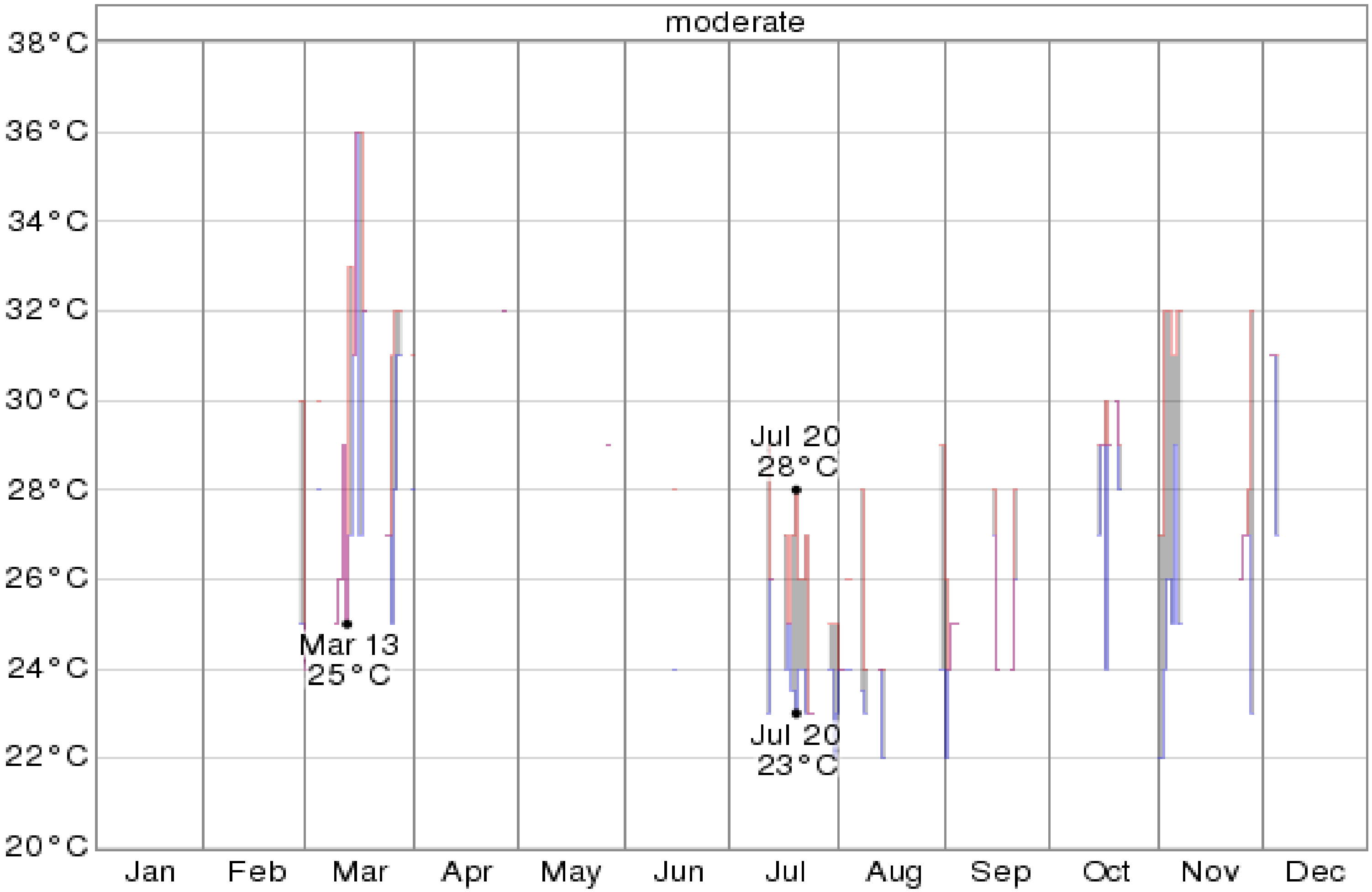

Figure 3.7. Temperature condition in Ibadan in the year 2012

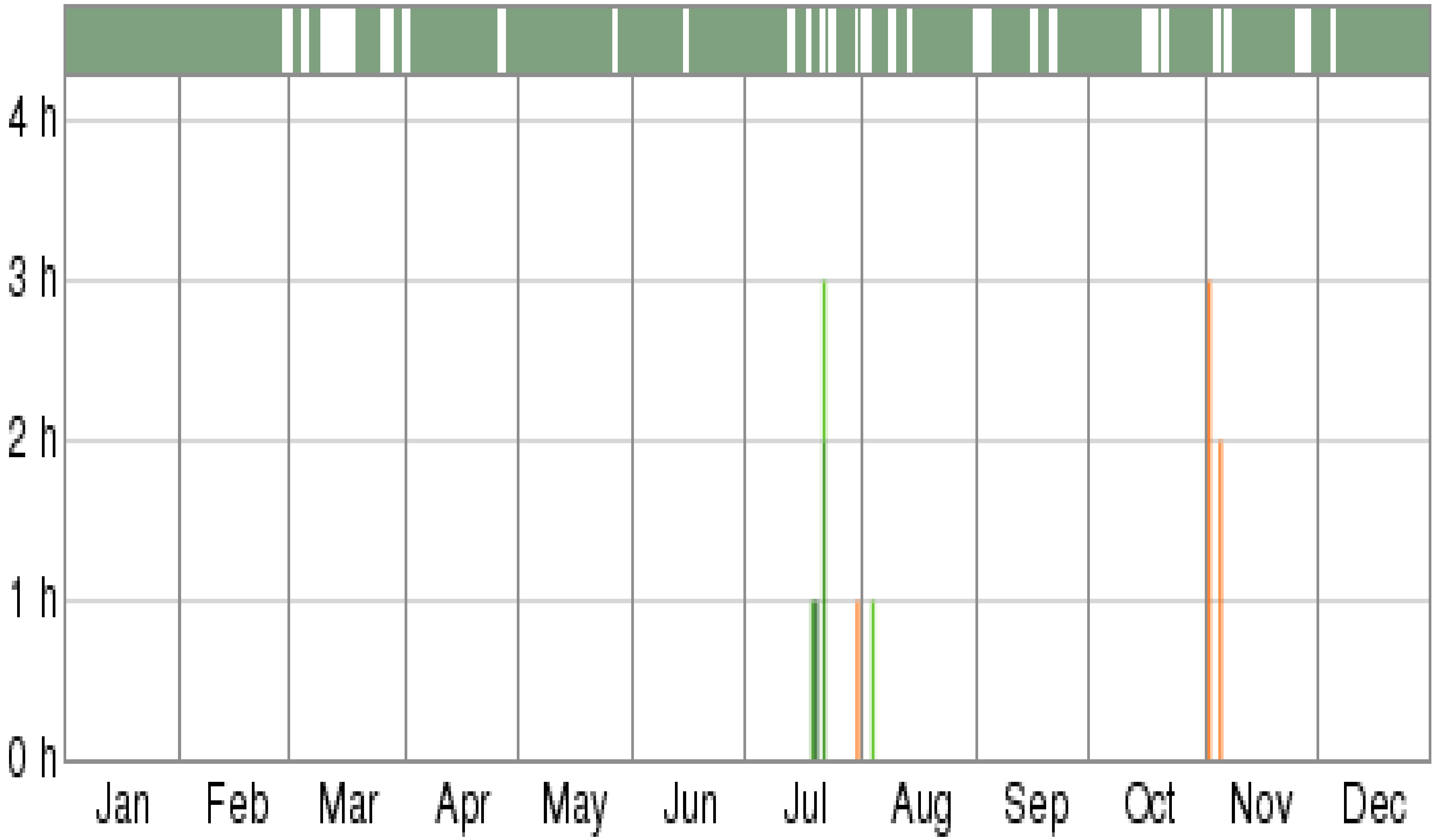

Figure 3.8. Precipitation condition in Ibadan in the year 2012

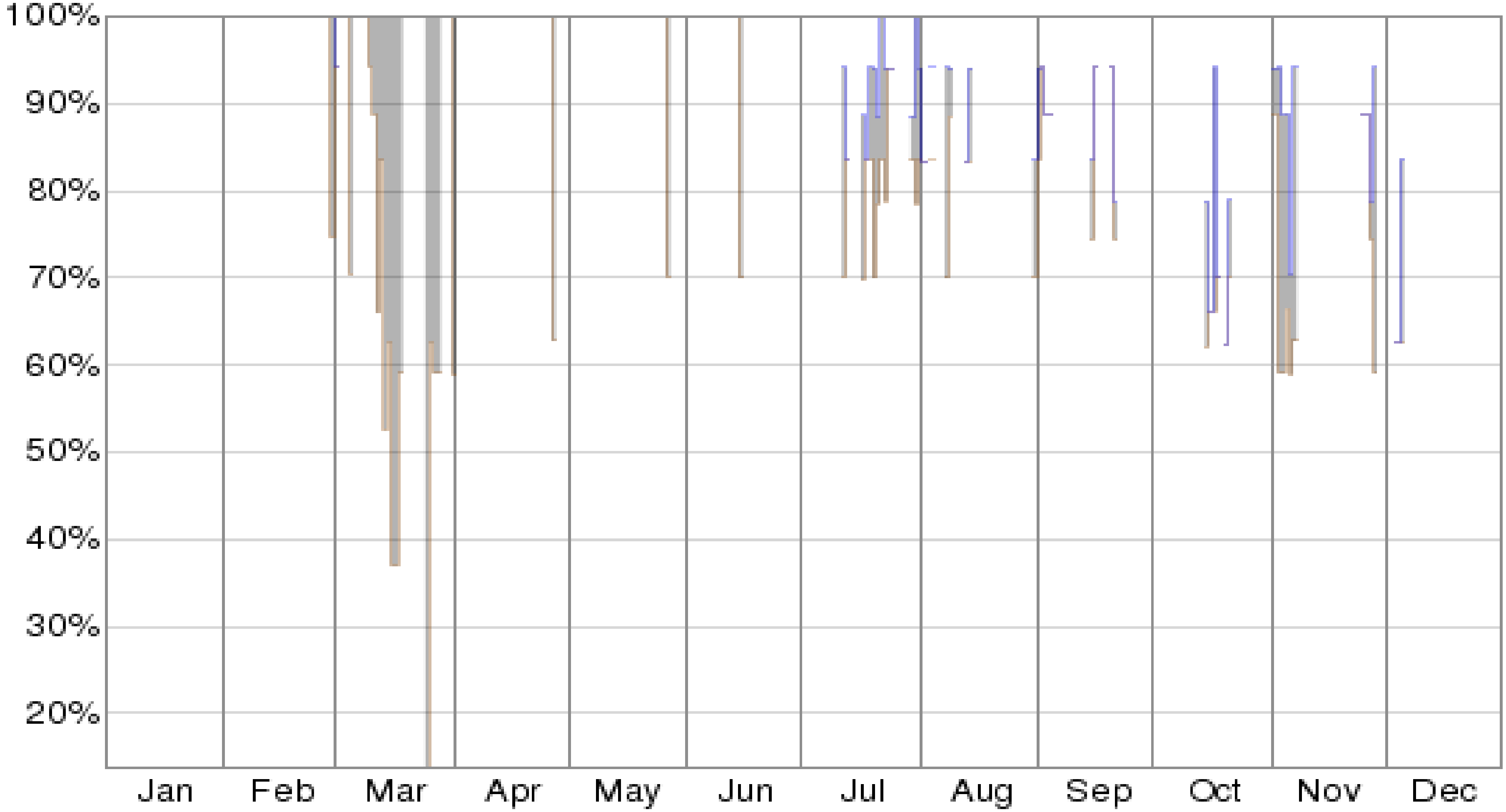

Figure 3.9. Humidity condition in Ibadan in the year 2012

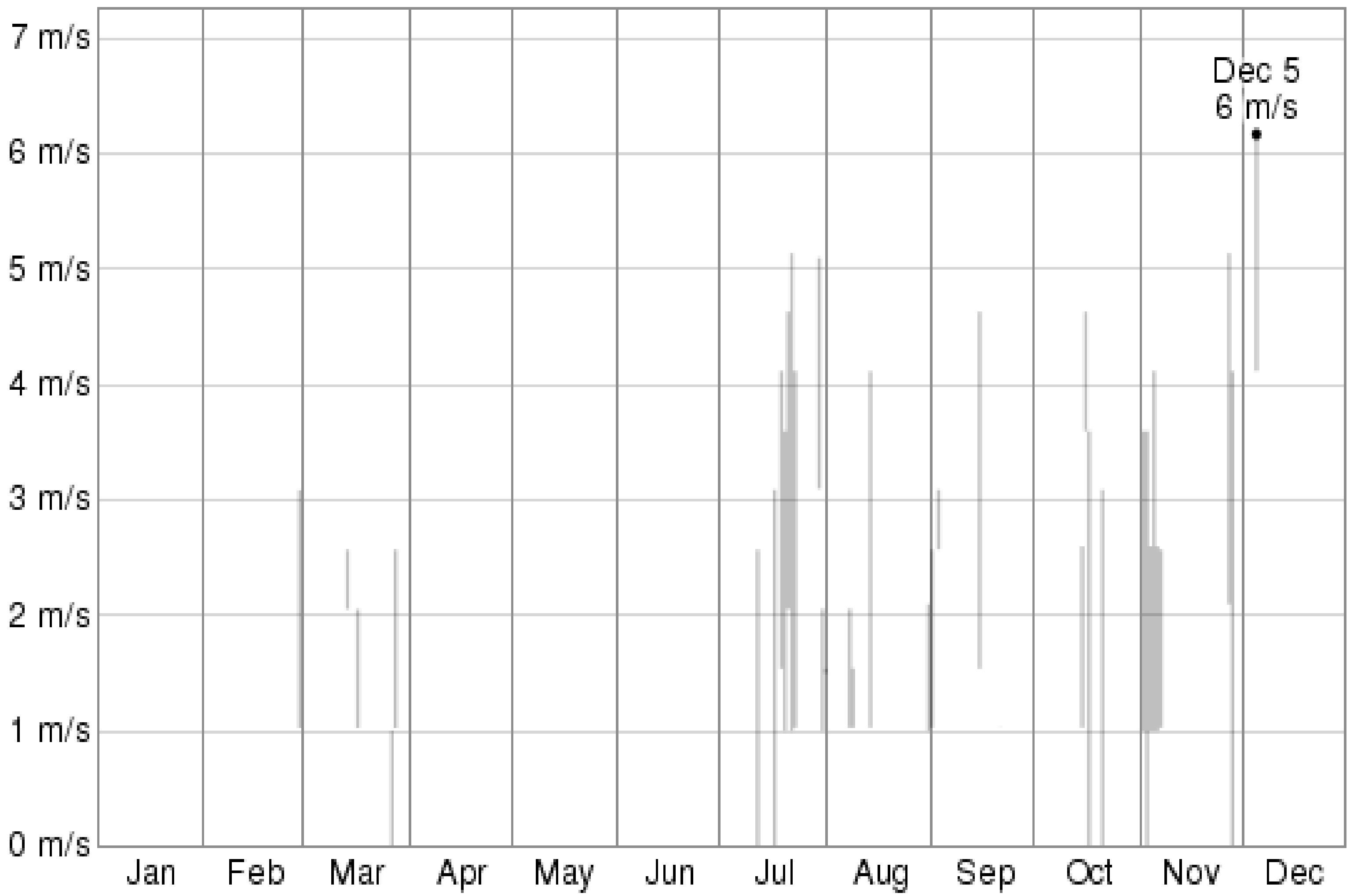

Figure 3.10. Wind speed condition in Ibadan in the year 2012

CHAPTER FOUR
RESULTS

4.1 Chemical Composition of Samples

Table 4.1 shows results of soil analysis for baseline data while Figures 4.1 and 4.2 present nutrient and heavy metal compositions of organic-rich materials. Results of other chemical analyses, including chemical binding forms of N, P, and K and seed germination toxicity test are shown in this section.

4.1.1 Baseline Characteristics of Soil and Fortifiers

The soil taken from the farm had more sand content (79.2 ± 0.0 %) than silt (13.4 ± 0.0 %) and clay (7.4 ± 0.0 %), indicating that the soil had very little humus composition and interference from background levels of nutrients (NPK) that could have resulted from loamy soil. The levels of macro nutrients were: N (0.2 ± 0.0 %); P (2.6 ± 0.0 %) and C (0.9 ± 0.0 %) as shown in Table 4.1. Also, from Figure 4.1, urea, organic mixture and bone were very rich in phosphorus while in addition to this urea had the highest quantity of nitrogen followed by cotton, animal blood and neem. Among all the materials, blood followed by the bone was found with the least quantity of heavy metals with the exception of iron. Compost contained the highest level of Zn while neem and horn had the highest quantity of Cu (Figure 4.2).

Table 4.1. Characteristics of soil used for farm plot experiment

S/N	Parameter	Value (Mean ± SD, n = 4)
1	IM KCL	6.9 ± 0.0
2	pH (H_2O)	7.6 ± 0.0
3	$E.C_{25}$ (mmho/cm)	18.0 ± 0.0
4	Org. C (%)	0.9 ± 0.0
5	Total N (%)	0.2 ± 0.0
6	Av. P (mg/kg)	2.6 ± 0.0
7	Sand (%)	79.2 ± 0.0
8	Silt (%)	13.4± 0.0
9	Clay (%)	7.4 ± 0.0
	Exchangeable Bases (Cmol/kg)	
10	Ca	0.5 ± 0.0
11	Mg	1.0 ± 0.0
12	Na	2.0 ± 0.0
13	K	0.7 ± 0.0
14	Ex. Acidity	0.2 ± 0.0
15	CEC	4.50± 0.0
	Extractable Micronutrient (mg/kg)	
16	B. Sat	95.6 ± 0.0
17	Mn	268.1± 0.1
18	Fe	186.0 ± 0.1
19	Cu	2.8 ± 0.0
20	Zn	7.5 ± 0.0

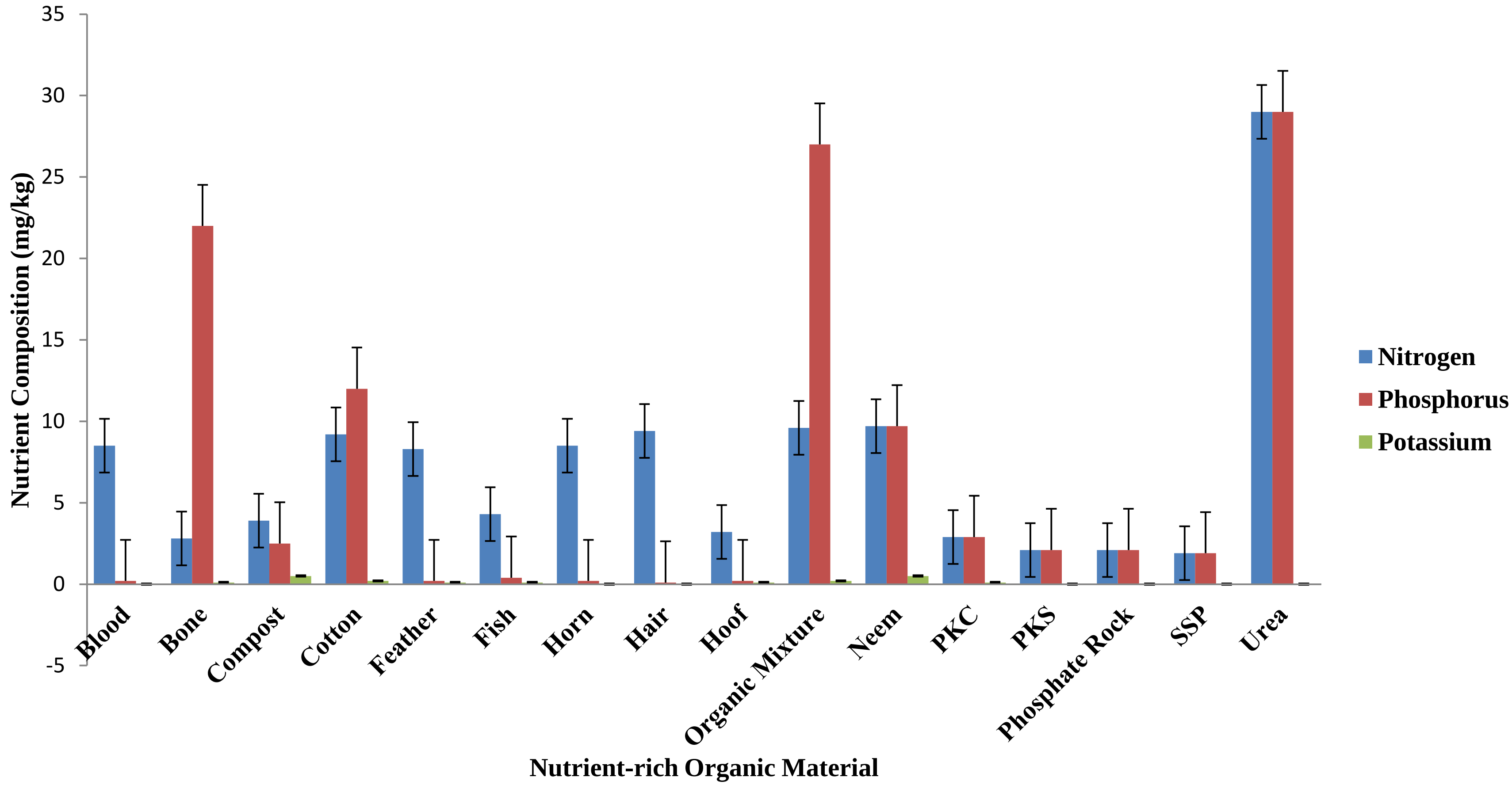

Figure 4.1. Nutrient composition of organic-rich material

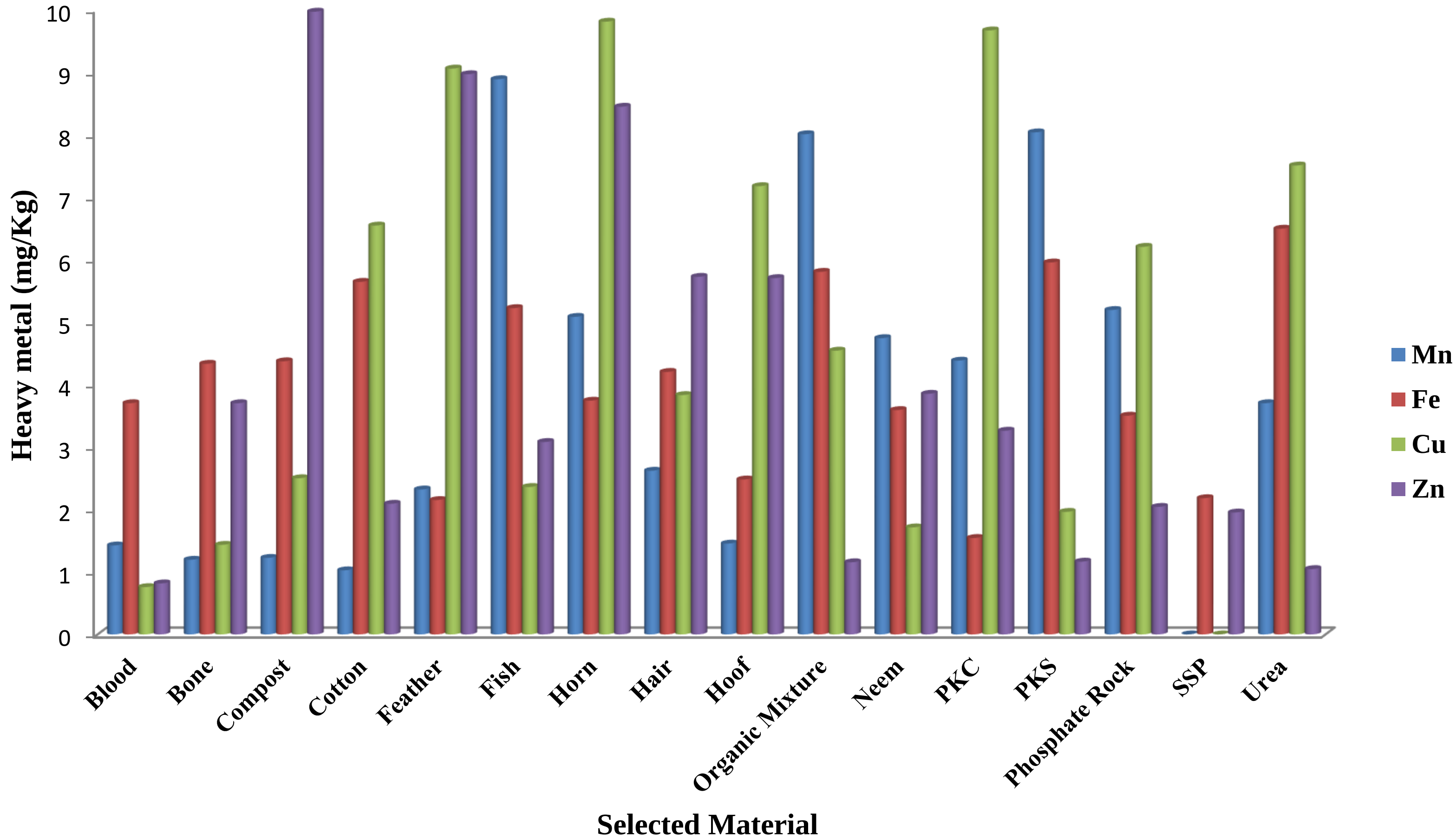

Figure 4.2. Heavy metal composition of organic-rich material

4.1.2 Chemical Characteristics of Organic Fortified Fertilizers

Organic carbon was found highest in the control. Nitrogen and C were higher in all the OFFs compared to P and K and effects of formulation was more predominant in TN and OC than other nutrients as shown in Figure 4.3. There were no significant differences in the nutrient values of all formulations. Chemical analysis of OFFs revealed organic-carbon (%): 33.2 ± 0.0, 38.4 ± 0.2, 27.7 ± 0.1, 34.8 ± 0.0, 28.4 ± 0.2, 32.8 ± 0.21; TKN (%): 5.69 ± 0.0, 5.74 ± 0.0, 5.85 ± 0.0, 6.05 ± 0.0, 6.15 ± 0.0, 3.21 ± 0.0, phosphorus (%):0.3 ± 0.0, 0.5 ± 0.0, 0.2 ± 0.0, 0.8 ± 0.0, 0.2 ± 0.0, 0.7 ± 0.1 and potassium (%): 0.5 ± 0.0, 0.7 ± 0.0, 0.4 ± 0.0, 1.0 ± 0.0, 0.4 ± 0.0, 0.9 ± 0.0 for PB, AB, RB, OM, SC and control respectively. The control had significantly higher phosphorus and potassium, and lower TKN than any of the formulations; it is also far rich in carbon content among the formulations.

Figure 4.4 shows the levels of heavy metal in the OFFs. Iron (Fe) dominated the contents of all the formulations; it was significantly higher in AB compared to any other fertilizers and rock based fertilizer contained the lowest quantity of Fe. Zinc was also found higher in compost and organic mixture than any other formulations. Generally, all the OFFs had low quantity of other heavy metals apart from Fe and Zn.

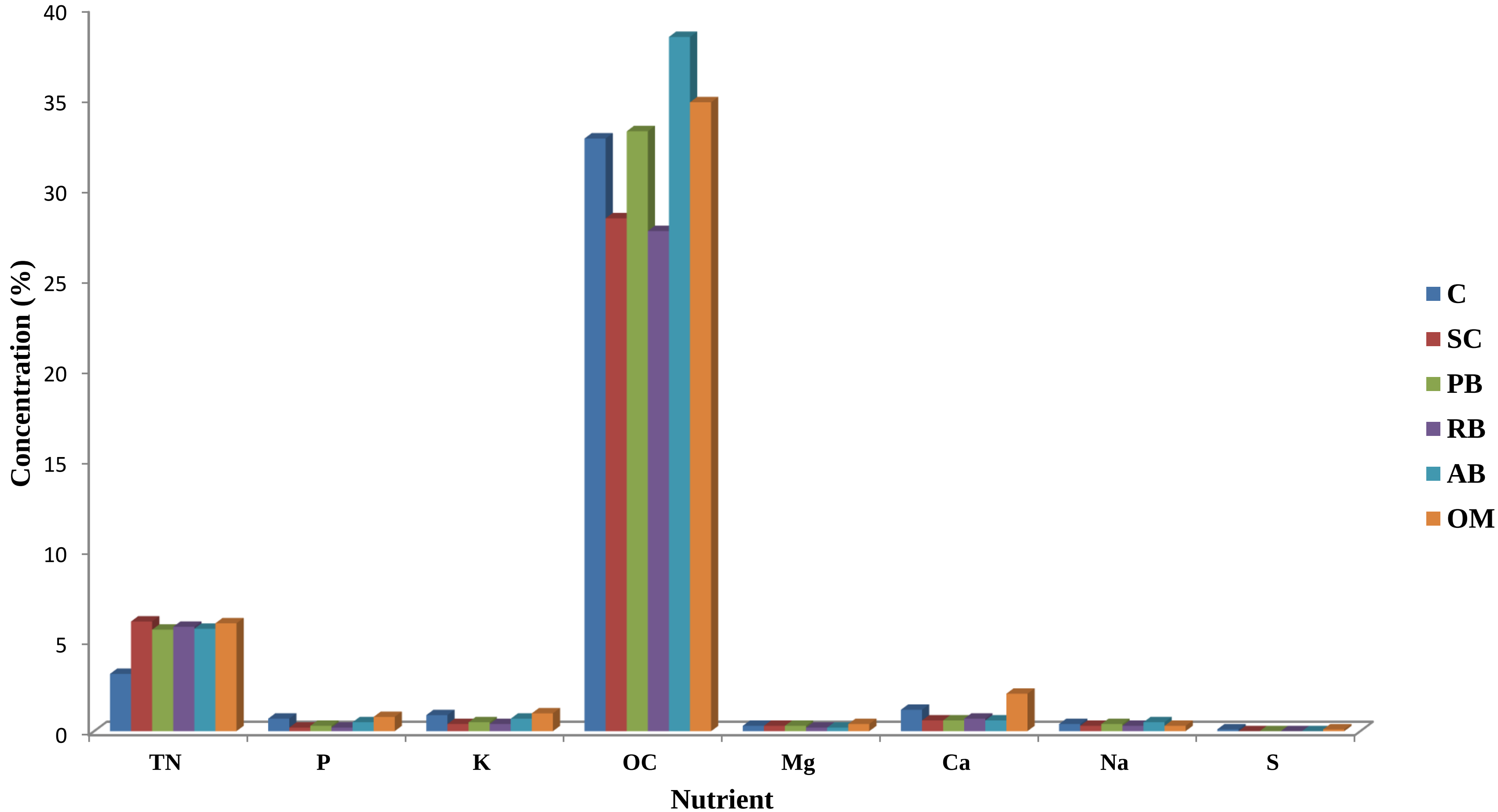

Figure 4.3. Nutrients composition of fertilizer (formulation)

Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic-based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

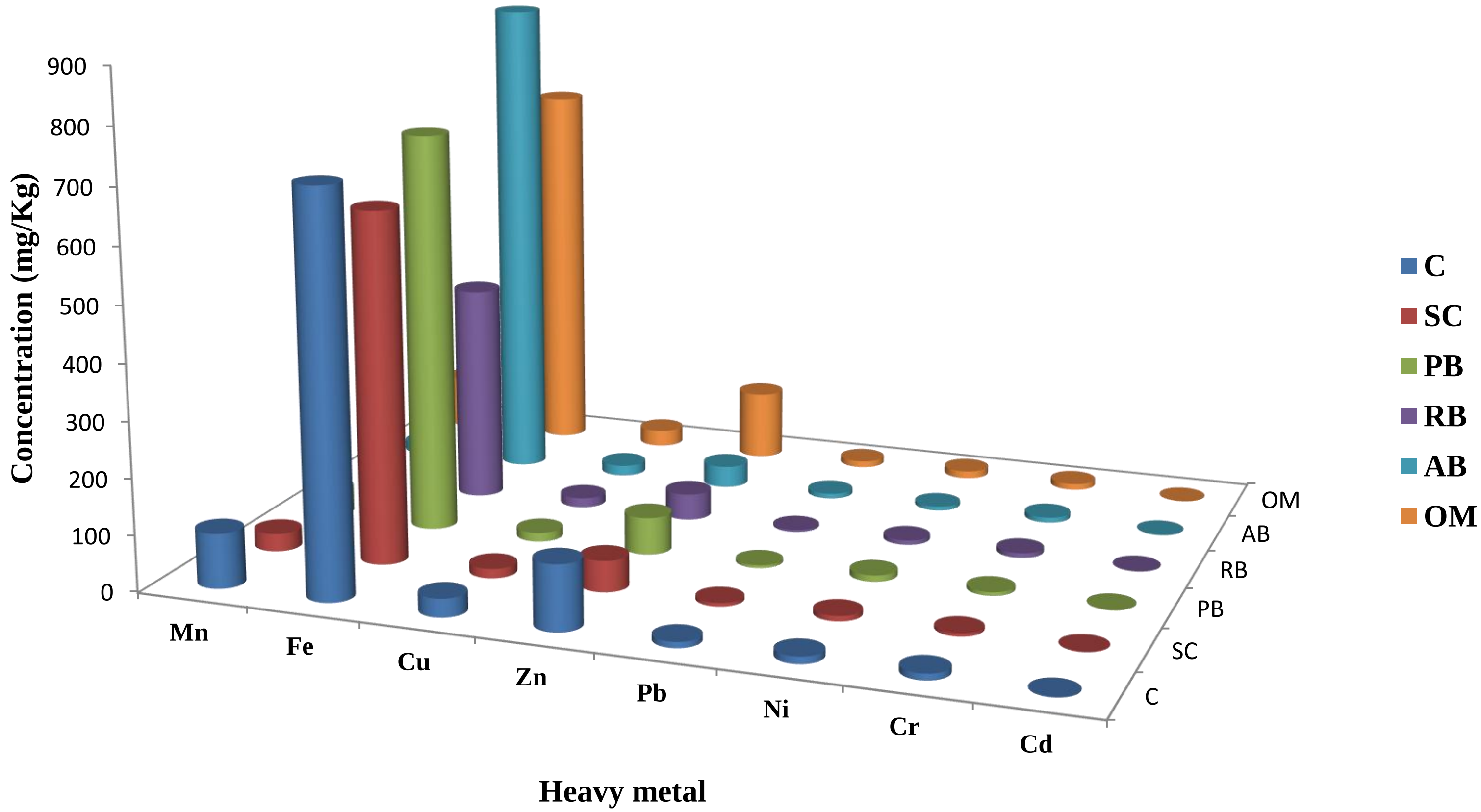

Figure 4.4. Heavy metal composition of fertilizer

Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic- based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

4.2 Chemical Binding Forms of N, P, and K in Organically Fortified Fertilizers

Table 4.2 shows the results obtained for the chemical binding form of nitrogen and phosphorus. Fertilizers made with AB and OM had highest levels of NH_4-N (ammoniacal) (0.3 ± 0.0 %) and NO_3-N (nitrate) (0.7 ± 0.0 %) each without significant difference; however, NH_4-N was more predominant in all fertilizers. In addition, other N forms: NO_3-N (nitrate), Urea-N (amide) and organic N were also detected at varying concentrations and their differences were significant across the formulations. In terms of phosphorus, RB contained highest levels of water soluble (7.0 ± 0.0 %) and neutral ammonium citrate soluble (4.1 ± 0.0 %). The SC had 0.7 ± 0.0 % of neutral ammonium citrate soluble, ranking second to RB. Other forms were found in low quantities.

4.3 Seed Germination Toxicity Test (Phyto-Toxicity)

Values obtained for phyto-toxicity of the formulations are shown in Table 4.3. The average Germination Index (GI) values at different rates of application were higher than the minimum limit of 80 in the standard compost (TACFS, 2005) except for the synthetic compost formulation that was toxic to soybean at 3.0 tons/ha rate of application (74.2). The highest levels of GI in maize noticed in plots applied with OM at 2.0 tons/ha was 197.6 and 2.5 tons/ha was 168.2. This was followed by the maize plots applied with RB at 167.8 and 161.0 respectively. In soybean, the highest value was that of RB applied at 2.0 tons/ha (133.4) followed by OM (127.2) applied at the same rate of 2.0 tons/ha.

4.4 Residual Potential of Chemical Contents of Organically Fortified Fertilizers

As shown in Figure 4.5, all the formulation showed residual nutrient potentials, though at varying levels. More quantities of C were retained in SC plots (for yam and maize) and K (for all plots) than any other plot applied with other formulations. Control plot retained highest levels of TN and P in the maize, yam and soybean plots. Other OOFs: AB, RB, OM showed almost constant residual levels of nutrients across all plots. In the entire main plots for maize, soybean and yam, all the formulations and control plots showed high percentage residual levels of Mn. In terms of residual nutrient levels, the SC showed the highest values in maize and yam (Figure 4.6). Apart from the Mn, heavy metals were almost not present after harvesting.

Table 4.2. Chemical binding form of nitrogen and phosphorus (Mean ± SD, n= 4)

Parameters	C	SC	PB	RB	AB	OM
			Nitrogen Forms (%)			
NH_4-N (ammoniacal)	0.2 ± 0.0b	0.2 ± 0.0ab	0.3 ± 0.0bc	0.2 ± 0.0a	0.3 ± 0.0c	0.3 ± 0.0c
NO_3-N (nitrate)	0.6 ± 0.0c	0.5 ± 0.0ab	0.6 ± 0.0bc	0.4 ± 0.0a	0.7 ± 0.0d	0.7 ± 0.0d
Urea-N (amide)	0.1 ± 0.0a	0.1 ± 0.0a	0.2 ± 0.0ab	0.1 ± 0.0a	0.2 ± 0.0bc	0.3 ± 0.0c
Organic N	0.2 ± 0.0bc	0.2 ± 0.0ab	0.2 ± 0.0bc	0.1 ± 0.0a	0.2 ± 0.0bc	0.3 ± 0.0c
			Phosphorus Forms (%)			
Water soluble	0.2 ± 0.0bc	0.3 ± 0.0c	0.3 ± 0.0d	7.0 ± 0.0e	0.2 ± 0.0b	0.2 ± 0.0bc
Neutral ammonium citrate soluble	0.3 ± 0.0c	0.7 ± 0.0a	0.3 ± 0.0c	4.1 ± 0.0d	0.2 ± 0.0c	0.3 ± 0.0d
Neutral ammonium citrate insoluble	0.1 ± 0.0ab	0.1 ± 0.0a	0.2 ± 0.0d	0.1 ± 0.0a	0.1 ± 0.0bc	0.1 ± 0.0a
Acid soluble	0.1 ± 0.0bc	0.0 ± 0.0a	0.1 ± 0.0bc	0.1 ± 0.0b	0.1 ± 0.0c	0.1 ± 0.0c

Values followed by different letters (a, b, c, d and e) along the rows are significant

Table 4.3: Seed germination toxicity of maize and soybean

	SC			PB			RB			AB			OM			TACFS
Parameter	**2.0 ton /ha**	**2.5 ton /ha**	**3.0 ton /ha**	**2.0 ton /ha**	**2.5 ton /ha**	**3.0 ton /ha**	**2.0 ton /ha**	**2.5 ton /ha**	**3.0 ton /ha**	**2.0 ton /ha**	**2.5 ton /ha**	**3.0 ton /ha**	**2.0 ton /ha**	**2.5 ton /ha**	**3.0 ton /ha**	**guideline in compost (2005)**
GI (Maize)	124.4	115.0	108.1	144.6	126.6	111.0	167.8	161.0	156.1	158.0	137.0	134.5	197.6	168.2	157.8	
G2 (Soybean)	108.9	101.3	74.2	123.7	109.46	95.2	133.4	114.8	106.8	125.4	114.8	107.3	127.2	116.4	99.3	**≥ 80**

Legend: PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic- based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

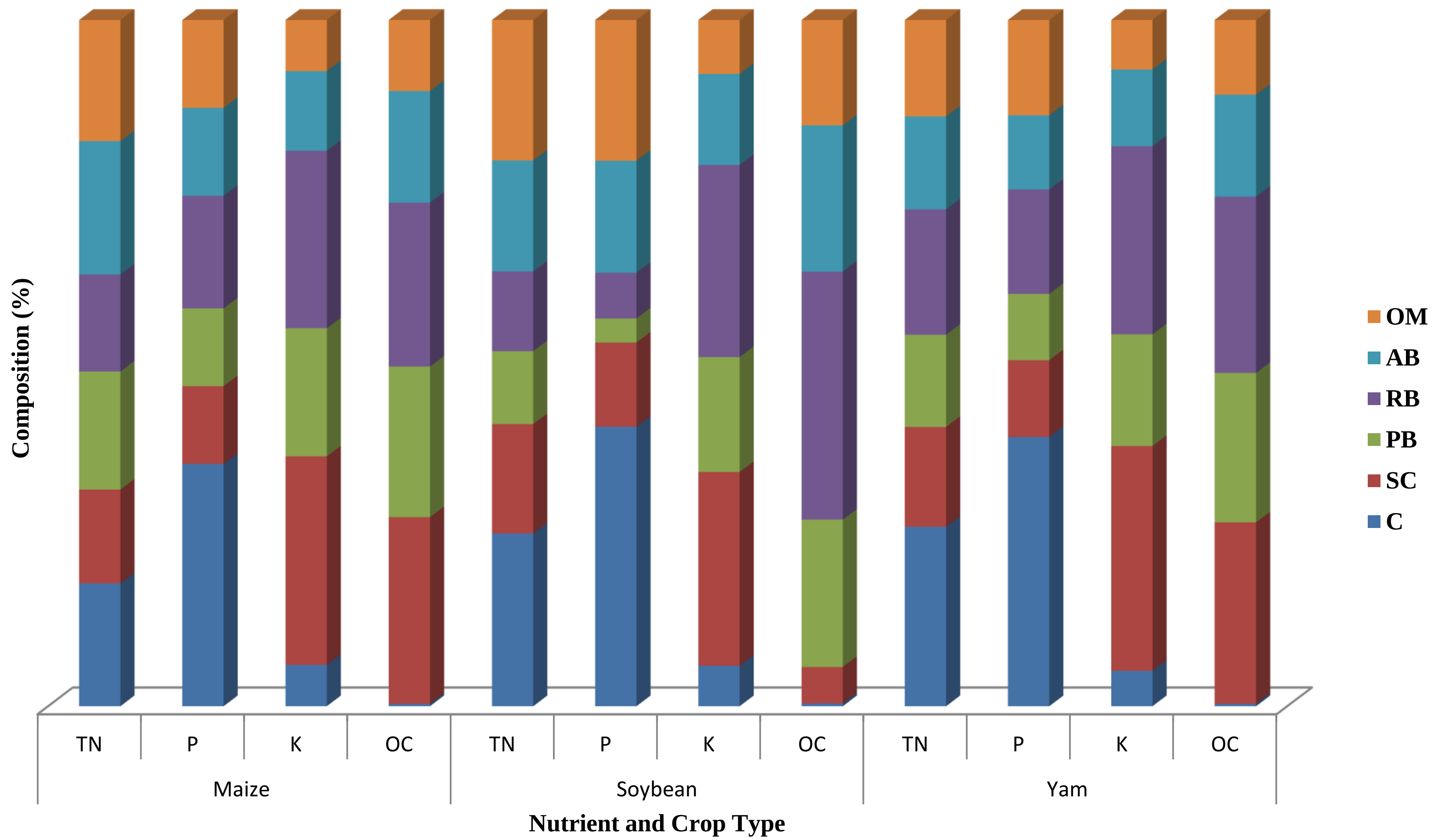

Figure 4.5. Residual nutrient of fertilizers in maize, soybean and yam plots (%)

Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic-based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

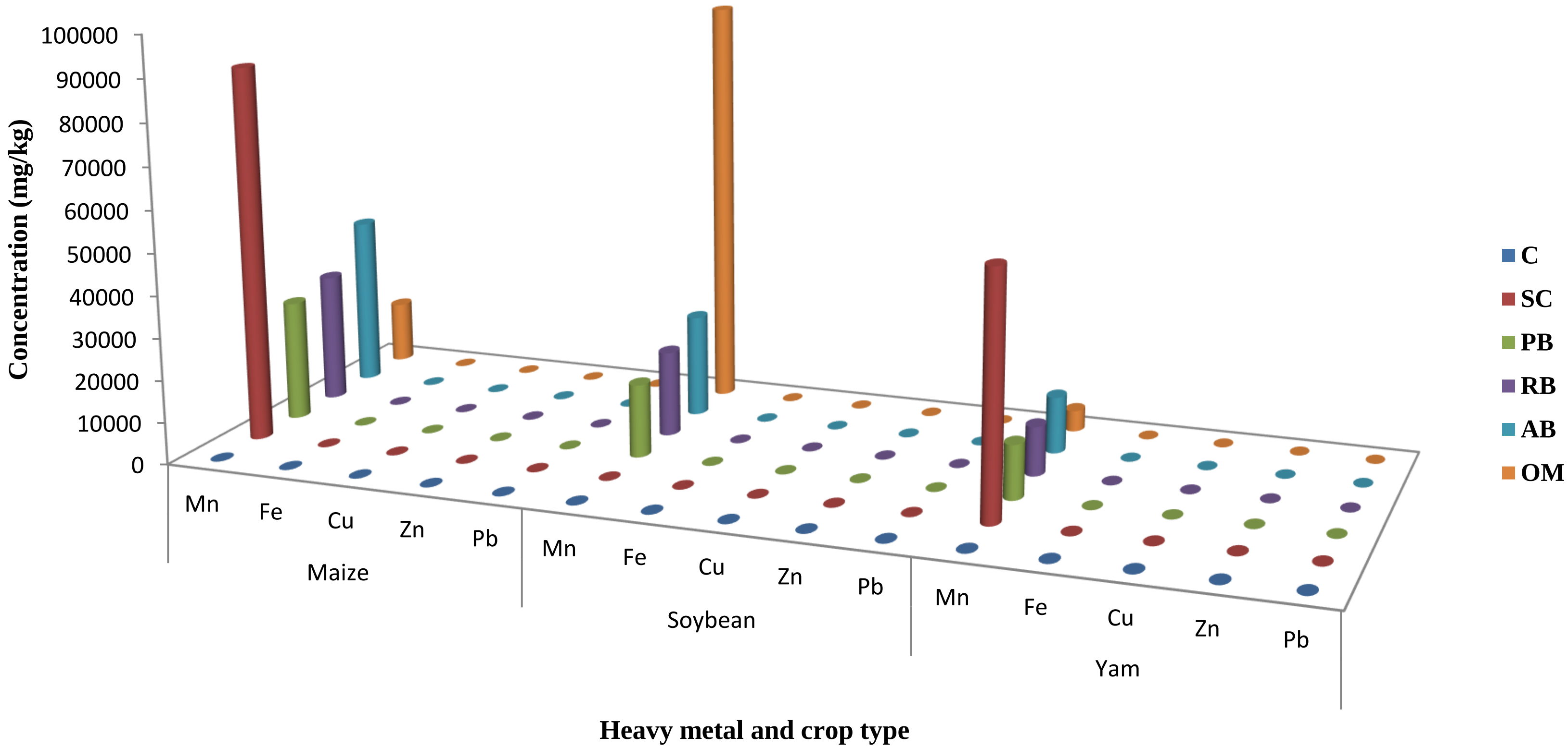

Figure 4.6. Residual heavy metal concentration of fertilizers in maize, soybean and yam plots (%)

Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic-based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

4.5 Effect of Fertilizer on the Agronomic Parameters of Crops

Tables 4.4, 4.5 and 4.6 reveal the effect of fertilizer formulations on the agronomic parameters of maize, soybean and yam. In addition, Figures 4.7- 4.14 show the pattern of crop development by weeks. From the Tables and Figures, it could be seen that the effects of the fertilizers on the agronomic data were crop specific. There were some significant differences at two weeks of application for all the crops. However, much more significant effects were noted at maturity. That is, all the fertilizers showed direct relationship pattern to the agronomic data from germination to the maturity. However, there was no indication that any of the fertilizer had effect on the stem girth of yam. The SC showed highest effect only in soybean plant height as at first week after the fertilizer application (13.9 ±5.4 cm).

Just like the effects of the formulations on the agronomic data were crop specific, the agronomic parameters were also found to be formulation specific. The following relationship existed between formulation and agronomic parameters: Maize: (PH- OM; NL- OM; SG- RB; LA- RB), Soybean: **(**PH- SC; NL- AB; SG- AB; LA- RB), and Yam (SG- RB; LA- RB). In maize, all the formulations performed better than the control (C) and SC; C and SC also showed little effects on the maize growth parameters. Maize showed non-selective effects towards parameters as OM generally performed best. Soybean seemed to be selective as OM generally had little effects on the agronomic data of soybean while AB performed best.

Specifically, OM and RB for maize [NL (10.0 ± 1.1; 9.2 ± 1.0), PH (23.9 ± 5.4cm; 22.7 ± 3.6cm), SG (2.2 ± 0.4 cm; 2.2 ± 0.4cm), LA (2.7 ± 0.1 cm^2; 3.4 ± 0.7 cm^2)]; AB and RB for soybean [NL (20.3 ± 10.1; 15.3 ± 4.5), PH (12.0 ± 3.5 cm; 10.8 ± 5.8cm), SG (0.4 ± 0.1cm; 0.4 ± 0.1 cm), LA (21.0 ± 15.7 cm^2; 18.7 ± 7.2 cm^2)] and RB for yam [PH (44.0 ± 24.0 cm); SG (0.8 ± 0.1 cm)] respectively gave the best crops' performances in APs among all the formulations and the control. From onsite observation, RB and AB first produced husk in maize; RB and OM first produced flower in soybean with more intense in RB plot. Multiple maize fruits (2 or 3 hairs) were noticed in RB while the rest had single fruit. Worm cast were found very predominant in AB and RB plot, followed by OM, PB and C; very little worm cast was found in SC plot. Maize stem girth reduced at maturity and the maize leaf number was constant at the appearance of husk. Soybean produced seeds at 10 weeks after planting in OM, AB, RP and SC.

Table 4.4. Effect of fertilizer on the agronomic parameters of maize (Mean ± SD, n=9)

Agronomic Parameter	Treatment C	SC	PB	RB	AB	OM	F value	P value
After 2 weeks of Application								
Plant Height	16.4 ± 4.9a	16.7± 6.6a	11.8 ± 4.1a	22.7 ± 3.6b	22.8 ± 4.1b	23.9 ± 5.4b	8.8	*0.0
Leave Area	2.0 ± 1.0ab	1.4 ± 0.6a	2.14 ± 0.1abc	3.4 ± 0.7d	2.9 ± 0.1cd	2.7 ± 0.1bcd	4.9	*0.0
Stem Girth	1.2 ± 0.5ab	1.5 ± 0.3a	1.7 ± 0.6b	2.2 ± 0.4c	2.2 ± 0.4c	2.2 ± 0.4c	9.8	*0.0
No. of Leaves	6.3 ± 1.5a	6.3 ± 1.6a	8.3 ± 1.9b	9.2 ± 1.0bc	8.8 ± 1.2bc	10.0 ± 1.1c	10.7	*0.0
At Maturity (12 weeks)								
Plant Height	218.2 ± 28.5a	274.2 ± 30.6b	284.9 ± 18.7bc	313.6 ±17.0bc	301.8 ± 15.2bc	326.9 ± 18.1c	6.8	*0.0
Leave Area	4.4 ± 0.2a	5.7 ± 0.2bc	5.3 ± 0.0b	6.5 ± 0.4c	5.8 ± 0.2bc	6.2 ± 0.1c	6.9	*0.0
Stem Girth	2.1 ± 0.5a	2.4 ± 0.2ab	2.4 ± 0.4ab	2.8 ± 0.4b	2.6 ± 0.4b	2.6 ± 0.4b	6.0	*0.0
No. of Leaves	12.4 ± 1.2a	12.8 ± 1.6ab	14.2 ± 2.4bc	14.9 ± 1.5cd	14.2 ± 1.2bc	15.9 ± 1.2d	3.5	*0.0

Different letters (a, b, c and d) indicate significant differences along the rows
***Significant at p = 0.05**

KEY: Plant Height (cm); Leave Area (cm^2); Stem Girth (cm)

Table 4.5. Effect of fertilizer on the agronomic parameters of soybean (Mean ± SD, n=9)

Agronomic Parameter	Treatment C	SC	PB	RB	AB	OM	F value	P value
After 2 weeks of Application								
Plant Height	9.6 ± 3.0ab	13.9 ± 5.4b	12.0 ± 4.8ab	10.8 ± 5.8ab	12.0 ± 3.5ab	8.9 ± 4.7a	1.4	*0.0
Leave Area	10.6 ± 4.8a	17.0 ± 8.4a	17.0 ± 12.1a	18.7 ± 7.2a	21.0 ± 15.7a	12.4 ± 7.4a	1.4	0.3
Stem Girth	0.3 ± 0.1a	0.4 ± 0.1a	0.4 ± 0.1a	0.4 ± 0.1a	0.4 ± 0.1a	0.3 ± 0.1a	1.4	0.3
No. of Leaves	11.2 ± 5.6a	17.3 ± 8.6ab	14.1 ± 8.7ab	15.3 ± 4.5ab	20.3 ± 10.1b	10.2 ± 4.9a	2.3	*0.0
At Maturity (12 weeks)								
Plant Height	51.8 ± 6.6a	53.7± 7.0a	51.7 ± 5.6a	55.6 ± 6.0a	53.4 ± 11.7a	53.5 ± 6.7a	0.3	0.9
Leave Area	40.0 ± 8.8a	44.1 ± 10.8a	47.3 ± 9.5ab	57.5 ± 15.1b	46.8 ± 7.4ab	46.7 ± 11.7ab	2.6	*0.0
Stem Girth	0.7 ± 0.1ab	0.8 ± 0.1b	0.7 ± 0.1ab	0.7 ± 0.1ab	0.7 ± 0.1ab	0.6 ± 0.1a	2.5	*0.0
No. of Leaves	70.1 ± 24.7a	98.0 ± 27.6ab	86.7 ± 35.5ab	110.1 ± 33.2b	98.8 ± 37.7ab	71.8 ± 20.0 a	2.5	*0.0

Different letters (a and b) indicate significant differences along the rows
***Significant at p = 0.05**

KEY: Plant Height (cm); Leave Area (cm^2); Stem Girth (cm)

Table 4.6. Effect of fertilizer on the agronomic parameters of yam (Mean ± SD, n=9)

Agronomic Parameter	Treatment C	SC	PB	RB	AB	OM	F value	P value
			After 2 weeks of Application					
Plant Height	21.7 ± 24.3$_{ab}$	13.0 ± 10.1$_{a}$	13.9 ± 11.2$_{a}$	44.0 ± 24.0$_{b}$	19.0 ± 15.5$_{a}$	15.3 ± 23.6$_{a}$	2.2	*0.0
Stem Girth	0.8 ± 0.0$_{cd}$	0.7 ± 0.1$_{bcd}$	0.4 ± 0.3$_{ab}$	0.8 ± 0.1$_{d}$	0.4 ± 0.3$_{abc}$	0.2 ± 0.4$_{a}$	5.1	*0.0
			At Maturity (12 weeks)					
Plant Height	67.5 ± 9.7$_{a}$	58.3 ± 13.0$_{a}$	70.4 ± 9.5$_{a}$	65.8 ± 3.1$_{a}$	69.5 ± 7.1$_{a}$	83.2 ± 13.6$_{b}$	4.0	*0.0
Stem Girth	0.8 ± 0.2$_{a}$	1.0 ± 0.2$_{a}$	0.9 ± 0.1$_{a}$	1.0 ± 0.1$_{a}$	1.0 ± 0.1$_{a}$	1.0 ± 0.1$_{a}$	0.9	0.5

Different letters (a, b, c and d) indicate significant differences along the rows
***Significant at p = 0.05**

KEY: Plant Height (cm); Leave Area (cm^2); Stem Girth (cm)

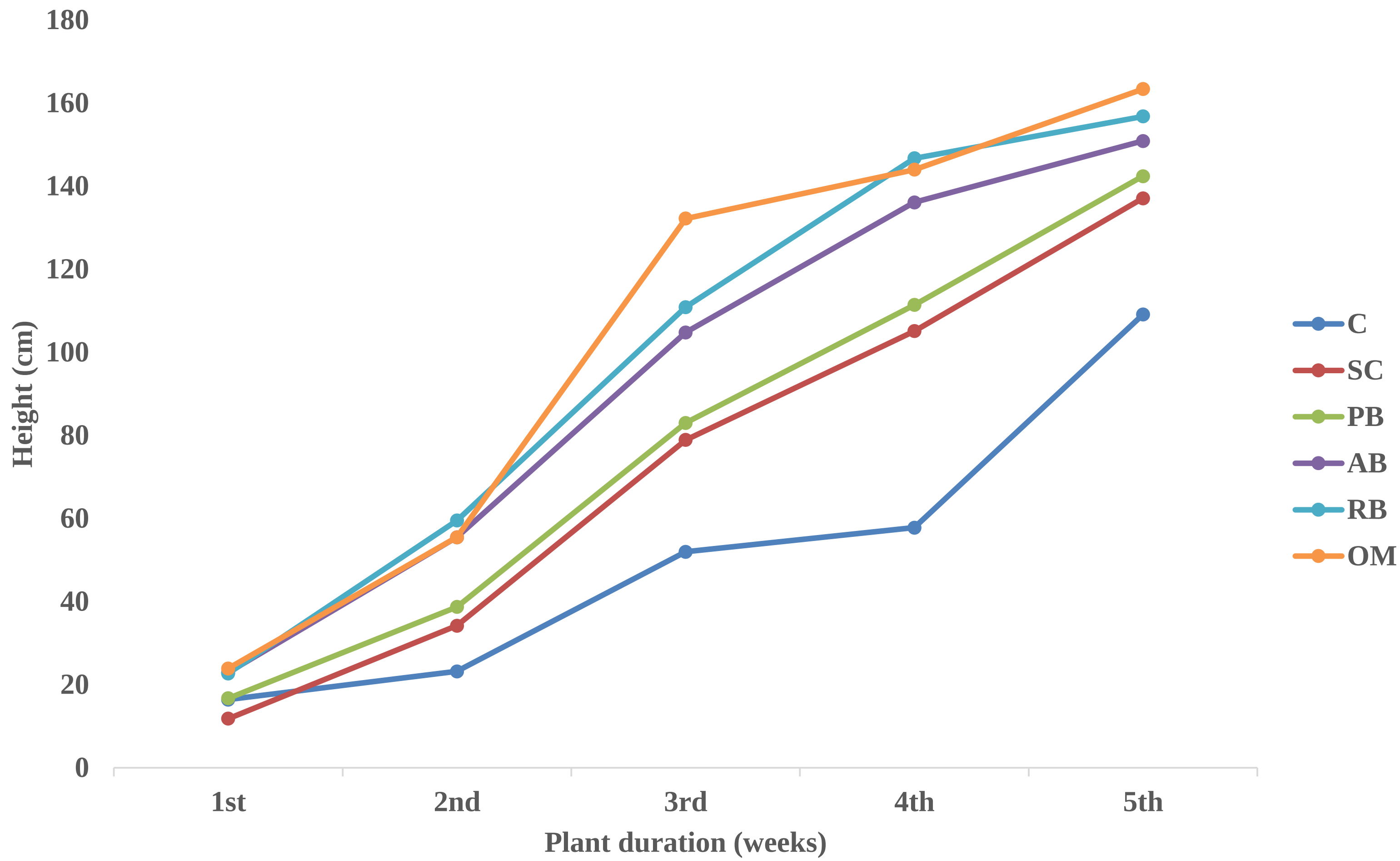

Figure 4.7. Trend of crop plant height development in maize plots by weeks

Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic-based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

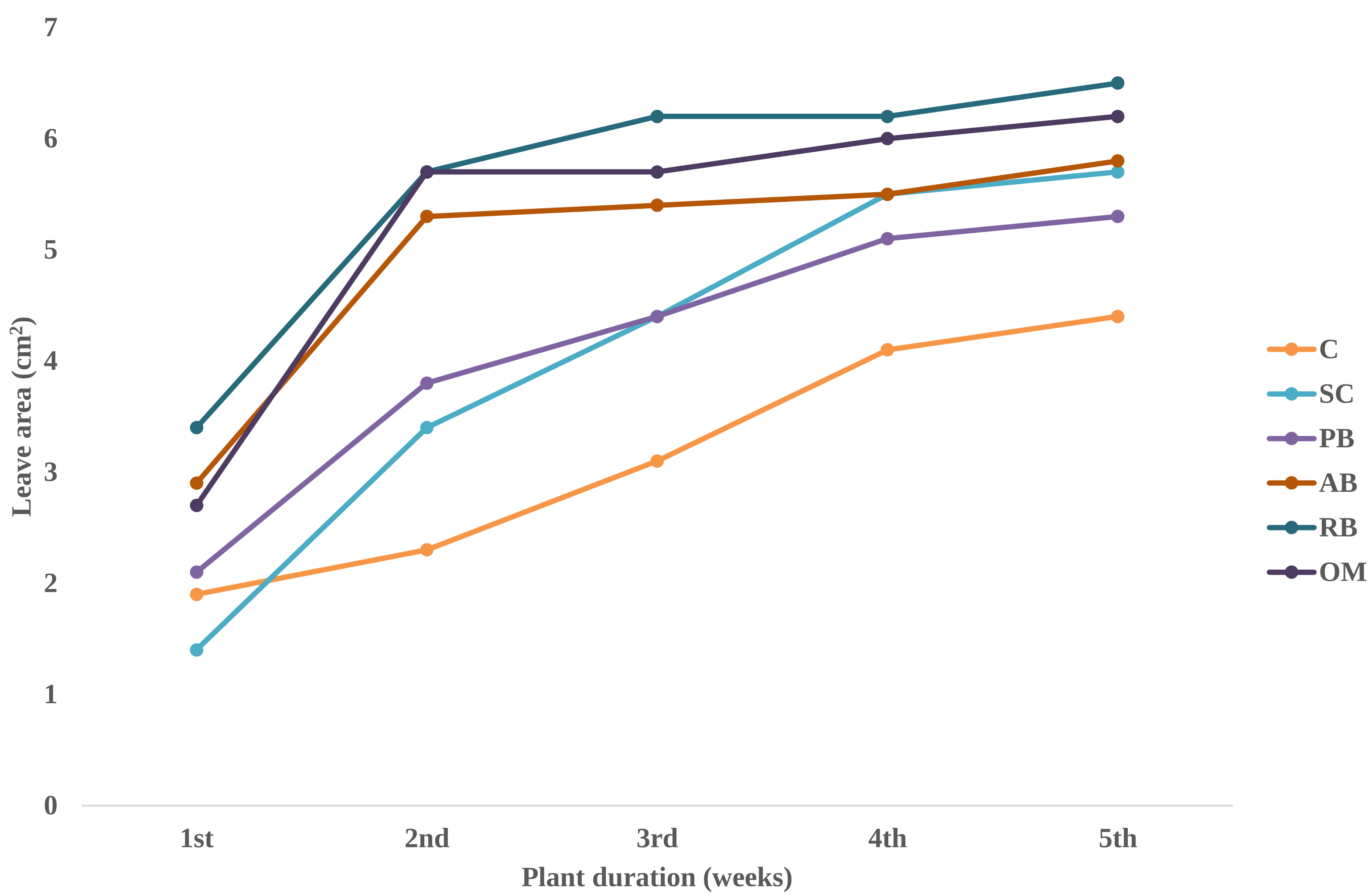

Figure 4.8. Trend of crop leave area development in maize plots by weeks

Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic-based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

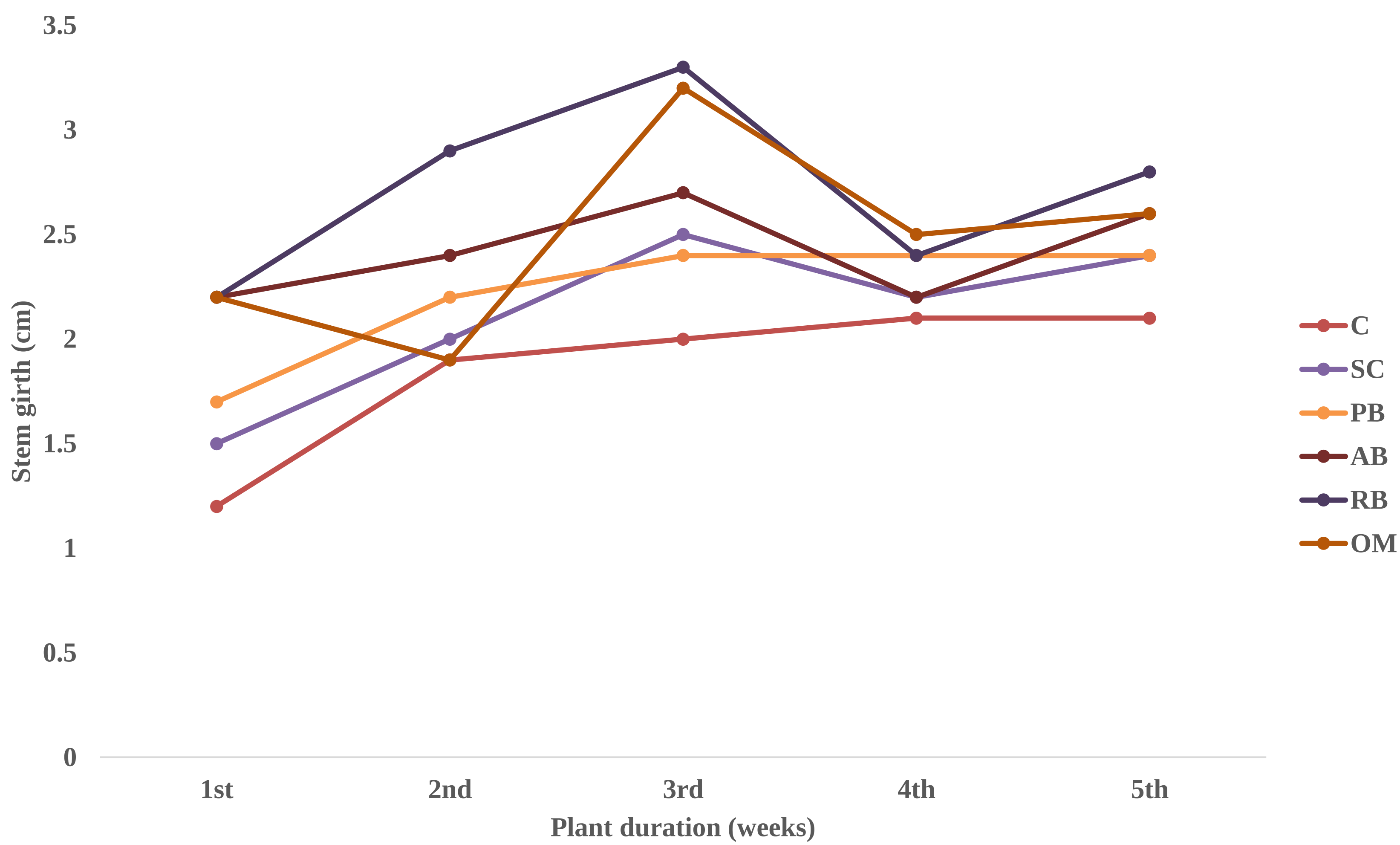

Figure 4.9. Trend of crop stem girth development in maize plots by weeks

Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic-based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

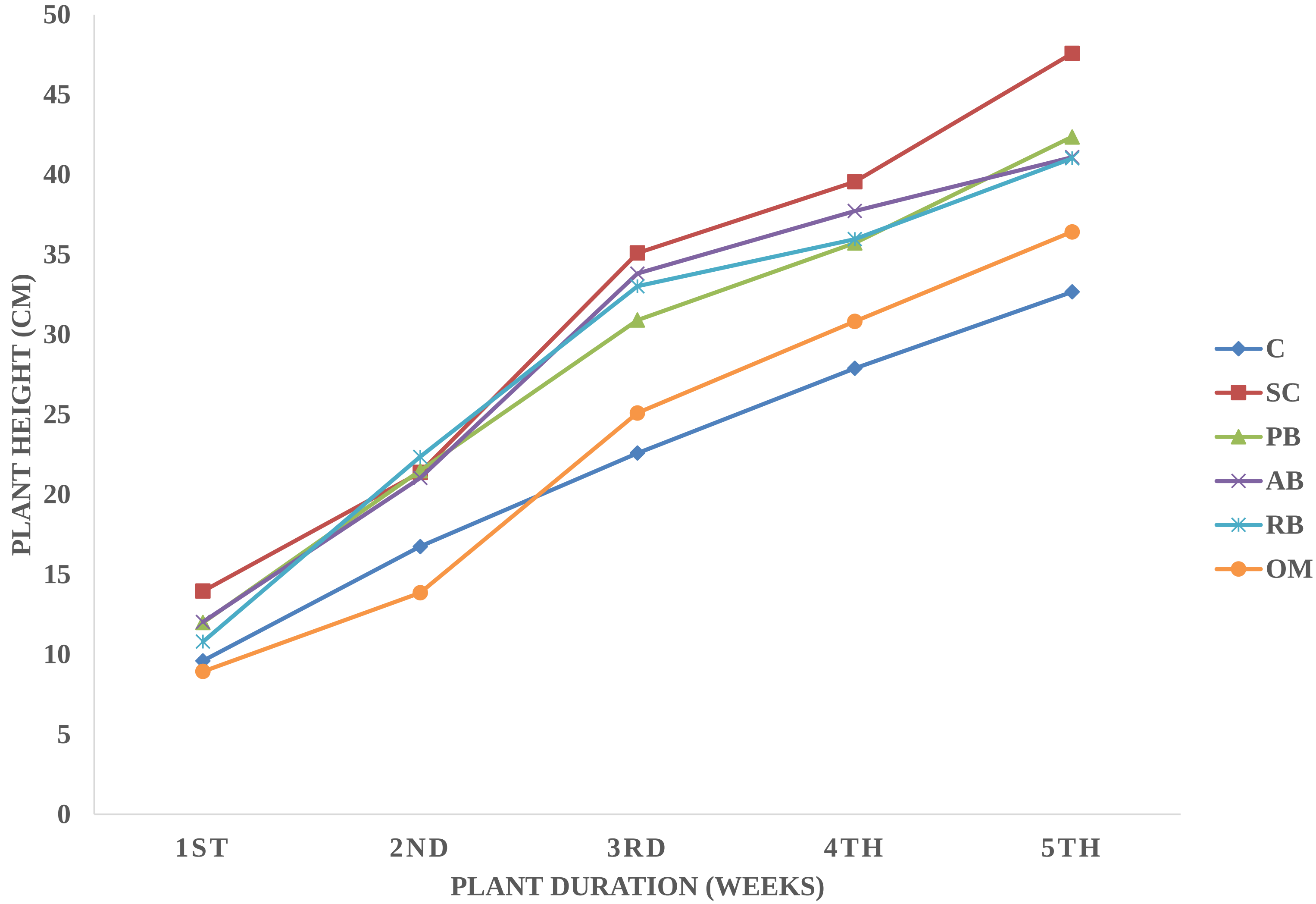

Figure 4.10. Trend of crop plant height development in the soybean plots by weeks

Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic-based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

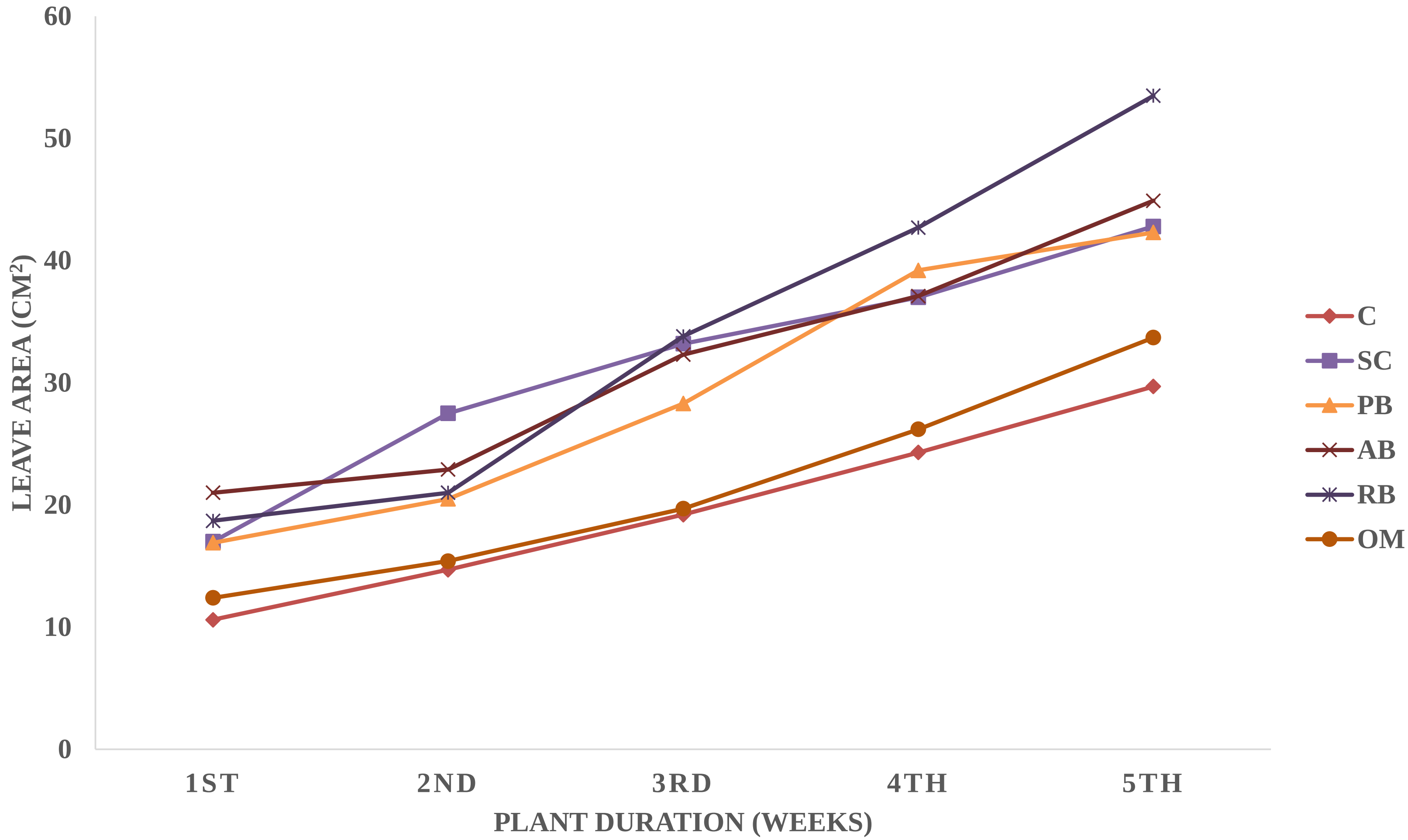

Figure 4.11. Trend of crop leave area development in the soybean plots by weeks
Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic-based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

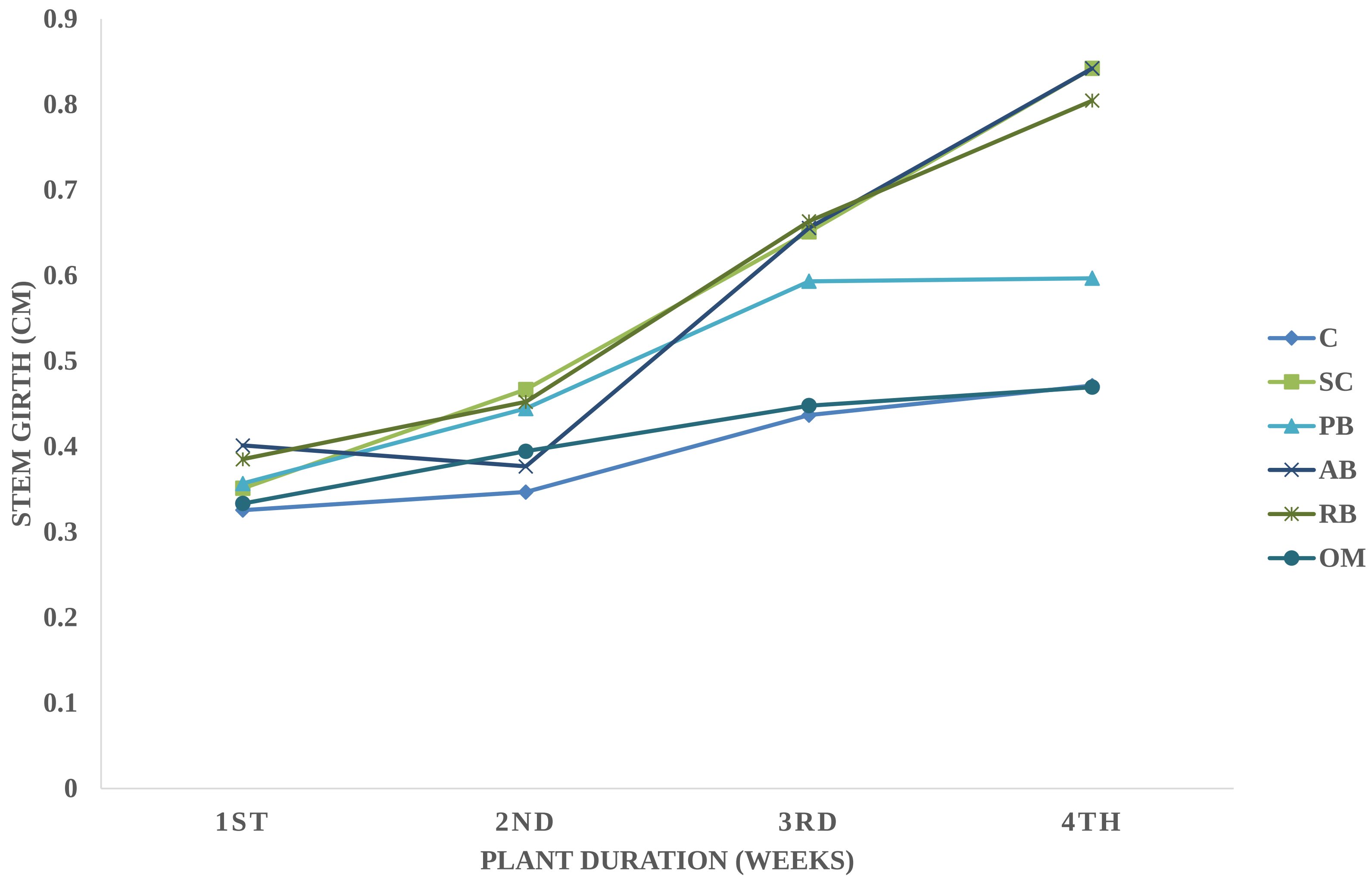

Figure 4.12. Trend of crop stem girth development in the soybean plots by weeks
Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic-based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

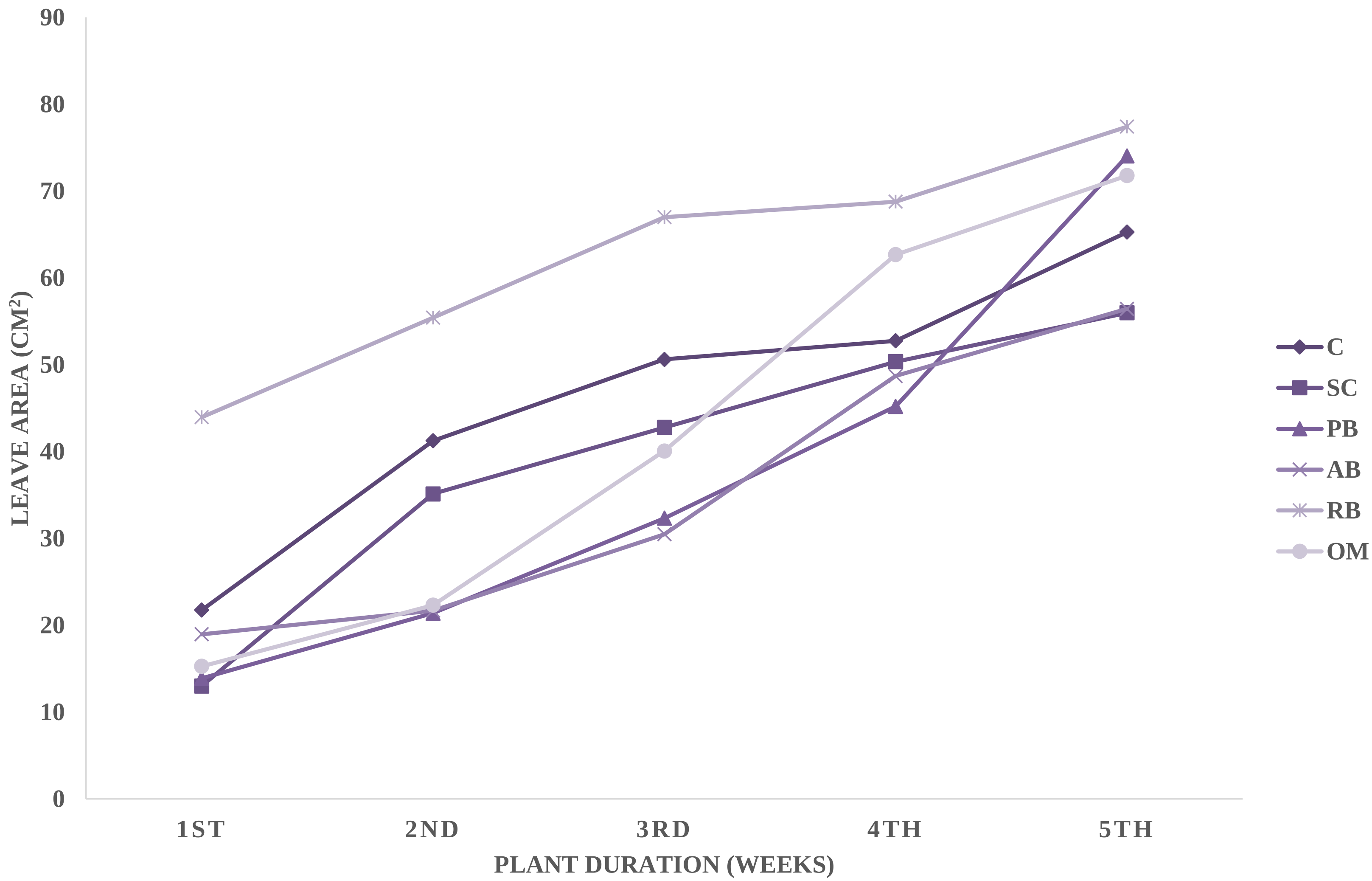

Figure 4.13. Trend of crop leave area development in the yam plots by weeks

Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic-based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

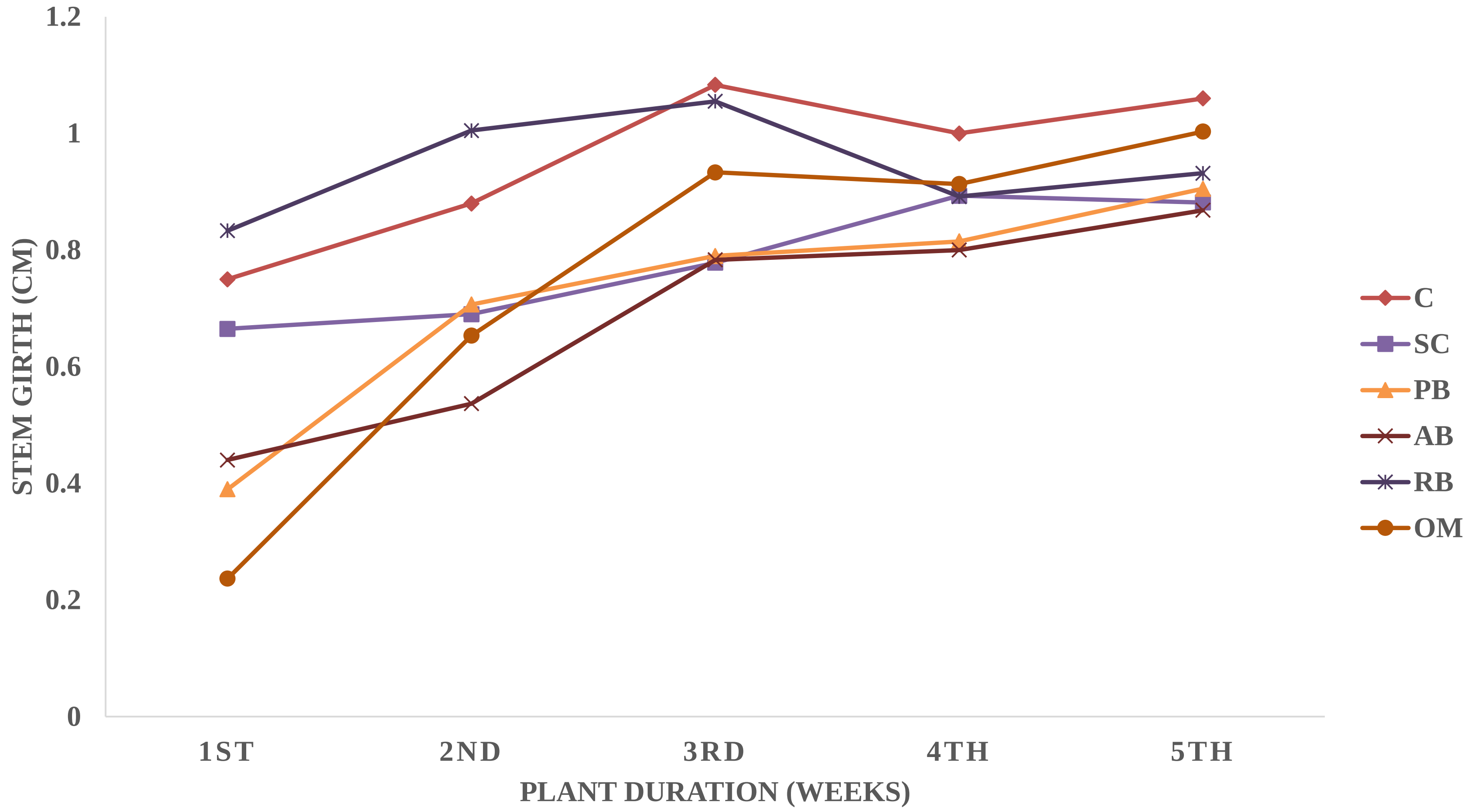

Figure 4.14. Trend of crop stem girth development in the yam plots by weeks

Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic- based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

4.6 Effect of Different Rates of OFF Application on the Test Crops

Figure 4.15 depicts the effects of different rates of RB application of OFFs on growth parameters of maize, soybean and yam during the two seasons. Also, the effects of different rates of AB application on maize and soybean are shown in Figure 4.16. The RB fertilizer generally affected plant height across all rates at different capacities. It enhanced the maize plant height (PH) at 2.5 ton/ha during the rainy season and gave best performance on the soybean number of leave (NL) and the leave area (LA) during the dry season when applied at the same rate of 2.5 ton/ha. For AB, different rates of application were also observed in the plant height with higher intensity in the rainy season. It greatly increased the plant height of maize at the rate of 2.0 tons/ha during the rainy season.

4.7 Effect of Seasonal Variation on Agronomic Parameters of the Test Crops

As shown in Figure 4.17, there were more growths in all the crops in the rainy season than the dry season with particular to all the agronomic parameters measured. An exceptional case was noticed in the yam leave area that was not affected by the seasonal variation. That is, season had only an improved effect on yam leave area with RB fertilizer. Effects of all the formulations were not observed in agronomic parameters of maize and soybean at first week to maturity at second cropping season. Also, plant height and leave area of maize increased markedly in the rainy than dry season.

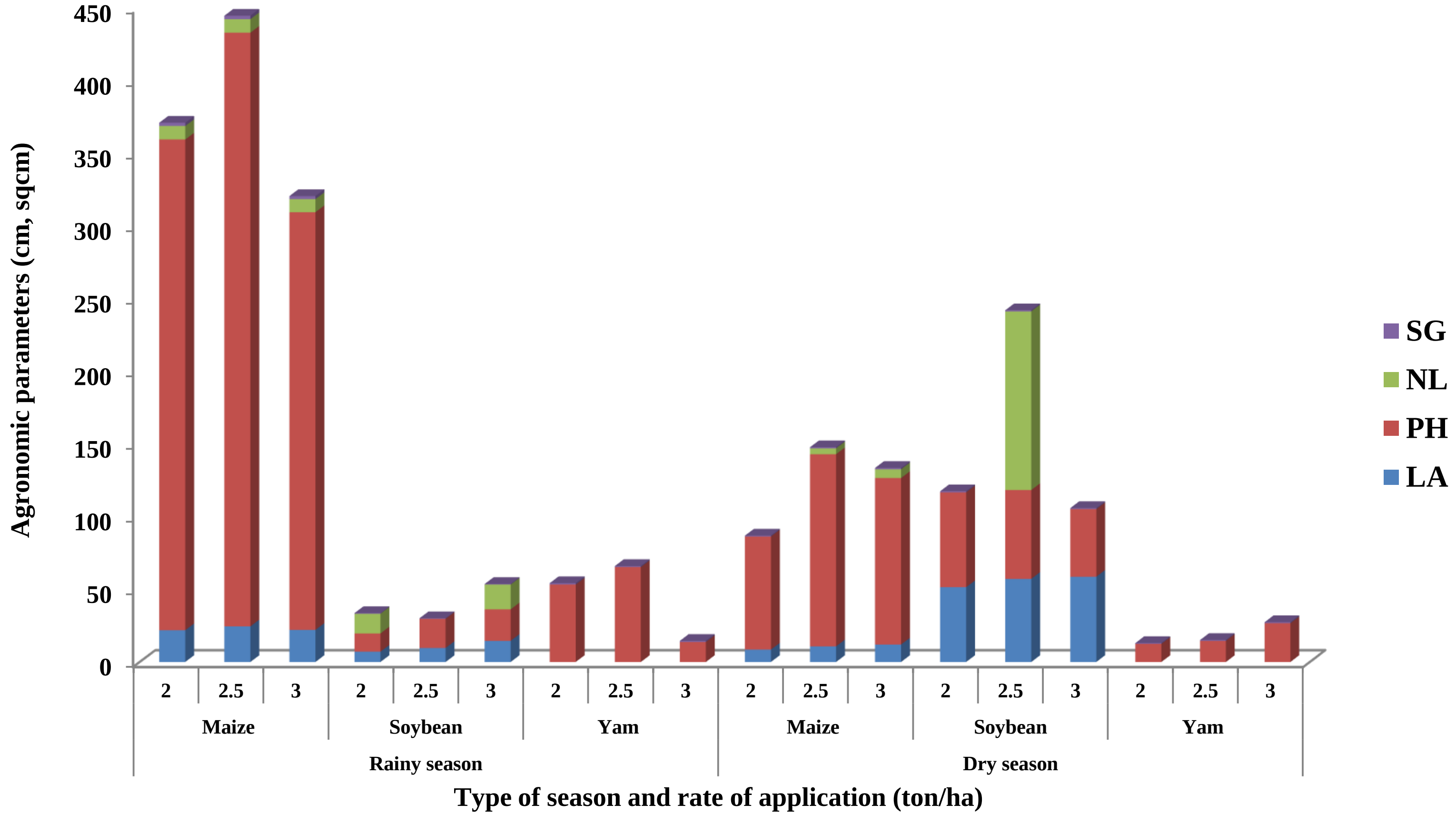

Figure 4.15. Effect of different rate of application of RB on agronomic parameters of the test crops

Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic- based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

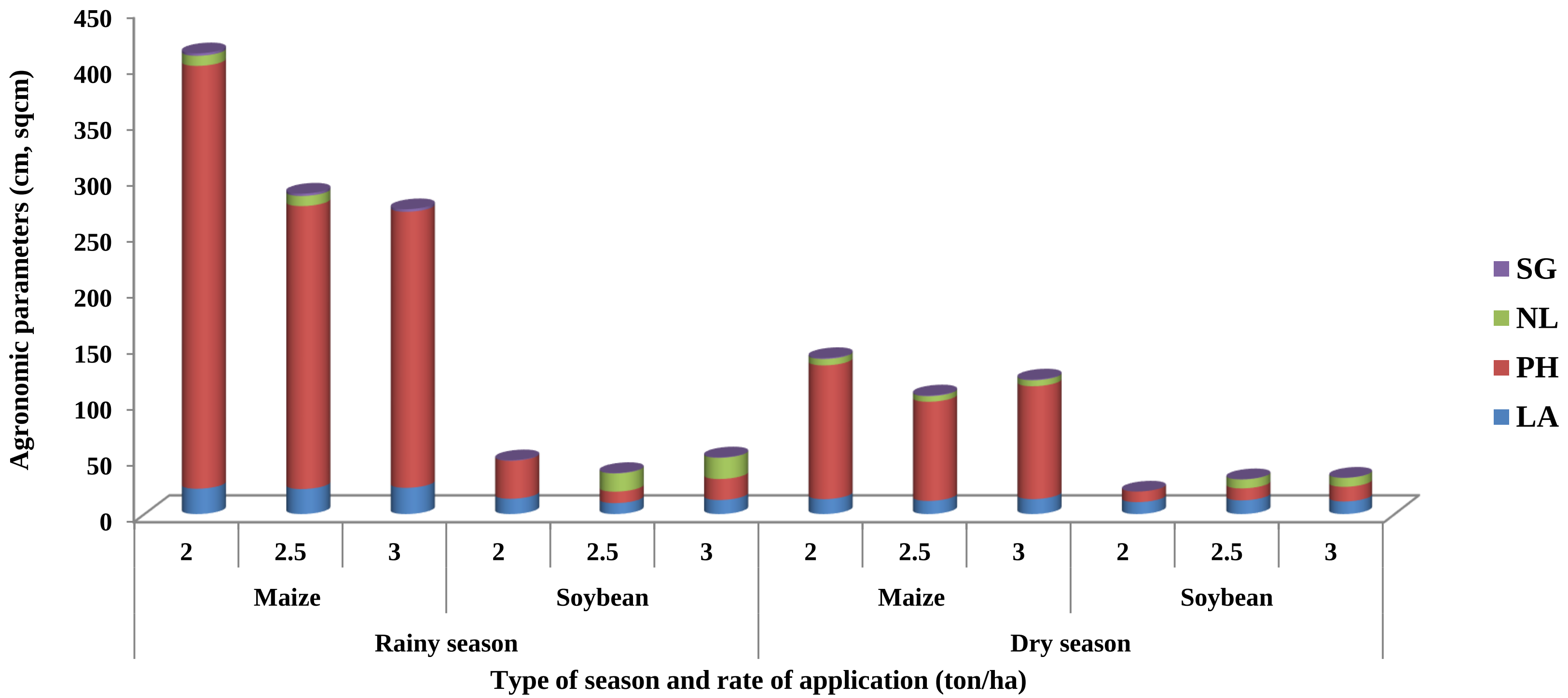

Figure 4.16. Effect of different rate of application of AB on agronomic parameter of maize and soybean

Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic-based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

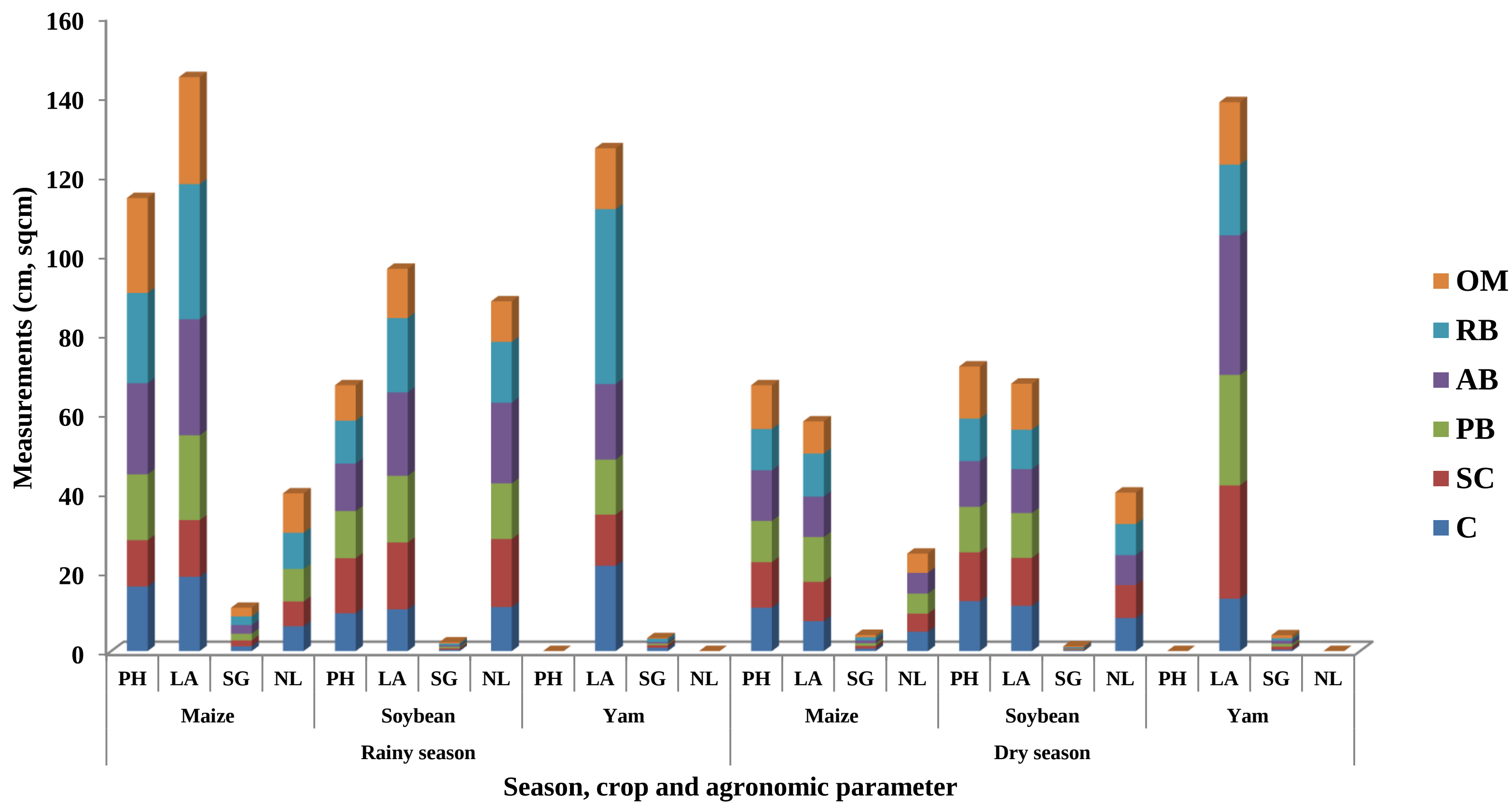

Figure 4.17. Effect of seasonal variation on agronomic parameter of the test crops

Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic- based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

4.8 Fresh Yield of Crops Applied with OFF at the First and Second Cropping Seasons

Figures 4.18, 4.19 and 4.20 show fresh yields of maize, soybean and yam when applied with different formulations at the two seasons respectively. In maize plots, formulations showed more effect on crop yield during the first cropping (rainy) than the second (dry) season. However, the yield in maize during the dry season far outweighed that of rainy season when RB was applied at 2.0 ton/ha. This was followed by AB (2.5 ton/ha); OM (3.0 ton/ha) and SC (2.5 ton/ha). Differences in the rate of OM showed no effect on crop yield of maize. The formulations showed more effect on the soybean yield during the second (dry) than the first cropping (rainy) season. AB at rate 2.0 ton/ha gave the highest yield followed by PB (2.5 ton/ha) during the first cropping while OM (3.0 ton/ha) gave the list- almost zero yield. At the second cropping season, OM (3.0 ton/ha) followed by AB (3.0 and 2.5 ton/ha), PB (3.0 and 2.5 ton/ha) and SC (3.0 ton/ha). OM (3.0) gave highest yam tuber yield. This was closely followed by RB (2.0 ton/ha), AB (2.5 ton/ha) and SC (3.0 ton/ha).

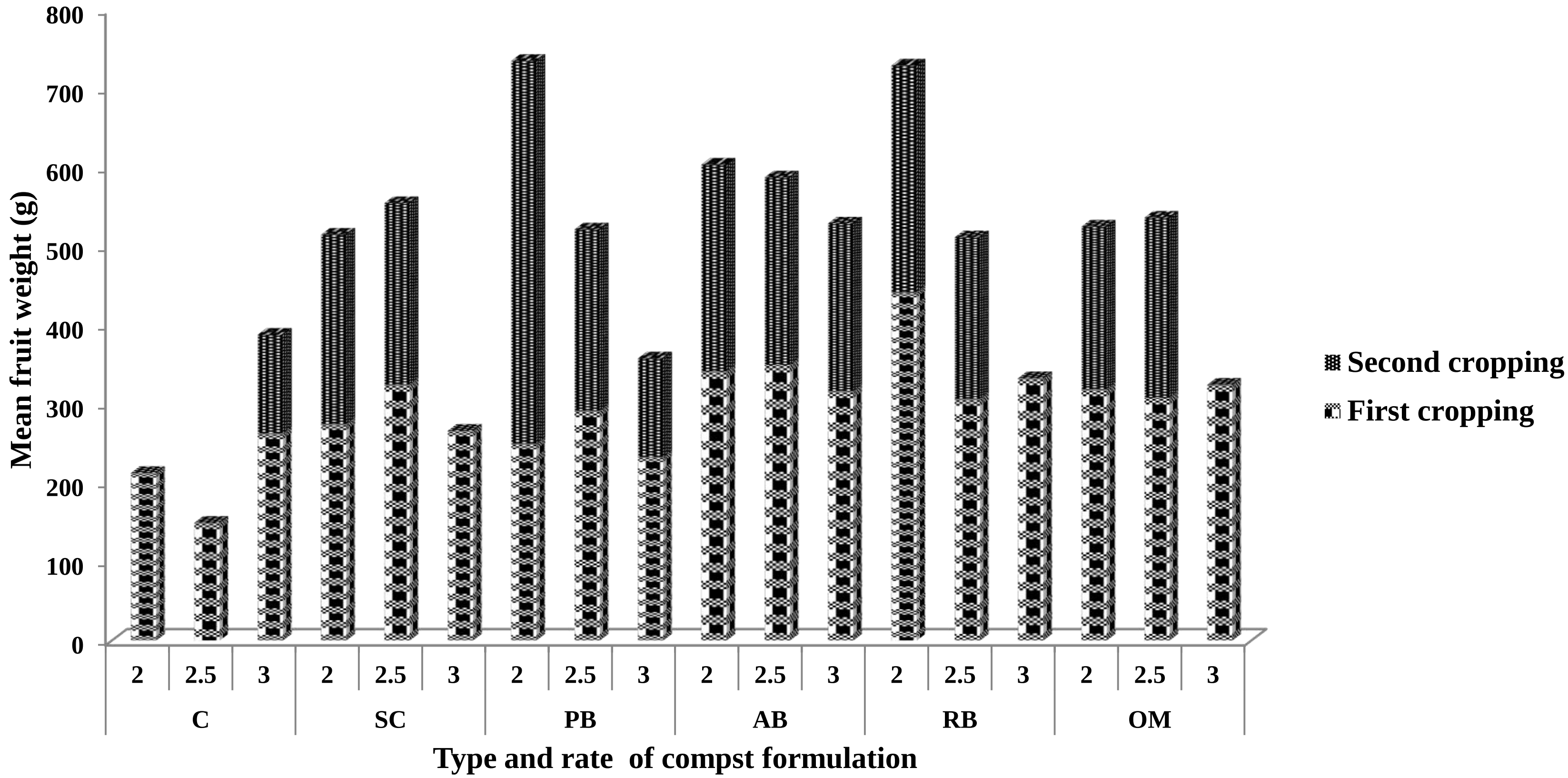

Figure 4.18. Fresh yield (mean fruit weight) of maize at first and second cropping seasons
Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic-based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

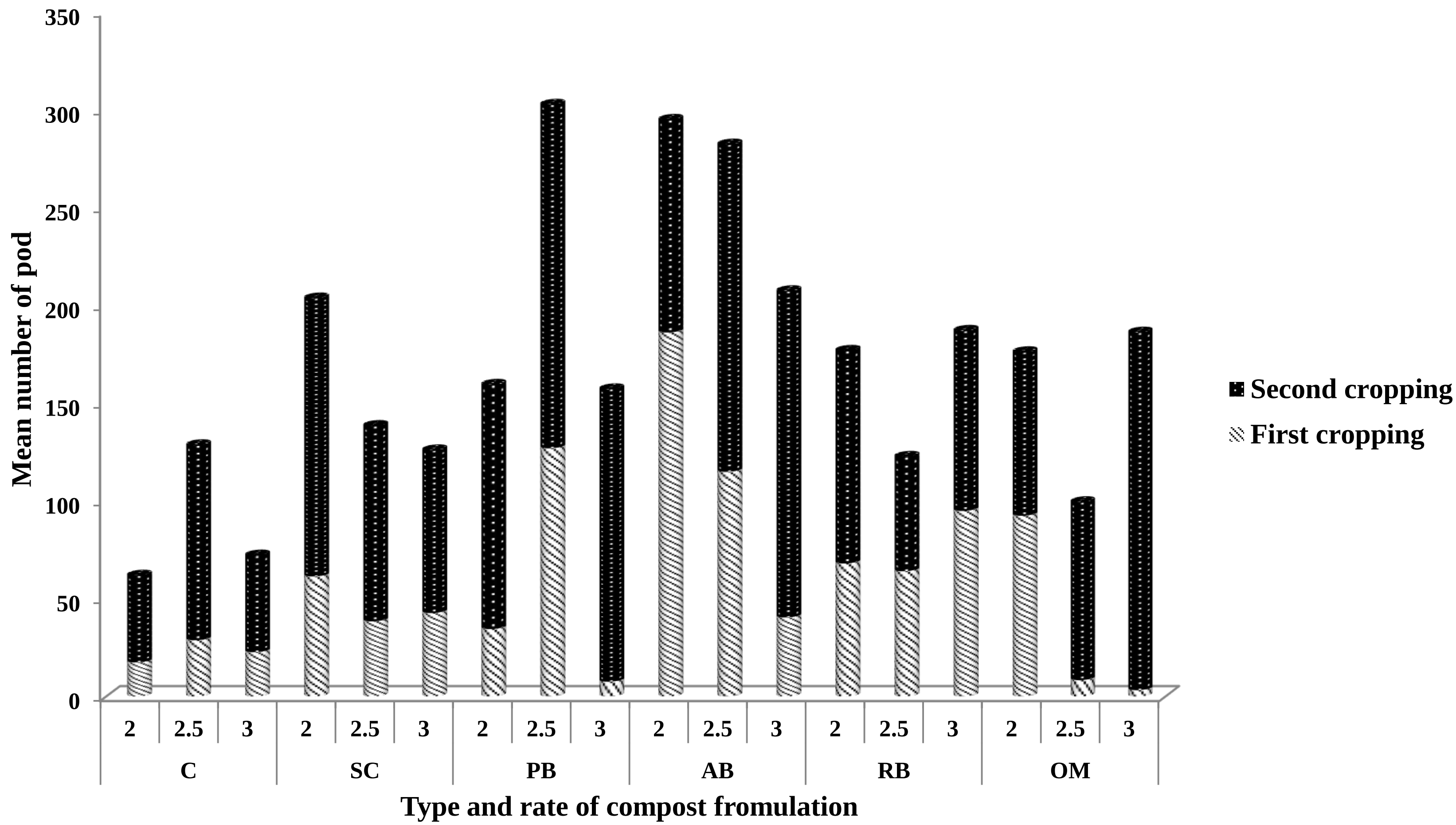

Figure 4.19. Fresh yield (mean pod number) of soybean at first and second cropping seasons

Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic-based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

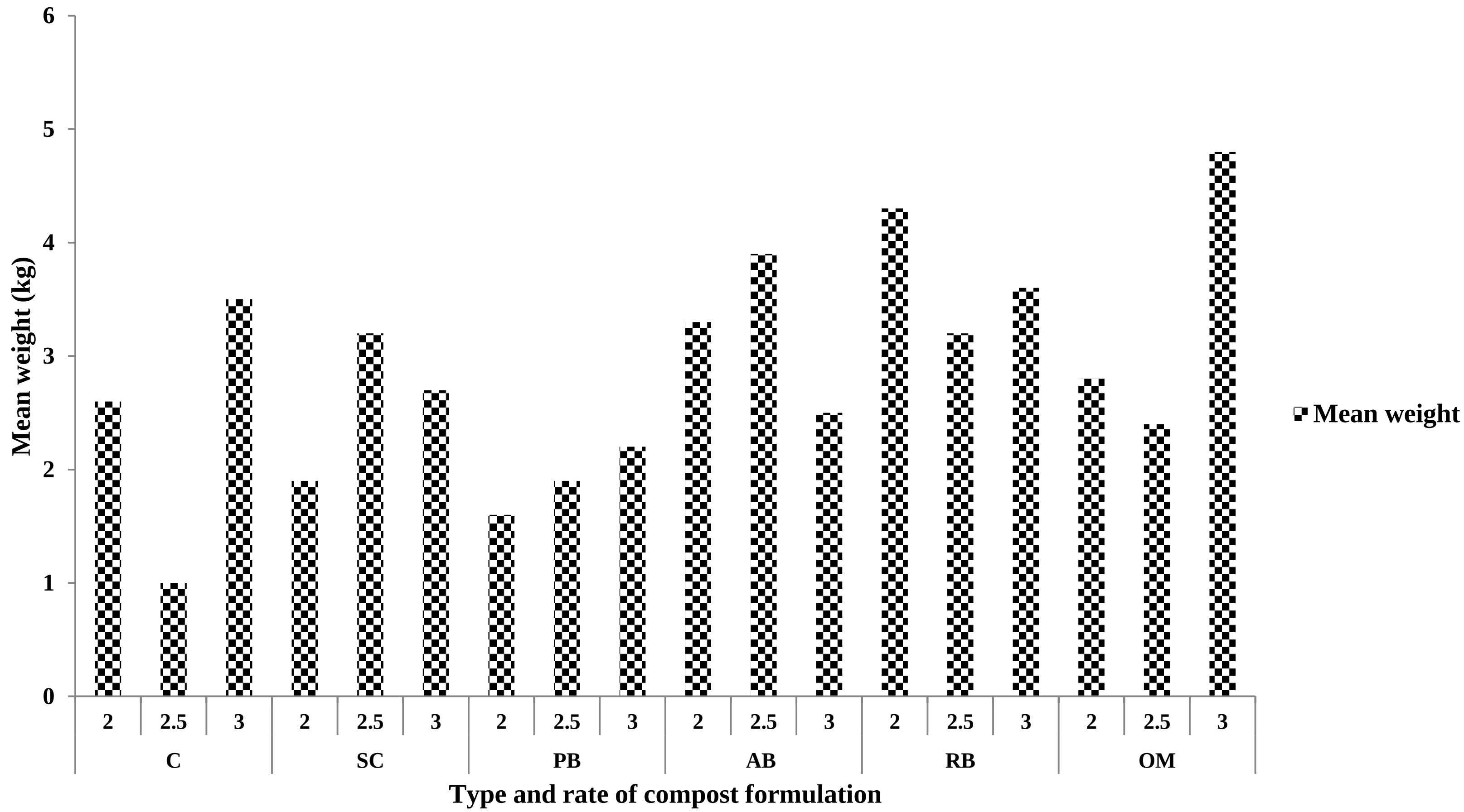

Figure 4.20. Fresh yield (mean weight of tuber) of yam

Legend: C - Control; PB- Plant- based fertilizer; AB- Animal/ Human -based fertilizer; RB- Rock- based fertilizer; OM- Organic-based fertilizer (Mixture of PB, AB, and RB); and, SC- Synthetic chemical fertilizer

4.9 Correlation Matrix between Agronomic Parameters for Maize and Soybean at First and Second Cropping

Tables 4.7- 4.10 show the correlation matrices between the agronomic parameters measured in maize and soybean during the first and second seasons. There was correlation between all agronomic parameters in maize when applied with ordinary compost during the first cropping. Very strong significant correlations were noted between PH and SG in maize plot applied with SC and PB during the first cropping with r = 0.818 and r = 0.694 respectively. In the plots applied with other formulation, no significant correlation existed; negative correlation was even noted in SG and LA in the plot applied with RB (r = -0.142) and between SG and PH (r = -0.206) in OM plot. A similar situation was observed in the second cropping. However, some parameters, exhibited strong relationship in RB and AB plots and some showed negative relationship in OM plot.

Correlation also existed in the soybean plots among different parameters during the two planting seasons. The observation in soybean parameter correlation was almost in the reverse direction to what obtained in the maize. Some negative correlations were observed in both rainy (NL Vs SG, r = -0.008) and dry (SG Vs PH: r = -0.075 and SG Vs LA: r = -0.134) seasons in the control plots. Common to both seasons, LA exhibited positive and significant relationship with other parameters.

Table 4.7 Correlation matrix between agronomic parameters for maize at first cropping

Parameters	Plant Height	Leave Area	Number of Leaves	Stem Girth
		Ordinary Compost (C)		
Plant Height	1			
Leave Area	0.931**	1		
Number of Leaves	0.825**	0.907**	1	
Stem Girth	0.696*	0.734*	0.707*	1
		Synthetic Fertilizer (SC)		
Plant Height	1			
Leave Area	0.523	1		
Number of Leaves	0.738*	0.437	1	
Stem Girth	0.818**	0.785*	0.714*	1
		Plant Based (PB)		
Plant Height	1			
Leave Area	0.615	1		
Number of Leaves	0.496	-0.106	1	
Stem Girth	0.694*	0.466	0.409	1
		Animal Based (AB)		
Plant Height	1			
Leave Area	0.505	1		
Number of Leaves	0.727*	0.766*	1	
Stem Girth	0.570	0.299	0.524	1
		Rock Based (RB)		
Plant Height	1			
Leave Area	0.277	1		
Number of Leaves	0.209	0.679*	1	
Stem Girth	0.266	-0.142	-0.159	1
		Organic Mixture (OM)		
Plant Height	1			
Leave Area	0.216	1		
Number of Leaves	0.435	0.116	1	
Stem Girth	-0.206	0.209	0.456	1

***Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).**

KEY: Plant Height (cm); Leave Area (cm^2); Stem Girth (cm)

Table 4.8 Correlation matrix between agronomic parameters for maize at second cropping

Parameters	Plant Height	Leave Area	Number of Leaves	Stem Girth
		Ordinary Compost (C)		
Plant Height	1			
Leave Area	0.696*	1		
Number of Leaves	0.571	0.651	1	
Stem Girth	0.546	0.856**	0.219	1
		Synthetic Fertilizer (SC)		
Plant Height	1			
Leave Area	0.682*	1		
Number of Leaves	0.776*	0.478	1	
Stem Girth	0.559	0.857**	0.580	1
		Plant Based (PB)		
Plant Height	1			
Leave Area	0.976**	1		
Number of Leaves	0.917**	0.905**	1	
Stem Girth	0.765*	0.783*	0.550	1
		Animal Based (AB)		
Plant Height	1			
Leave Area	0.746*	1		
Number of Leaves	0.799**	0.814**	1	
Stem Girth	0.333	0.116	0.093	1
		Rock Based (RB)		
Plant Height	1			
Leave Area	0.873**	1		
Number of Leaves	0.889**	0.928**	1	
Stem Girth	0.908**	0.905**	0.855**	1
		Organic Mixture (OM)		
Plant Height	1			
Leave Area	-0.324	1		
Number of Leaves	0.032	0.366	1	
Stem Girth	-0.203	0.501	0.453	1

***Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).**

KEY: Plant Height (cm); Leave Area (cm^2); Stem Girth (cm)

Table 4.9 Correlation matrix between agronomic parameters for soybean at first cropping

Parameters	Plant Height	Leave Area	Number of Leaves	Stem Girth
		Ordinary Compost (C)		
Plant Height	1			
Leave Area	0.787*	1		
Number of Leaves	0.754*	0.929**	1	
Stem Girth	0.514	0.008	-0.008	1
		Synthetic Fertilizer (SC)		
Plant Height	1			
Leave Area	0.913**	1		
Number of Leaves	0.659	0.804**	1	
Stem Girth	0.868**	0.847**	0.846**	1
		Plant Based (PB)		
Plant Height	1			
Leave Area	0.859**	1		
Number of Leaves	0.895**	0.768*	1	
Stem Girth	0.516	0.346	0.182	1
		Animal Based (AB)		
Plant Height	1			
Leave Area	0.324	1		
Number of Leaves	0.551	0.329	1	
Stem Girth	0.586	0.659	0.895**	1
		Rock Based (RB)		
Plant Height	1			
Leave Area	0.883**	1		
Number of Leaves	0.761*	0.878**	1	
Stem Girth	0.732*	0.889**	0.856**	1
		Organic Mixture (OM)		
Plant Height	1			
Leave Area	0.938**	1		
Number of Leaves	0.809**	0.890**	1	
Stem Girth	0.294	0.305	0.416	1

***Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).**

KEY: Plant Height (cm); Leave Area (cm^2); Stem Girth (cm)

Table 4.10 Correlation matrix between agronomic parameters for soybean at second cropping

Parameters	Plant Height	Leave Area	Number of Leaves	Stem Girth
		Ordinary Compost (C)		
Plant Height	1			
Leave Area	0.771*	1		
Number of Leaves	0.861**	0.702*	1	
Stem Girth	-0.075	-0.134	0.024	1
		Synthetic Fertilizer (SC)		
Plant Height	1			
Leave Area	0.500	1		
Number of Leaves	0.881**	0.315	1	
Stem Girth	0.107	0.488	0.068	1
		Plant Based (PB)		
Plant Height	1			
Leave Area	0.533	1		
Number of Leaves	0.676*	0.838**	1	
Stem Girth	0.793*	0.260	0.433	1
		Animal Based (AB)		
Plant Height	1			
Leave Area	0.772*	1		
Number of Leaves	0.854**	0.739*	1	
Stem Girth	0.123	-0.278	0.226	1
		Rock Based (RB)		
Plant Height	1			
Leave Area	0.018	1		
Number of Leaves	0.856**	0.092	1	
Stem Girth	-0.042	0.698*	0.112	1
		Organic Mixture (OM)		
Plant Height	1			
Leave Area	0.037	1		
Number of Leaves	-0.231	0.406	1	
Stem Girth	-0.230	-0.316	-0.084	1

***Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).**

KEY: Plant Height (cm); Leave Area (cm^2); Stem Girth (cm)

CHAPTER FIVE

DISCUSSION

5.1 Chemical Composition of Soil and Fortifiers

The soil taken from the farm plot had low nitrogen content due to a high level of sand and low level of silt contents that are usually rich in humus, natural source nitrogen in the soil. The capacity to produce plant biomass remains an essential function of the soil productivity. This function depends on nutrient status of the soil, the amount of clay materials, among others (Alley and Vanlauwe, 2009). Among all the fortifiers, blood and bone had the least quantity of heavy metals: Lead (Pb), Manganese (Mn), Nickel (Ni), Zinc (Zn), and Cadmium (Cd) and highest concentration of Iron (Fe). The reason could be due to the fact that animals including humans have threshold levels of these chemicals beyond which they may not remain alive (Veeken and Haneters, 2002). In addition, Fe is a major component of food taken by animals. According to Li et al. (2007), application of organic matter increased concentration of Fe in the soil. All the fortifiers increased nutrient and heavy metal levels of the compost after the fortification with reference to macro nutrients: Carbon (C), Nitrogen (N), Phosphorus (P), and Potassium (K).

The primary nutrients required by microorganisms for growth are: C, N, P, and K (Tchobanoglouse et al., 1993). The C and N play the most important role in the composting process: C is used by microorganisms for energy and growth while N is needed for protein and production (Metcalf and Edd, 2003). Neem and horn had the highest quantity of Cu. The presence of high Cu content in the compost confirmed their high molecular weight humic acid generally found in soil with well-decomposed organic matter (Prechthai et al., 2008) which reduces the bioavailability of the heavy metal and its toxicity in plant (Inaba and Takenaka, 2005).

5.2 Chemical Characteristics of Organically Fortified Fertilizers (OFFs)

There was no significance difference in the nutrient composition of the compost fortified with different nutrient rich organic materials when compared to chemical fertilizer. This was a clear indication of an effectiveness of formulation which raised the nutrient composition of the compost to the status of synthetic chemical fertilizer. This observation conforms to findings of previous researchers (Mayer et al., 2008: Bouis et al., 2011: Thavarajah and Thavarajah, 2012). As reported by Fang et al. (2008), the goal of compost fortification is not only to increase yield of crops and their qualities, but also to meet the demand for minerals required by humans. Compost contained the highest level of Zn. In composting process, Zn and Pb are significant contaminants. According to Mariachiara et al. (2005), at the end of composting process the concentration is 2.6 times the initial value for Zn and 1.6 times the initial value for Pb. Another researcher reported that application of compost increased Mn, Cu and Zn contents of the soil but lowered Fe content (Courtney and Mullen, 2008).

5.3 Chemical Binding Forms of N, P, and K in OFFs

Performance of fertilizers on the agronomic parameters of plants has a relationship with nutrient binding forms. Therefore, in fertilizer analysis, in addition to estimating total nutrient content, it is necessary to estimate the forms of nutrients and other associated compounds in order to assess their quality properly. Those fertilizers with nutrient forms that are available to plant in neutral pH condition of soil performed better than those that are available to plant in acidic pH (Johannes, 2000). In this study, AB, RB and OM formulations had highest levels of NH_4-N (ammoniacal) and NO_3-N (nitrate) which could be readily available to crops. These probably influenced the formulations' good performances on agronomic data. Other N forms: NO_3-N (nitrate), Urea-N (amide) and organic N were also detected at small concentrations.

According to CalRecycle (2004), only a small proportion of nitrogen is directly available to plants initially and the remainder being mineralised and released only over time (3 – 4 years). That is, in total, approximately 40 % of all nitrogen contained in compost at the time of application will become available to plants. Also, according to Reza-Bagheri et al. (2011), the quantity and forms of nitrogen in soils is constantly changing due to biological, chemical, and physical processes. A phosphatic fertilizer may have water-soluble, citrate-soluble, water-insoluble or citrate-insoluble forms of phosphate. The major differentiating factor is the availability of P. The RB contained highest levels of water soluble and neutral ammonium citrate soluble. Water soluble form can be used immediately by plants (Johannes, 2000). However, approximately 20 % of phosphorus in compost react like P in mineral fertilizers and are immediately available for plant uptake while the remainder is more strongly bound and will become available later.

Soil phosphorus exists in bound or dissolved inorganic or organic form. The organic forms of P are the compound of phytins, phospholipids, nucleic acids and inositol phosphates while the inorganic forms are the compounds of Ca, Fe, Al and F (Brady, 2001). According to Khosro and Asad (2015), soils have a high reserve of total phosphorus accounting for about 0.05% of soil content on average; however, only 0.1% of the total P is available to plants. Phosphorus besides nitrogen is one of the most important elements in crop production. It makes up to about 0.2% of plant dry weight. It has a role in plant metabolism such as cell division, development, photosynthesis, breakdown of sugar, nuclear transport within the plant, transfer of genetic characteristics from one generation to another and regulation of metabolic path ways (Khosro and Asad, 2015).

As with any of the fertilizer products, especially those with varying analysis, availability coefficient should be used to determine the available P as a part of the reported total P. Phosphorus from manure or sludge should be comparable to P from inorganic fertilizer. Therefore, if a producer has a P recommendation for 30 lbs/A of P_2O_5, applying approximately 65 lbs of 18-46-0 (DAP) or 6 tons of 11-6-9 (manure, 80% available P coefficient) should provide equivalent results (George et al., 2002).

5.4 Seed Germination Toxicity Test

The average Germination Index (GI) values observed at different rates of application of different OFFs were higher than the minimum limit of 80 in the standard compost (TACFS, 2005). This means that the formulations were relatively safe. However, synthetic compost formulation was found toxic to soybean at 3.0 tons/ha rate of application. These results signified the complete degradation of organic matter in the formulations, assuring their safety of the formulations to be applied as fertilizers (Prechthai et al., 2008). Results also signified that the lower the quantity of compost formulation the safer the test crops will become. Benth et al. (2009) carried out a study on the effects of lead and cadmium on seed germination, seedling, root, shoot length and seedling dry biomass of *Albizia lebbeck* and concluded that Lead and cadmium treatments at 10, 30, 50, 70 and 90 μmol/L affected seed germination and seedling growth of *A. lebbeck* as compared to control. In this study, worm casts were predominant in AB and RB plots, followed by OM, PB and C; and very little worm cast was observed in SC plots. This suggested different levels of phyto-toxicity. The worm cast improves the quality of soil and may enhance the performance of OFFs. According to various recent researches (Reddy et al., 2013; Samoraj and Chojnacka, 2013: Tuhy et al., 2013), germination test is carried out to observe the fertilizing ability of formulations on living organisms, including plant and microbes in the soil.

5.5 Residual Potential of Chemical Contents of OFFs

All the fertilizers increased nutrient and heavy metal levels of the soil after plantation. Control plot retained highest levels of TN and P in the maize, yam and soybean plots simply because the nutrients were not in the form that could be readily absorbed by the plant roots. Apart from the Mn, other heavy metals were almost found at zero level. The high values of Mn were due to its initial levels in the soil and compost used for fortification. Generally, organic fertilizer has binding site to immobilize heavy metals, leading to highest values exhibited by SC in maize and yam plots. However, the factor that was responsible for the disparity in soybean plot is yet to be understood. Also, the presence of high molecular weight humic acid generally found in soil with well-decomposed organic matter reduces the bioavailability of heavy metal and its toxicity in plant (Inaba and Takenaka, 2005), making them to be retained in the soil.

5.6 Effect of Fertilizer on the Agronomic Parameters of Crops

From the results, it could be seen that effects of the formulations on the agronomic data were crop specific; and the agronomic parameters were also formulation specific. The formulation had selective activities on type of crop and parameters. The reasons could be associated with different environmental, chemical (including, toxicity and binding forms of formulation) and genetic factors of a crop. In selecting any type of the OFFs, one should consider which part of a plant is given more priority: leave area, plant height etc. In an experiment conducted by Ayoola and Makinde (2008) to assess the growth and yield of maize with nitrogen-enriched cow dung, the plants were comparable in height and leaf area with those grown with inorganic fertilizer. It was found that application of organic fertilizer improved growth and yield of bean plants compared with those amended with mineral fertilizer (Fernadez-Luqueno et al., 2010)

Pathak et al. (2002) conducted a long term manorial trial to evaluate the efficacy of organic sources; i.e. farmyard manures, rice straw in organo-inorganic combinations, in the maize-wheat cropping system. Growth parameters, yield attributes, yield and economics of maize were optimum in the substitution of 25 % of the recommended dose of fertilizers. The pattern of crop development shown in the graph suggested that the formulations have residual effects on their respective plots. Maize stem girth reduced at maturity and the maize leaf number was constant at the appearance of husk because there was no more growing of the plant, stoppage of leave development and folia covering of the stem, making the stem thinner at maturity.

Furthermore, in testing the effects of organic fertilizer on agronomic data, Satyanarayana et al. (2002) conducted a study to evaluate the influence of application of farmyard manure in combination with three levels of N: P_2O_5 : K_2O chemical fertilizers (80:40:30, 12:60:45 and 160:80:60 kg/ha) on yield of irrigated lowland rice. The results showed that application of farmyard manure at 10 t/ha increased grain yield of rice by 25 % compared to the control. Similar observations were also made on straw yield, tiller number and filled grains per panicle and 1000-grain weight. Francesco and Lionello (1992) carried out trials for five years, on two typical kinds of soil in the Northeast of Italy. A maize crop was applied with: two rates of mineral fertilizers, three rates of municipal solid wastes plus sewage sludge compost, or two rates of a mixture of compost plus mineral fertilizers. From the agronomical point of view, the basic difference between the two kinds of fertilization, observed for both soils, showed that growth responses to inorganic fertilizers didn't provide a maximum, whereas those related to compost application showed a maximum in correspondence.

5.7 Effect of Different Rate of OFF Application of the Test Crops

Apart from type of OFFs, chemical forms and toxicity, another major factor that affected the plant growth was rate of application of OFFs. That is, plant growth performance is also rate specific.

Kolade et al. (2005) carried out a study in which palm kernel waste was converted into compost using goat manure and poultry droppings as nitrogen supplements. The results indicated that the composts can be applied at 4 tons/ha to obtain yields comparable to those of organo-mineral fertilizer and chemical fertilizer which are popular among Nigerian farmers. In a study, Bolanle et al. (2010) compared effect of finished compost obtained from Ayeye Waste Sorting Centre in Ibadan, Nigeria that was amended with N and P (Organo-mineral fertiliser) and NPK fertilizer (15:15:15) on maize and other vegetable crops grown on demonstration plots. The NPK fertilizer gave a lower yield (5.40 t/ha) to that of organo-mineral fertilizer (6.06 t/ha) when applied at a rate of 1.5 t/ha.

In another similar study, Adediran, et al. (2004) evaluated the influence of five rates each of compost, inorganic fertilizer and combination of both fertilizers on maize at Ilora in the derived savanna and Ibadan in the forest zones of Nigeria. Application of fertilizers led to increases in maize grain yields and improved the nutrient element concentrations in maize leaf tissue. According to Saïdou et al., (2003), application of about 1.9 t/ha dry matter of mulch of *Senna siamea* combined with 30 kg N/ha, 22 kg P/ha and 25 kg K/ha as compound fertilizer was compared with 60 kg N/ha, 43 kg P/ha and 50 kg K/ha as compound fertilizer alone, mulch of *S. siamea* alone (about 3.2 t/ha dry matter), and a control treatment. Criteria were soil properties, yields, nutrient uptakes, and nutrient budgets. Application of sole mulch had no significant effects ($P>0.05$) on maize yields, while combined application of prunings and NPK fertilizers or sole NPK increased yields significantly ($P<0.05$).

5.8 Effect of Seasonal Variation on Agronomic Parameter of the Test Crops

Almost all the agronomic parameters measured increased markedly in the rainy than dry season. This could probably be due to the fact that organic fertilizer depends on soil microbes which are living organisms for bio-mineralization, growth conditions, cultural practices and soil characristics (Below, 2001), seasonal variation and changes in weather conditions should predict the performance of microbes and consequently, level of bio-mineralization of organic fertilizer (CalRecycle, 2004). According to Obiokoro (2005), climate is one of the physical factors which determine the nature of the natural vegetation, the characteristics of the soils, the crops that can be grown, and the type of farming that can be practiced in any region. In a related study that dealt with the response of *Dioscorea alata* to NPK-Ca fertilization as affected by differences in weather conditions in two growing seasons. Hgaza et al. (2010) conducted experiments in the central Côte d’Ivoire in 2006 and 2007. The dose of 160-10-180-110 kg/ha of NPK-Ca, respectively was compared to the control (no fertilizers applied). Growth parameters and weather conditions were measured during the growth periods. They found out that fertilization significantly increased the tuber yield of both years.

The most important climatic elements for crop growth and yield are radiant energy, or solar radiation, temperature and water or rainfall (Ekaputa, 2004). Solar radiation in turn determines the thermal characteristics of the environment, namely net radiation, day-length or photoperiod, the air and soil temperatures (Danjuma, 2004). Soil and air temperatures affect the developmental stages more than any other factor (Ayoade, 2002). Of the two, soil temperature is a better indicator of energy condition required for crop development and yield than air temperature (Song, 2003). In addition, temperature and wind determine the state of soil moisture, and the rate of evaporation (Okpemuoghor, 2005). In order to determine the optimum microclimatic condition for crops' growth and yield, various soil surface modification systems such as mulching and ridge construction were used in the plot experiment during this study.

5.9 Fresh Yield of Crops Applied with OFF at the First and Second Cropping Seasons

Generally, formulations showed more effects on crop yield during the first cropping (rainy) than the second (dry) season. However, the yield in maize during the dry season far outweighed that of rainy season; when RB was applied at 2.0 ton/ha. This observation may also suggest seasonal specificity for OFFs. There are many researches on the effect of organic fertilizer and crop yield. Loeeke et al. (2004) reported that composted manure increased corn grain yield more than fresh manure. Jayaprakash et al. (2003) conducted a field experiment to determine the effect of organic and inorganic fertilizers on the yield and yield attributes of maize under irrigated condition. The treatments consisted of compost at 2 t ha-1 and 5 levels (100, 125, 150,175 and 200 %) of the recommended dose of chemical fertilizers (150:75:37.5 kg NPK/ha). Significantly highest grain yield was obtained with application of compost at 2 t/ha, similar to what obtained for RB during dry season in this study.

The tuber yield responses to OFF application in this study are contrary to the findings of Sotomayor-Ramirez et al. (2003). The lack of tuber yield responses in their studies might be due to pest and diseases or the closeness of fertilized and non-fertilized plots as the length of roots can reach 5.5 m (O'Sullivan, 2008). Organic manure can serve as alternative practice to mineral fertilizers (Wong et al., 1999; Naeem et al., 2006) for improving soil structure (Dauda et al., 2008) and microbial biomass (Suresh et al., 2004). Therefore, utilization of locally produced manures by vegetable production operations may increase crop yields with less use of chemical fertilizer. The use of chemical fertilizers alone to sustain high crop yield has not been quite successful due to enhancement of soil acidity, nutrient leaching and degradation of soil physical and organic matter status (Nottidge et al., 2005).

5.10 Relationship between Agronomic Parameters of Maize and Soybean

Correlation between one parameter and others existed in this study during the two planting seasons. This may be a clear indication that a formulation may be chosen for dual or multiple purposes. However, the observation in soybean parameter correlation was almost in opposite direction to what was obtained in the maize. This disparity might be a consequence of specific nature of OFF application to different crops. In general, good knowledge of correlation between parameters will lead to reduction in financial cost that could have been used in obtaining two or more types of OFFs for each targeted parameter instead of obtaining a single one with dual or multiple purposes.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Chemical fertilizers have potentials to pollute the environment and damage soil, animals and humans who may eat contaminated plants even at low concentration. This study has showed that composted market organic waste enriched with nutrient-rich naturally available materials performed better than the organo-mineral fertilizer on the three crops (maize, soybean and yam) selected for this study in terms of key agronomic parameters and better crop yield.

The study also clearly demonstrated that composts can be fortified with nutrient rich natural materials and applied at two tons/ha to obtain yields of the three crops comparable to those of organo-mineral fertilizer and chemical fertilizer which are popular among Nigerian farmers. However, apart from yield, rate of application had no effects on other agronomic performance of maize from germination period to maturity.

Seasonal variation had strong effects on the crop development and yield of the crops applied with different formulations. All parameters showed better performances for maize when applied with all the formulations and there was an improved effect of the formulations on yam leave area when applied with rock based formulation (RB) during the rainy season (i.e first cropping). All the formulations had no effects on agronomic values of maize from first week to maturity at second cropping season. Meanwhile, soybean had the higher yield during the dry season (second cropping).

Chemical forms of macronutrients, phyto-toxic effects of formulations and nutrient residual levels had effects on the agronomic performance of the test crops. The lower the quantity of compost formulation the safer were the test crops.

It was observed that effects of the formulations on crops and crop growth parameters, nutrient binding forms, rate of application, cropping season and toxic effect of formulation were crop specific.

Finally, a formulation performed dual or multiple purposes. That is, a single formulation could enhance both plant height and leave area development simultaneously. Hence, in selecting any type of the organic fertilizer formulation, one should consider which part of a plant is of priority, viz leave area, plant height etc., before selecting the formulation to reduce financial cost.

6.2 Recommendations

Based on the findings of this study, the following recommendations are therefore proffered:

i. Chemical and synthetic fertilizers which are potentially harmful to the environment and public health should be replaced by fortified organic fertilizer that is more environmental friendly
ii. Compost manufacturers, farmers and other end users of compost should be trained on how to make different compost formulations to reduce their over dependency on the synthetic fertilizers
iii. There is need for more researches on compost quality improvement for crop production, food security and better environmental sanitation
iv. Effective control of compost production should be intensified at material recovery plants through operators' capacity building
v. There should be replication of compost facilities across the country to reduce the menace of organic waste in the environment
vi. Fortification of compost with natural materials which are readily available and environmentally friendly should be promoted among the farmers, horticulturists and organic fertilizer manufacturers

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APPENDICES

APPENDIX A: SUPPLEMENTARY RESULTS

Table A. Chemical composition of organic fortifiers

Sample		Nutrient Composition							Heavy Metal Composition			
		TN	**P**	**K**	**S**	**Na**	**Ca**	**Mg**	**Mn**	**Fe**	**Cu**	**Zn**
Blood	I	8.62	0.21	0.04	0.03	7.50	1.69	0.13	1.44	3.71	0.75	0.84
	II	8.42	0.26	0.02	0.06	7.20	1.71	0.14	1.42	3.70	0.76	0.80
Bone	I	2.78	22.00	0.08	0.05	4.82	3.87	0.88	1.20	4.34	1.43	3.71
	II	2.80	22.01	0.05	0.03	4.84	3.89	0.85	1.19	4.33	1.44	3.70
Compost	I	3.90	2.49	0.50	0.07	3.75	2.00	1.74	1.22	4.39	2.50	9.96
	II	3.80	2.45	0.53	0.06	3.72	2.00	1.73	1.24	4.37	2.51	9.98
Cotton	I	9.23	12.2	0.16	0.04	1.08	0.53	0.25	1.04	5.70	6.54	2.09
	II	9.20	12.0	0.17	0.05	1.09	0.50	0.24	1.02	5.69	6.55	2.10
Feather	I	8.30	0.13	0.08	0.05	1.33	1.64	0.23	2.34	2.16	9.06	8.96
	II	8.32	0.12	0.07	0.03	1.32	1.62	0.21	2.32	2.15	9.05	8.97
Fish	I	4.32	0.38	0.13	0.07	4.99	5.28	0.36	8.88	5.22	2.38	3.09
	II	4.30	0.36	0.12	0.06	4.97	5.29	0.38	8.90	5.24	2.36	3.08
Horn	I	8.53	0.17	0.03	0.05	1.18	0.42	0.22	5.08	3.74	9.80	8.43
	II	8.55	0.16	0.02	0.04	1.18	0.43	0.24	5.09	3.76	9.81	8.46
Hair	I	9.39	0.12	0.02	0.04	6.02	0.08	0.08	2.62	4.21	3.84	5.74
	II	9.36	0.10	0.03	0.03	6.03	0.07	0.07	2.64	4.20	3.83	5.72
Hoof	I	3.24	0.21	0.06	0.04	1.82	5.15	0.47	1.45	2.49	7.18	5.70
	II	3.22	0.23	0.07	0.02	1.83	5.14	0.45	1.46	2.48	7.17	5.72
Organic	I	9.60	27.0	0.19	0.07	6.48	2.67	0.39	8.00	5.80	4.56	1.16
mixture	II	9.61	26.0	0.16	0.05	6.47	2.69	0.38	8.01	5.82	4.54	1.16
Neem	I	9.60	0.13	0.51	0.04	11.12	2.80	0.26	4.74	3.59	1.72	3.87
	II	9.79	0.12	0.53	0.03	11.13	2.81	0.25	4.75	3.60	1.71	3.85
PKC	I	2.89	0.19	0.12	0.05	1.21	0.08	0.56	4.40	1.56	9.68	3.26
	II	2.88	0.17	0.13	0.07	1.22	0.06	0.54	4.38	1.54	9.65	3.27
PKS	I	2.10	0.19	0.02	0.05	11.90	3.25	0.13	8.04	5.95	1.98	1.16
	II	2.18	0.20	0.01	0.07	11.91	3.23	0.14	8.04	5.97	1.96	1.18
Phosph-	I	2.10	17.72	0.01	0.05	0.37	1.39	3.81	5.20	3.50	6.20	2.06
ate Rock	II	2.11	17.70	0.02	0.07	0.36	1.41	3.80	5.19	3.52	6.21	2.04
SSP	I	1.90	29.97	0.00	0.01	2.88	0.06	0.01	N.D	2.18	N.D	1.96
	II	1.92	29.96	0.01	0.02	2.89	0.05	0.00	N.D	2.19	N.D	1.95
Urea	I	29.00	0.22	0.01	0.06	4.88	0.07	0.06	3.72	6.49	7.51	1.04
	II	29.01	0.20	0.03	0.04	4.85	0.06	0.05	3.70	6.51	7.50	1.05

Table B. Chemical composition of fertilizers

Parameters	C	SC	PB	RB	AB	OM
TN (%)	3.21±0.0	6.15±0.0	5.69±0.0	5.85±0.0	5.74±0.0	6.05±0.0
P ,,	0.7±0.1	0.2±0.0	0.3±0.0	0.2±0.0	0.5±0.0	0.8±0.0
K ,,	0.9±0.0	0.4±0.0	0.5±0.0	0.4±0.0	0.7±0.0	1.0±0.0
OC ,,	32.8±0.21	28.4±0.2	33.2±0.0	27.7±0.1	38.4±0.2	34.8±0.0
Mg (mg/kg)	0.3±0.0	0.3±0.0	0.3±0.0	0.2±0.0	0.2±0.0	0.4±0.0
Ca ,,	1.2±0.0	0.6±0.0	0.6±0.0	0.7±0.0	0.6±0.2	2.1±0.1
Na ,,	0.4±0.1	0.3±0.0	0.4±0.0	0.3±0.0	0.5±0.0	0.3±0.0
S (%)	0.1±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.1±0.0
Mn (Mg/kg)	98.2±0.1	32.2±0.6	48.4±0.1	21.4±0.2	18.4±0.2	96.4±0.2
Fe ,,	713.5±0.1	628.6±0.2	718.5±0.1	390.4±5.9	876.4±0.2	678.3±0.1
Cu ,,	33.4±0.212	17.0±0.4	16.0±0.2	17.4±0.1	19.1±0.2	29.7±2.1
Zn ,,	118.5±0.2	56.4±0.1	67.4±0.2	47.4±0.2	39.1±0.3	124.5±0.3
Pb ,,	10.7±0.2	6.5±0.4	5.1±0.3	3.7±0.1	8.8±0.2	11.4±0.3
Ni ,,	12.8±0.2	9.6±0.4	11.5±0.1	7.9±0.4	7.0±0.4	13.4±0.1
Cr ,,	11.60±0.1	5.4±0.2	6.6±0.1	8.6±0.2	9.4±0.1	11.0±0.3
Cd ,,	0.7±0.0	0.5±0.0	0.7±0.0	0.6±0.0	0.7±0.0	0.9±0.0

Table C. Residual chemical composition of fertilizers in maize plot (%)

Parameter	C		SC		PR		RB		AB		OB	
	I	II	I	II	I	II	I	II	I	II	I	II
TN ,,	18.38	20.25	12.84	16.75	19.14	18.46	14.54	16.03	21.60	20.38	18.63	19.51
P ,,	43.66	52.11	15.97	14.83	14.47	15.75	22.75	21.89	17.70	17.08	16.49	18.29
K ,,	158.5	160.6	815.00	795.00	500.00	490.32	695.24	676.19	312.00	304.00	198.81	196.43
OC ,,	7.69	8.15	620.00	633.33	498.00	514.00	532.50	570.00	379.17	370.83	234.61	243.27
Mg ,,	123.33	146.67	1.16	1.09	0.84	0.78	0.65	0.83	1.22	1.33	1.41	1.52
Ca ,,	2.95	25.41	150.00	139.28	144.00	136.00	204.54	195.45	233.53	200.00	114.28	122.86
Na ,,	45.00	55.00	26.67	23.33	33.33	51.67	43.08	38.46	46.77	50.00	16.19	17.07
S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mn (Mg/kg)	9.78	9.47	87,000.00	91,000.00	28,000.00	29,000.00	30,250.00	30,750.00	39,667.00	40,333.00	14,000.00	15,136.00
Fe ,,	0.36	0.37	8.48	8.35	5.80	5.87	13.63	13.49	16.08	16.62	3.28	3.26
Cu ,,	0.69	0.75	0.06	0.06	0.06	6.40	0.12	0.13	0.06	0.06	0.08	0.08
Zn ,,	4.14	4.30	27.14	24.78	33.23	29.47	32.18	33.91	33.07	32.02	22.26	24.62
Pb ,,	3.19	2.91	0.64	2.30	0.64	0.67	1.08	1.12	1.25	12.02	0.44	0.47
Ni ,,	24.31	26.67	65.12	56.36	47.06	4.01	89.19	100.00	24.00	20.57	13.16	16.67
Cr ,,	13.79	16.38	33.51	21.99	13.04	11.30	14.01	17.83	35.97	37.41	23.13	25.37
Cd ,,	10.00	7.14	0.56	0.75	0.15	0.76	0.70	0.35	0.11	0.32	0.54	0.27

Table D. Residua chemical composition of fertilizers in soybean plot (%)

Parameters	C		SC		PR		RB		AB		OB	
	I	II	I	II	I	II	I	II	I	II	I	II
TN ,,	21.49	23.98	13.97	14.80	9.03	10.08	10.90	12.39	13.76	15.50	19.86	17.05
P ,,	25.35	21.13	7.97	63.12	2.25	1.67	6.01	10.30	9.93	8.69	11.34	12.03
K ,,	126.60	123.40	590.0	605.00	358.06	351.61	600.00	585.71	274.00	288.00	167.86	165.48
OC ,,	7.27	7.36	96.75	94.95	392.00	384.00	642.50	665.00	380.55	390.28	275.00	280.77
Mg ,,	26.67	36.67	368.55	0.53	0.18	0.24	0.65	0.83	0.68	0.76	0.54	0.69
Ca ,,	18.85	20.49	75.00	67.85	44.00	52.00	122.73	118.18	129.41	117.65	65.71	60.00
Na ,,	30.00	22.50	13.33	10.00	11.67	15.00	16.92	23.08	20.97	25.81	5.36	6.83
S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mn (Mg/kg)	11.51	11.72	4.20	47,000.00	16,750.00	18,000.00	20,750.00	19,750.00	24,667.00	23,667.00	98,5667.00	94,277.0
Fe ,,	0.34	0.35	5.19	5.31	6.61	7.23	12.50	12.32	13.68	13.84	2.72	2.75
Cu ,,	4.78	0.54	0.02	0.01	0.03	0.03	0.09	0.08	0.04	0.04	0.06	0.60
Zn ,,	6.42	6.67	31.27	32.44	57.05	58.31	37.36	39.08	37.27	38.32	27.65	28.67
Pb ,,	2.35	2.67	0.38	0.32	0.52	0.56	0.48	0.55	0.79	0.84	0.33	0.31
Ni ,,	18.04	31.76	31.00	26.35	52.94	56.86	83.78	89.19	32.00	36.57	30.70	28.95
Cr ,,	15.52	13.80	11.52	13.61	18.27	20.00	37.39	30.57	37.41	33.09	21.64	23.13
Cd ,,	18.57	15.71	1.49	0.93	1.67	2.12	1.87	1.53	1.17	0.85	0.54	0.81

Table E. Fresh yield (number of pod) of soybean at first cropping (rainy) season

	C			SC			PB			AB			RB			OM		
Replicate	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**
R1	35	15	2	150	22	15	25	250	8	260	12	28	30	25	125	160	12.5	4
R2	8	60	40	7	25	25	50	55	5	70	325	75	2	132.5	37.5	75	8	3
R3	10	12.5	27	30	70	90	30	78	10	230	10	20	175	37.5	125	45	5	3
Mean	**17.7**	**29.2**	**23**	**62.3**	**39.0**	**43.3**	**35**	**127.7**	**7.7**	**186.7**	**115.7**	**41.0**	**69**	**65**	**95.8**	**93.3**	**8.5**	**3.3**

(Average weight of a pod = 0.7g)

Table F. Fresh yield (mean number of pod) of soybean at second cropping (dry) season

	C			SC			PB			AB			RB			OM		
Replicate	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**
R1	100	50	25	25	100	50	175	50	175	75	75	125	125	50	50	25	100	200
R2	25	100	50	200	175	100	150	250	125	150	300	200	100	100	100	125	25	150
R3	10	150	75	200	125	100	50	225	150	100	125	175	100	25	125	100	150	200
Mean	**45.0**	**100.0**	**50.0**	**141.7**	**100.0**	**83.3**	**125.0**	**175.0**	**150.0**	**108.3**	**166.7**	**166.7**	**108.3**	**58.3**	**91.7**	**83.3**	**91.7**	**183.3**

Table G. Fresh yield of maize at first cropping season

	C			SC			PB			AB			RB			OM		
REPLICATE	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**
									Length of Fruit (cm)									
R1	25	29	-	30	30	26	28	30	31.5	33	27.5	30	29	28.5	28	26.5	28.5	28.5
R2	-	-	29	28	37	31	29	31	25	32	24	32	29	29	23	29.5	28.5	37
R3	29	23	30	30	27	29.5	31	29	29.5	30	31.5	29	29	25	28.5	34	33	29
M ±SD																		
									Fruit Diameter (cm)									
R1	4.5	4.3	-	5.57	4.3	5.4	5.5	5.1	5.4	5.78	5.55	5.54	5.2	5.55	4.96	5.4	5.3	4.5
R2	-	-	4.1	5.3	5.4	5.7	3.75	6.2	4.5	5.8	5.75	5.05	6.1	5.3	4.49	5.5	5.45	7.0
R3	5.3	4.3	5.7	5.1	5.4	4.8	5.88	4.6	4.9	5.7	6.1	5.64	5.4	6.04	4.8	5.89	5.9	6.1
M ±SD																		
									Fruit Weight (g)									
R1	150	200	265	275	200	275	300	275	275	400	275	325	425	275	450	282	225	50
R2	215	150	175	300	400	325	125	400	175	325	375	325	375	270	200	300	300	600
R3	275	100	350	250	375	200	325	200	250	300	400	300	525	375	350	375	400	325
M ±SD																		

Table H. Fresh yield of maize at second cropping season

	C			SC			PB			AB			RB			OM		
REPLICATE	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**
							Length of Fruit (cm)											
R1	-	-	26	-	-	-	25	-	23	31	25	27	26	25	-	23	27	-
R2	-	-	-	27	-	-	-	-	-	-	27	-	27	27	-	26	29	-
R3	-	-	-	-	31	-	27	26	-	27	-	27	24	-	-	-	23	-
M ±SD																		
							Fruit Diameter (cm)											
R1	-	-	3.3	-	-	-	4.1	-	3.5	5.47	4.4	4.3	4.1	4.24	-	4.34	4.41	-
R2	-	-	-	4.57	-	-	-	-	-	-	4.93	-	4.75	4.57	-	3.85	4.87	-
R3	-	-	-	-	4.82	-	5.2	4.4	-	4.7	-	4.6	4.2	-	-	-	4.6	-
M ±SD																		
							Fruit Weight (g)											
R1	-	-	125	-	-	-	485	-	125	300	225	200	275	225	-	212.5	235	-
R2	-	-	-	240	-	-	-	-	-	-	250	-	-	185	-	100	275	-
R3	-	-	-	-	230	-	-	230	-	225	-	225	300	-	-	-	175	-
M ±SD																		

Table I. Fresh yield (mean pod number) of soybean at first and second cropping seasons

Replicate	C			SC			PB			AB			RB			OB		
	2.0	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**
First cropping	17.7	29.2	23	62.3	39.0	43.3	35	127.7	7.7	186.7	115.7	41.0	69	65	95.8	93.3	8.5	3.3
Second cropping	45.0	100.0	50.0	141.7	100.0	83.3	125.0	175.0	150.0	108.3	166.7	166.7	108.3	58.3	91.7	83.3	91.7	183.3

Table J. Fresh yield (mean weight of tuber) of yam (kg)

	C			SC			PB			AB			RB			OM		
Replicate	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**
R2	3.5	1.1	4.4	1.2	4.5	2.9	0.4	1.5	3.1	3.8	2.1	2.3	3.3	3.7	2.5	4.4	2.7	2.2
R3	3.8	2.0	4.2	1.1	4.2	2.8	0.6	1.5	2.8	1.5	2.3	3.6	3.1	2.1	4.9	0.6	2.7	5.5
R3	1.4	0.5	3.5	1.7	2.0	1.6	2.6	3.9	1.6	2.4	2.2	2.0	5.4	3.4	4.6	5.0	0.6	5.5
R4	1.5	0.5	2.1	3.4	1.9	3.6	2.6	0.8	1.2	5.5	9.0	1.98	5.5	3.4	2.2	1.2	3.6	6.0
Mean	**2.6**	**1.0**	**3.5**	**1.9**	**3.2**	**2.7**	**1.6**	**1.9**	**2.2**	**3.3**	**3.9**	**2.5**	**4.3**	**3.2**	**3.6**	**2.8**	**2.4**	**4.8**

Table K. Effect of different rate of application of RB on agronomic parameter of the test crops

	Rainy season									Dry season								
	Maize			Soybean			Yam			Maize			Soybean			Yam		
	2.0	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**
LA	21.8	24.4	22.0	7.1	9.6	14.5	0.0	0.0	0.0	8.5	10.7	12.0	51.3	57.0	58.5	0.0	0.0	0.0
PH	337.6	408.5	287.3	12.5	20.0	21.6	53.1	65.1	13.7	77.6	132.0	114.3	65.1	61.0	46.4	12.4	14.5	26.6
NL	9.3	9.3	9.0	13.5	14.7	17.0	0.0	0.0	0.0	4. 7	4.0	6.0	96.7	123.0	110.7	0.0	0.0	0.0
SG	2.2	2.4	2.1	0.4	0.4	0.4	1.0	0.7	0.8	0.6	0.8	0.9	0.8	0.8	0.7	0.6	0.6	0.7

Plant Height (PH), Leave Area (LA), Stem Girth (SG), No. of Leaves (NL)

Table L. Effect of different rate of application of AB on agronomic parameter of maize and soybean

Parameter	Rainy season						Dry season					
	Maize			Soybean			Maize			Soybean		
	2.0	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**	**2.0**	**2.5**	**3.0**
LA	22.7	22.4	23.5	13.7	9.8	12.6	13.37	11.8	13.4	10.7	12.3	11.3
PH	377.4	252.7	246.5	34.0	10.3	18.8	119.7	88.8	101.1	9.5	10.7	13.1
NL	9.0	9.0	8. 7	25. 7	16.3	19.0	5.7	5.0	5.3	6. 7	8.0	8.0
SG	2.2	2.1	2.3	0.5	0.4	0.4	0.8	0.7	0.7	0.1	0.2	0.2

Plant Height (PH), Leave Area (LA), Stem Girth (SG), No. of Leaves (NL)

APPENDIX B: SUPPLEMENTARY PLATES

Plate 1. Experimental farm plot at preparatory stage

Plate 2. Experimental farm plot at week four

Plate 3. Experimental farm plot at week six

Plate 4. Date collection exercise on the farm