EFFECTS OF INTEGRATED SOIL FERTILITY MANAGEMENT TECHNOLOGY ON SOIL FERTILITY AND CROP PRODUCTIVITY OF SMALL HOLDER FARMS IN IKARA, NORTHERN GUINEA SAVANNA OF NIGERIA

BY

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DECLARATION

I hereby declare that this dissertation entitled "Effects of Integrated Soil Fertility Management Technology on Soil Fertility and Crop Productivity of Smallholder Farms in Ikara; northern Guinea savanna of Nigeria" has been carried out by me in the Department of Soil Science. The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any institution.

Chibuikem Gabriel UKAH-ONUOHA ______________ ______________

Signature Date

CERTIFICATION

This dissertation entitled EFFECTS OF INTEGRATED SOIL FERTILITY MANAGEMENT TECHNOLOGY ON SOIL FERTILITY AND CROP PRODUCTIVITY OF SMALLHOLDER FARMS IN IKARA; NORTHERN GUINEA SAVANNA OF NIGERIA by Chibuikem Gabriel UKAH-ONUOHA meets the regulations governing the award of degree of Masters of Science (Soil Science) of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Prof. I. Y. Amapu Chairman, Supervisory Committee	______________ Signature	____________ Date
Prof. E. O. Uyovbisere Member Supervisory Committee	______________ Signature	____________ Date
Prof. A. C. Odunze Member Supervisory Committee	______________ Signature	____________ Date
Prof. Ado A. Yusuf Head of Department	______________ Signature	____________ Date
Prof. Kabir Bala Dean, Postgraduate School	______________ Signature	____________ Date

DEDICATION

Dedicated to my late father and tough teacher, Chief Ignatius Chimaroke Ukah for insisting that we acquired sound education at all cost and for being an unrepentant advocate for higher education.

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ABSTRACT

Integrated Soil Fertility Management (ISFM) is the application of soil fertility management principles and the knowledge to adapt these to local conditions which optimizes fertilizer and organic resource use efficiency and crop productivity. These practices necessarily include proper fertilizer and organic input management in combination with the utilization of germplasm. The objective of the study was determined the effects of the combined application of inorganic N fertilizer with manures and the maize–legume cropping systems on the fertility and crop productivity of smallholder farms. The study consisted of three experiments; a fertilizer-manure combination experiment, a maize-legume cropping systems experiment and an N response experiment. The treatments consisted of five levels of inorganic N fertilizer (0, 30, 60, 90.and 120 kg N ha^{-1})each combined with 2.5 t ha^{-1} sheep and goat manure except the zero, five maize legume cropping systems; soybean-maize rotation plus cowpea relay (SBMZRT), groundnut-maize rotation plus cowpea relay (GNMZRT), soybean/maize strip cropping (SBMZSP), groundnut/maize strip (GNMZSP) and a continuous maize cowpea intercrop (CTMZCPInt), and five levels of inorganic N fertilizer (0, 30, 60, 90.and 120 kg N ha^{-1}). The treatments were laid out in a randomized complete block design (RCBD) and replicated four times. The experiments were carried out in 2012 and 2013, and repeated on three smallholder farms in Pampaida, Saulawa and Fulani Sule in Ikara Kaduna northern Guinea savanna Nigeria. The results showed that compared with sole fertilizer, combined application of inorganic fertilizer with sheep and goat manure significantly increased nutrient uptake (45.74 and 71.09 kg ha^{-1} respectively), grain yield (2.89 and 5.58 t ha^{-1} respectively), both of which increased with increasing N-levels, and AEN (18.38 and 51.07 kg kg^{-1} respectively) which decreased with increasing N levels. SBMZRT, on the other hand, gave the highest grain yield (6.96 t ha^{-1}), nutrient uptake (111.58

kg ha^{-1}) and AEN (63.74 kg kg^{-1}) even though they did not differ significantly from the other maize-legume systems except the CTMZCPint which gave the lowest values (3.23 t ha^{-1}, 40.66 kg ha^{-1} and 16.5 kg kg^{-1} respectively). Application of 90 kg N ha^{-1} when combined with 2.5 t ha^{-1} sheep and goat manure resulted in significantly higher SMBN (21.67 mg kg^{-1}) and lowest C/N ratio (7.25), while 120 kg N ha^{-1} gave the highest SMBC in the same scenario but did not significantly differ with 90 kg N ha^{-1} when compared with other N levels. Combined application of inorganic fertilizer with sheep and goat manure proved to be more profitable (VCR = 3.06) than the sole fertilizer application (VCR =1.9).maize rotation with legumes are more profitable, returning higher value per unit cost invested than maize/legume strip cropping. There was however no significant difference between them, and they were all significantly better than the continuous maize cowpea relay. The information obtained indicates that AEN is amenable to improved management practices and that the various components of the ISFM results in improvement of AEN, grain yield and nutrient uptake of maize. These options also gave high soil microbial biomass as well as represented economically profitable alternatives for smallholder farmers.

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CHAPTER ONE

1.0 INTRODUCTION

In recent years, the trend of agricultural productivity in the sub-Saharan Africa has declined drastically owing to decreasing conditions of soil fertility and crop productivityin the region, particularly the northern Guinea savanna (NGS) of Nigeria. The zone is dominated by smallholders (70%), whose average of 5 ha of cultivated land accounts for 90 percent of total farm output (NAIP, 2010). This area of land is continually decreasing per farmer as a result increasing population, leading to intensive cultivation, soil nutrients depletion and reduced crop productivity.

Major crops cultivated in the area are cereals and legumes, maize being the most prominent. Maize has been an important diet in Nigeria for centuries. It is cultivated mainly in the rainforest and guinea savanna zones of Nigeria. From a subsistent cropcenturies back, maize has now risen to a more important and commercial crop on which many agro-based industries depend for raw materials. But crop productivity is still much lower in the sub-Saharan Africa (SSA) generally relative to the rest of the world as a result of low soil fertility.

Yusuf and Yusuf, (2008)identified the geological origin of parent materials from which the soils have developed which consist of old and weathered parent materials and inherently do not contain many nutrient-bearing minerals, as the fundamental problem of inherently low soil fertility in this region. But the decreasing size of land available to a farmer, due to the burgeoning populationis increasingly becoming a major factor since it has made continuous cropping inevitable. As such soil nutrient depletion on smallholder farms as observed by Sanchez and Leakey (1997) continues to cause lowper capita food production in Africa.The high soil acidity in the region which resulted from highly weathered parent materials, weathering and leaching (Obi and Ekperigin, 2001) was made worseby the continuous use of acid formingfertilizers (Ayeni, 2010). The inability of smallholder farmers to access better sources of mineral fertilizers and improved seeds due to high costs, and other socio-economic factors are also leading to low crop productivity.

Some of the approaches that have been explored in tackling these problems as x-rayed by Vanlauwe *et al*., (2006) have now evolved as paradigms with improved knowledge leading from one paradigm to another. These paradigms include; the external input paradigm of 1960s and 70s, the organic input paradigm of the 1980s, the Sanchez's second paradigm of the 1990s and currently the ISFM paradigm. Preceding these soil fertility management paradigms was the use of animal manure, a practice which became common since the 1930's. But these paradigms recorded limited success becauseof shortfalls in infrastructure and supply of fertilizers and excessive amount of land and laborneeded to produce adequate amount of organic matter, among others. Yet proper maintenance and management of soil organic matter (SOM)remain central to sustaining soil fertility on smallholder farms in the sub-Saharan Africa (Woomer and Swift, 1994), especially since soil organic matter contributes to greater efficiency of fertilizer use (Dudal and Roy, 1995; Rosen., 2003). Although mineral fertilizers have recorded increased crop yields in this region in the past, in addition to recording yield decreases in more recent times, research results show that continuous cropping and fertilization with inorganic fertilizers have impaired many soil properties (Yusuf and Yusuf; 2008).

Therefore integrated soil fertility management (ISFM) which involves the combined application inorganic fertilizer and manure, innovative maize-legume integration, and the use of improved germplasm has been proposed as a more sustainable means of alleviating the soil fertility and crop productivity constraints of the sub-Saharan Africa. Sanginga and Woomer, (2009) defined ISFM as the application of soil fertility management principles and the knowledge to adapt these to local conditions which maximize fertilizer and organic resource use efficiency and crop productivity. These practices necessarily include adequate fertilizer and organic input management in combination with the utilization of improved germplasm.

Combining inorganic fertilizer addition with locally available organic inputs while retaining or enriching crop residues and increasing maize yields, improves nutrient use efficiency and protects soil quality (Sanginga and Woomer, 2009).Soil microbial biomass carbon (SMB_C) and nitrogen (SMB_N) which are indicators of soil microbial activities are an important parameters that measure soil quality. Innovations in maize-legume intercropping systems permit more productive intercropping with groundnut, soybean and other high-value food legumes like cowpea that are otherwise not intercropped with maize because of excessive shading (Woomer *et al.*, 2004).Besides improved profit and increased income, these maize-legume systems serve as entry point to several practices relating to ISFM, including improved fertilizer use efficiency, increased biological nitrogen fixation (BNF), etc (Sanginga and Woomer, 2009).On its part, the introduction of improved crop varieties and modest amounts of mineral fertilizer combined with manure will improve crop yields at high agronomic efficiency (AE) of nutrient use.

1.1 Justification

The United Nations' Department for Economics and Social Affairs (UN DESA)has predicted that in the next 35 years, the world population would increase by at least 2 billion people (UN DESA, 2015), requiring farmers to grow 70% more food than they currently do on the same amount of land (IFDC, 2015). As daunting a task as this may sound, recognition is growing that fertilizer use alone may not be able to achieve the required agricultural production growth ratesneeded to reduce poverty and hunger (Murage*et al.* 2000; Kaboré and Reij 2004), and satisfy this anticipated growth in world population. But we know that increasing fertilizer and organic input use efficiency will greatly boost crop productivity, and this is why ISFM is increasingly seen in sub-Saharan Africa as a way to improve fertilizer efficiency, bolster soil quality and increase yields (Place *et al*. 2003).

The effectiveness and beneficial effects of the ISFM practices are likely to differ from place to place in the sub-Saharan Africa, due to the many heterogeneous agro ecological zones. Therefore localized experiments needed to be carried out in the northern Guinea savanna of Nigeria to come up with reliable information on ISFM practice in this region. Available reviews on the effects are general and inconclusive (Place *et al.* 2003). Hence, only limited empirical evidence exist on the potential of ISFM technology for improving crop productivity and profitability that can be used to support the arguments for its use as an alternative to high doses of fertilizers, in maintaining favorable nutrient balances and soil quality in the NGS of Nigeria (World Bank 2006).

The aim of this study therefore,was to evaluate the effects of combined application of inorganic N fertilizer with manure andmaize-legume cropping systems, on soil fertility and crop productivity of smallholder farms in Ikara, northern Guinea savanna of Nigeria.

Objectives were to;

i. compare the effects of the combined application of inorganicN fertilizer with manure and maize-legume cropping systems on the soil microbial biomass carbon and nitrogen.
ii. determine the nitrogen use efficiency of maize under a combined application of inorganic N fertilizer with manure and maize-legume systems in smallholder farms.

iii. compare thevalue cost ratio, input output ratio and output input price ratio of fertilizer use in sole fertilizer application with a combined application of inorganic N fertilizer and manure on smallholder farms.

CHAPTERTWO

2.0 LITRETURE REVIEW

2.1 The Northern Guinea Savanna

2.1.1 An overview

The moist savanna agro ecology covers the West and Central Africa which is the Guinea savanna zone, including the coastal lowland of East and Southern Africa (Odunze, 2006). The zone is divided into the northern and southern Guinea savannas and the derived savannas in the West and Central Africa. It covers an approximate area of 56 million km representing 29% of the total crop land in the sub-Saharan Africa (SSA). It has about 42% of the SSA's human population with potentials for increased crop and livestock production (Jabbar, 1996; McIntire *et al.*, 1992; Winrock, 1992).

The northern Guinea savanna has a monomodal rainfall pattern with an annual precipitation of 900-1300 mm and a growing period of 150-180 days from June to October (IITA, 1992; Tian *et al.*, 1995). The vegetation is generally dominated by fire-tender and fire-tolerant tress with an under storey of shrubs and grasses. In both the northern and southern Guinea savannas, tree covers vary from open woodland to light forest. Commonly occurring trees include *Isoberlina doka*, *Afzella Africana*, *Batryspernum paradoxi*, *Uapaca*, *Daniella oliveri*, *Terminalia,* and shrubs and grasses like *Imperata cylindrical*, *Andropogon spp.* and *Hparrchia* spp. (Kowal and Kassam, 1987; Carsky *et al.*, 1998).

2.1.2 Crops and cropping systems

In a general survey covering Nigeria, Benin Republic, Niger, Togo, Cameroon, and Burkin Faso all in West and Central Africa, 15 major cropping systems not including several others which varied from farmer to farmer were identified (Singh *et al.*, 2004). In the forest and Guinea savanna zones, cowpea is intercropped primarily with maize (*Zea mays* L.), cassava(*Manihot esculenta*), yam (*Diascorea rotundata*), groundnut (*Arachishypogea* L.) and soybean (*Glycine max* L). In the northern Guinea savanna of Nigeria, cowpea is intercropped with maize, sorghum (*Sorghum bicolor* L.) and/or groundnut. Fallow and legumes play a vital role in soil fertility maintenance. Among the legumes, cowpea is the most important for food, fodder, cash and the maintenance of soil fertility. One cereal crop may be grown in a mixture with a legume such as soybean, cowpea or groundnut. In this system, the legume is planted 3 to 6 weeks after the cereal has been planted.

2.1.3 Soils

Alfisols, Entisols, Inceptisols and Ultisols are the four major soil groups that dominate the moist Guinea savanna and they are characterized by low activity kaolinite clays with the presence of iron (Fe) oxyhydroxides which constitute 80-90% of savanna soils of Nigeria (Vanlauwe *et al.*,2002).

2.1.4 Maize production

The northern Guinea savanna of Nigeria is an important region for cereal production in the country and in the sub-Saharan Africa (SSA). Maize in Nigeria is usually intercropped, with yam, cassava, guinea corn, rice, cowpea, groundnut and soybeans (FAO, 2013).Nigeria is the 10th largest producer of maize in the world and largest maize producer in Africa (USDA 2010). The crop is grown throughout the country (both yellow and white varieties), but the northern Guinea savanna zone is the main producing area. Looking at yearly figures, of about 4.5 million tons produced in the country from 3.5 million hectares of land in 1983, the Guinea savanna accounted for 70 percent of this total production (Enwenzor*et al*., 1989). Again the North Central region accounted for an average of 31% of total national production in 2006 and 2007, 44 % in

2009 and 58% in 2008 (Cadoniand Angelucci, 2013).Interestingly, seventy percent of farmers in this area are smallholders, whose average of 5 ha of cultivated land accounts for 90 percent of total farm output (Cadoniand Angelucci, 2013). The decreasing size of land available for maize production is surely likely going to affect maize productivity. In 1984, land area under maize cultivation in Nigeria was estimated to be about 653,000 ha and it rose to about 5.4m ha in 1994, but lately decreased to 4.5m ha in 2004 (Federal Ministry of Agriculture (FMA), 2005). A number of factors are responsible for this chief among which is the growing population which has led to the continuous decline in the amount of land available to a farmer and the diversified use of land for other competing purposes.

With continuous cropping and use of fertilizer, yield of maize have averaged at 1.36 tons ha^{-1} in Nigeria. This is about 20% of the average yield obtained in North America and other intensive maize producing regions in the world (Afolami and Fawole, 1991). Meanwhile with 90 kg N ha^{-1}, the highest maize grain yield obtained by Yusuf *et al.*, (2009) over a two year period was 3.3 t ha^{-1} and 2.8 t ha^{-1} with maize-soybean rotation. These results buttress the importance of proper soil fertility management practice in maize productivity in the northern Guinea savanna Nigeria. Several researchers have reported improved maize yield after a crop of legume in this agro ecological zone (AEZ) (Kaleem, 1993; Carsky *et al.*, 1997; 1999; Sanginga *et al.*, 2002), as well as maize response to N application (Uyovbisere *et al.*, 1997; Carsky and Iwuafor, 1999; Sanginga *et al.*, 2001; Yusuf *et al.*, 2003).

2.2 Soil Fertility Challenges in the Northern Guinea Savanna (NGS) Nigeria

2.2.1 Inherent low fertility

Savanna soils have coarse-textured surfaces and are prone to severe accelerated soil erosion when unprotected, with supra-optimal soil temperature (Odunze, 2006). They experience rapid decline in soil organic matter, and reduction in biotic activities of soil fauna (Lal *et al.*, 1980), crusting and compaction (Odunze, 2006), leading to a general decline in soil quality.According to Agboola *et al*., (1992), soils in Nigeria suffer deficiencies common to tropical soils, including low organic matter content, shallow depth and high acidity. About 63% of agricultural soils in Nigeria are low in productivity and over 90% are Alfisols and Ultisols that are low in **organic matter** and have low activity clays.Most Nigerian soils are acidic due to the nature of their parent materials (Yusuf and Yusuf; 2008) which consist of old and weathered materials, and inherently low in nutrient-bearing minerals, are easily leached and easily weathered (Ano, 1990). Some researchers reported that micronutrients such as Zn, B and Cu are lacking in soils of several parts of Nigeria.In the northern Guinea savanna (NGS) ecological zone, these low-activity clays and low soil organic matter (SOM) impact low buffering capacities to the soils (Odunze, 2003), making the soils susceptible to major chemical, physical and biological limitations which reduce crop yields.Ayeni (2011) reported that as one moves from South to the North,amount of organic matter declines, which he attributed to decrease in the amount of rainfall. Generally, savanna soils have lower N status and wider C/N ratio than forest soils which greatly affect N availability (FPDD, 1990), and are also inherently low in sulphur, phosphorus and exchangeable potassium, as well as cation exchange capacity (CEC) and buffering capacity. There are moderate P fixation properties and soil reaction is acidic fertility (Odunze, 2006). Soils under savanna vegetation have higher K contents than soils in forest region (Akinrinde and Obigbesan, 2005).

2.2.2 Intensive cultivation

Soil degradation due to nutrient mining, erosion and desertification is a major threat to food production in Northern Nigeria (Balasubramanian*et al*., 1984; Singh and Balasubramanian, 1979; Bationo*et al*., 1996; Chude, 1998). Problems of declining soil fertility are widespread in SSA, largely as a consequence of continued cultivation of crops with low levels of nutrient inputs (Zingore, 2011). About 70% of Nigerian population depends on farming for their livelihood and 90% of these groups are constrained by resources (Jones and Stockinger, 1976).Apart from inherent low fertility of soils in the sub-Saharan Africa, continuous cropping is another major cause of low fertility. With intensification of cropping, the little organic matter and N in the soils are readily depleted, while phosphorus (P) and other nutrient reserves are slowly but steadily mined (Tanimu*et al*., 2013).Also Eche*et al.,* (2013)lamented that intensified maize production adversely affected soil quality particularly in the various managed ecosystems of northern Guinea savanna. Oikeh*et al.,* (2003) believe that these exploitations have resulted in serious land degradation and nutrient depletion. Nutrient balances are negative for many cropping systems, indicating that farmers are mining their soils (Yusuf and Yusuf, 2008). Estimates in the country indicate that in 1983, for a total of 32.8 million hectares of land cultivated, soil nutrient mining amounted to a total loss of 111,000 tons of nitrogen (N), 317,000 tons of P_2O_5 and 946,000 tons of K_2O (Stoorvogel and Smaling, 1990) equivalent to over US$800 million of N, phosphorus (P) and potassium (K) fertilizers.Odunze *et al*. (2012) fear that this trend coupled with application of sole urea fertilizer could alter the soil physical and chemical properties by decreasing the pH and reducing exchangeable base contents, leading to soil degradation.Little wonder then the NGS of Nigeria is witnessing a continued decline in agricultural productivity. Crop growth variability within African farming systems; most of them smallholder farms, is attributed to soil properties (Van Asten, 2003), agronomic practices (Mutsaers*et al*., 1995), farmers' resource allocation decisions (Nkonya*et al*., 2005), or combinations of these (Samake´ *et al*., 2006).The gap between potential and actual maize yields is principally caused by limiting factors such as N and P availability, and by growth-reducing factors such as striga infestation (Tittonell*et al*., 2005).Strigainfestation is frequently associated with low soil fertility (Carsky *et al.*, 2000; Schultz *et al.*, 2003), hence improved soil fertility conditions are likely to lead to reduced infestation (Debra *et al.*, 1998). The use of inappropriate tools, use of poor seed quality and inaccessibility to sufficient inorganic fertilizer quantity has continued to impoverish the soils for sustainable crop and livestock production (Sanchez; 2002, Odunze*et al*., 2012, Bundy *et al*., 2011).

2.3 Soil Fertility Management

With the current realities in the SSA particularly the Guinea savanna of Nigeria, increasing crop productivity in the region will be impossible without due attention to proper natural resource management or the fragile soil resource of the region and could impose negative consequences. It is estimated that as much as 85% of land in this region is threatened by degradation (Badiane and Delgado, 1995).The current global drive for sustainable agricultural systems that optimize use of low inputs, require close monitoring of soil quality (FAO, 1986). To achieve this, integrated soil fertility management systems; which involve combining the use of chemical amendment, biological and local organic resources; such as crop residues, green manure, biological N fixation and agro-forestry for low activity clays of the savanna soil, have been suggested (Kang and Wilson, 1987). The critical factor for success of improved farming systems seems to be the efficient recycling of organic materials (Kang and Duguma, 1985).

2.3.1 The role of organic matter

Soil organic matter (SOM) is an essential component of the soil and a measure of soil fertility, manure being its major building block. Manure is recognized as a key resource in sustaining soil fertility in the tropics, supplying the soil with a range of macro- and micro- nutrients and organic matter, making it a valuable nutrient source for crops (Alley and Vanlauwe, 2009). Manure use has been described as critical in meeting the soil fertility requirements especially for carbon and nitrogen which are limiting in the Guinea Savanna and Sudan Savanna areas (Olawale*et al*., 2011), Manure effect on soil physical properties include increased infiltration (Risse*et al*., 2006), water holding capacity (Liang *et al*., 2011; Salahin*et al*., 2011; Rasoulzadeh and Yaghoubi, 2010) and reduced compaction and erosion (Salahin*et al*., 2011). According to Kihanda*et al*. (2007), manure application is one of the most effective ways of improving fertility in tropical soils.

Generally, organic manure vary in nutrient composition depending on the source and handling procedure, supplying mainly N, P, K, Zn, Fe, Cu, Mn and B although, large quantities of animal manures would be required to produce large nutrient inputs to the soils.Organic manure sources include animal manure, crop residues, composts, farmyard manure, domestic wastes etc. Animal manure consist of partly decomposed mixture of dung and urine (Defoer *et al.*, 2000), and their nutrient contentsvary widely with animal species, age, quality of ration and feed consumption, as well as with different methods of storage and handling, housing type, temperature, moisture content, treatment and land application (Camberato*et al*., 1996; Fulhage, 2000). The cumulative N, P and K concentration of sheep and goat manure evaluated for the guinea savanna region by FAO, (2004) is presented in Table 2.1.

Table 2.1: Estimated nutrient content of the sheep and goat manure by dry weight.

Source	Nutrient concentration (g/kg)		
	N	P	K
Sheep and goat	7.9	2.0	5.0

Source: FAO,(2004).

Animal manurehas long been beneficiallyused in crop production (Schlecht*et al*., 1995; Harris *et al*., 1997) and has been an integral part of the Nigerian Guinea savanna farmers (Harris and Yusuf, 2001; Iwuafor*et al*., 2002), although theirnitrogen content is often below 2% due to the low quality of feeds which livestock receives. Organic nutrient sources, such as compost and farmyard manure, may also play an important role in replenishing soil fertility, but available quantities are limited and the quality is often very poor (Zingore 2011).Though recently there is a boost in poultry business in urban areas in Nigeria and huge poultry waste dumps are found lying waste, they are not enough and many farmers are not ready to use them(Adediran *et al*., 2003).Manyong*et al*. (2003) reported that farmers' use of manure in northern Nigeria was 485 kg ha^{-1} while Chianu*et al*., (2004) found manure application rate in northern Nigeria to be 2000 kg ha^{-1}. Overall, there is knowledge gap in the actual and potential use of manure in Nigeria (Olawale*et al.*, 2011).

2.3.2 The role of inorganic fertilizer

Inorganic fertilizers are synthetic chemical formulations that are applied to soils or plant tissues to supply one or more nutrients necessary for plant growth.Inorganic fertilizer is a convenient sourceof nitrogen and other nutrient elements for crop growth; its use is not only indispensable to alleviate nutrient constraints, but also stands central in crop production in SSA, although it is ultimately hampered by economic and environmental considerations (Sanginga and Woomer, 2009). Throughout Africa, mineral fertilizers are not available at right times during the year, mainly due to high transaction costs and inefficiencies throughout the production chain (Quiňones *et al.*, 1997). Of the potentially arable land in sub-Saharan Africa, 165 million hectare is cultivated. Approximately 1.38 million tons of fertilizer is appliedper year to cultivated lands during 2002 resulting in an average fertilizer consumption of 8.3 kg ha^{-1}. This consumption represents just 2%of worldwide demand (64.5 MT) and is by far the lowest rate of fertilizer use in Africa (Morris *et al.*, 2007). Adeleke and Haruna, (2012) reported that the inconsistencies in government policies on fertilizer subsidiary in Nigeria had led to the problem of high price of fertilizer which was beyond what a peasant farmer could afford. Other identifiable problems encountered by smallholder farmer included adulteration. When the subsidy was finally replaced, hoarding culminated in non-availability of fertilizers when needed by the farmers (Haruna*et al.*, 2011). Thus the use of commercial fertilizers to address the declining soil fertility remains minimal due to farmers' low income; which limits their ability to purchase fertilizers. Added to some of the factors identified above, lack of credit, delays in delivery due to poor transport and marketing infrastructure, and lack of know-how about their usage, have individually or jointly constrained fertilizer optimal use (Heisey and Mwangi, 1996).

Yet, researchers continue to insist that fertilizer is highly needed at the low levels of soil nutrients to reverse declining soil fertility (Olawale*et al.*, 2009; Manyong*et al*., 2001; 2002).Ologunde and Ogunlela (1984) added that for maximum maize grain yield to be realized in the northern Guinea savanna of Nigeria, addition of 120 $kgNha^{-1}$ of inorganic fertilizer is required.Many studies of farmingsystems in Africa reveal that fertilizers are used on some crops, though often only by the wealthier farmers, or on crops specifically grown for sale (Mapfumo and Giller, 2001).

It is important to note that smallholder farmers indeed appreciate the importance of fertilizer in crop production and that the contrary is not in any way the cause of low fertilizer use in this region, but the small quantities which they apply as a result of the factors identified above. For instance, results from a survey with 200 farmers in two villages in the northern Guinea savanna of Nigeria revealed that more than 90% of maize farmers use fertilizers but up to 81% of the fields receive less than half of the recommended 120 kg N ha^{-1}(Manyong*et al*., 2001). Hence it is a misrepresentation of facts to assert that 'fertilizers are not used by smallholder farmers in Africa because they are too expensive'. Such conclusions according to Vanlauwe and Giller (2006) are simplistic and hard to support.

Evaluating factors that influence adoption of fertilizers, Chianu *et al.,* (2004) found that the probability of adoption of fertilizer increases with increasing targeting of farmers from Guinea savanna zone, younger farmers, better educated farmers, and farmers who diversified into many crops. Realizing the urgent need to reverse the trend in fertilizer use, and promote food security in the continent, African leaders converged for the African Fertilizer Summit in Abuja, Nigeria in June 2006 (Roy*etal.,*2006). Among other decisions taken at the summit was a recommendation '*to increase fertilizer use from the current 8 to 50 kg* ha^{-1} *nutrients by 2015'* which reinforces the role of fertilizer as a key entry point in increasing crop productivity and attaining food security and rural well-being in the Sub-Saharan Africa (Alley and Vanlauwe, 2009). Nitrogen (N) is the nutrient most deficient in the soils and most often limits maize yield (Carsky and Iwuafor, 1995), and Kamara*et al.,* (2011) reported that availability of N fertilizers is limited for smallholder farms; implying that it will gradually become difficult for smallholder farmers to produce more than enough for their households.

The environmental problems associated with excessive use of nitrogen fertilizer is now a contentious issue, as a recentstudy showed that application of inorganic N depleted soil organic carbon and N (Adeleke and Haruna, 2012). Better management of fertilizer, which calls for increased farmer knowledge since excessive fertilizer use is a causative factor, will take care of this problems. Corresponding action include promotion of fertilizer micro-dosing, management of SOM and better integration of legumes into farm enterprises (Sanginga and Woomer, 2009), which are all part of the ISFM practices.

2.3.3 Cereal-legume cropping systems

One of the two large opportunities that exist to strengthen soil fertility management in the maize-based cropping systems of moist savanna and woodland zone is the intensification of legume cultivation. Legume enterprises may be established as either intercrops or in rotation with cereals with different legumes assuming importance within various climatic and socio-economic settings (Yusuf *et al.*, 2009a). Grain and herbaceous legumes intercropped or relayed with cereals are good sources of SOM as they produce adequate quantities of biomass and contain considerable amounts of N fixed from the atmosphere (Odunze*et al.*, 2004).Legumes play a wide role in contributing to food security, income generation, and maintenance of environment for millions of small-scale farmers in sub-Saharan Africa (Tarawali*et al.*, 2002).Adeleke and Haruna, (2012) reported that in most parts of sub-Saharan Africa, legumes are usually intercropped with cereals and improve land productivity through soil amelioration.Crop rotation with legumes was reported by (Nnadi, 1990) to have reduced rate of applied N for the succeeding maize crop. Innovative intercropping is reported to complement the promotion of mineral fertilizer for small-scale farmers (Sanginga and Woomer, 2009). In crop rotation, legumes contribute to a diversification of cropping systems. As N_2-fixing plant they can reduce the mineral N fertilizer demand. Grain legumes cause significant and positive yield effects on subsequent cereal crop when compared with rotations with non-legumes (Shultz*et al*., 2001).Maize rotation with legumes is also reported to improve soil physical, chemical and biological conditions (Chan and Heenan, 1996; Bagayoko*et al.,* 2000; Yusuf *et al.,* 2009a), thereby enhancing soil nutrient availability (Loewy, 1987).Other benefits derivable by soils cultivated with grain legumes include improvement in soil structure, breaking of pest and disease cycles and phytotoxic and allopathic effects of crop residues (Adeleke and Haruna, 2012). Vanlauwe*et al*., (2001) also observed that maize-soybean rotation is efficient because these crops use less of available phosphorous than other grains and herbaceous legumes, which are more efficient for extracting phosphorous from the soil than other crops.Akintola *et al*., (2009) reported that maize-soybean rotation involving late-maturing soybean varieties contributed residual nitrogen to maize through biological nitrogen fixation (BNF). Soybean, like other leguminous crops has a positive impact on the soil; canopies of soybean cover the soil and protect it from recurrent erosion (Latif *et al*., 1992). Soybean's potential to fix N from the atmosphere through BNF was also confirmed by Nieuwenhuis and Nieuwelink, (2002), and Sanginga, (2003) has demonstrated that some varieties of this crop have the ability to fix from 44 to 103 kg N ha^{-1} annually. In addition to replenishing soil nutrient and improving organic resource availability, cereal-legume systems, the legume varieties have traits that are appreciated by farmers such as high yields of grain and fodder, pest and disease resistance and promiscuous root nodulation by rhizobia that greatly improve farm income by 50-70% compared to continuous maize cultivation (Sanginga and Woomer, 2009). Extensive economic analysis of on-farm experiments by Ugbabe*et al*. (2007)

show that cereal-legume rotations under the balanced nutrient management systems(BNMS) technology options are profitable. Several researchers have reported that this is important in farming systems like the NGS Nigeria, where soils are continuously exploited since the increasing population demands increased food production.

2.4 Integrated Soil Fertility Management (ISFM) Options

It is widely acknowledged that poor soil fertility is the principal constraint to crop production in smallholder farming systems in Africa (Vanlauwe and Giller, 2006)**.**Major investment in improving soil and crop managementas stated by Titonell *et al*., (2008)is widely recognized as an important requirement to raise agricultural productivity in sub-Saharan Africa. The evidence is a widespread negative nutrient balances on smallholder farms and the large yield gap between potential and actual yields, both observations being causally related (Vanlauwe and Giller, 2006) have earlier been reviewed. Given that crop growth potential at a given location is determined by genotype and climate, whereas actual crop yields result from the interactions of local growth-limiting and growth-reducing factors (De Wit, 1992), appropriate management methods must be adopted to sustain productivity of soils without degrading the soil physical, chemical and biological quality for high crop productivity. The management methods will include integrated plant nutrition measures that centers on local available materials (Ayeni, 2011).

The ISFM is the application of soil fertility management practices, and the knowledge to adapt these to local conditions, which maximize fertilizer and organic resource use efficiency and crop productivity (Sanginga and Woomer, 2009). These practices necessarily include appropriate fertilizer and organic input management in addition to the utilization of improved germplasm(Sanginga and Woomer, 2009).The ISFMoptions include;

i. use of organic and inorganic resources in an integrated manner which maximizes their use efficiencies and increase crop productivity,
ii. innovative cereal-legume cropping systems that combine the benefits of high grain and fodder yields with increased biological nitrogen fixation (BNF) to benefit the farmer in higher profits and healthier soils,
iii. the utilization of improved seeds,
iv. adoption of input applications rates to within farm soil fertility gradients, among others (Sanginga and Woomer, 2009; Vanlauwe *et al.*, 2010; Fairhurst, 2012).

Sanginga *et al*., (2003) identified increased use of organic and mineral fertilizers, together with diversification in cropping to include legumes grown in rotation as important tools in restoring and sustaining soil fertility of the dry savannas.

2.4.1 Combined application of organic and inorganic inputs

In recent years the focus of soil fertility research has shifted towards combined application of organic matter and fertilizers as a way to arrest the ongoing soil fertility decline in Sub-Saharan Africa (Vanlauwe, *et al*., 2001). This is because according to research findings, neither mineral fertilizer nor organic manure is a panacea to soil fertility management. It is common knowledge that both mineral fertilizers and organic manures have their own roles to play in soil fertility management as confirmed by Uyobisere and Elemo, (2000), yet none can solely supply all the nutrients and other conditions of growth for producing crops that can feed the ever teeming population.Research shows that application of manure significantly impact on the chemical, physical and biological properties of soils. Most of these effects are due to increase in soil organic matter (Shirani *et al*., 2002; Liang *et al*., 2011; Bakayoko *et al*., 2009) resulting from manure application. Therefore, manure is an excellent source of major plant nutrients; such as nitrogen, phosphorus and potassium, and also provides many of the secondary nutrients that plants require.In Southern Nigeria, (Ayeni *et al*., 2008; Ayeni and Adetunji, 2010; Adeleye and Ayeni, 2010) reported morepositive responses on soil **chemical properties** and maize yield, as well as tomato whenthey combined cow dung, poultry manure and swine manure with mineral fertilizers than when not combined. Other research findings like Agbim and Adeoye, (1991), Nottidge *et al*. (2005) show that, use of inorganic fertilizer in combination with organic materials results in higher and sustainable crop yields than using either inorganic fertilizer or animal manure alone. Also, wood ash, pea nut residues and NPK combinations gave higher **dry matter** yields and leaf N, K, Ca and Mg contents compared with each treatment applied alone (Agbim and Adeoye, 1991; Nottidge *et al*., 2005). In another experiment (Nottidge *et al*., 2005) showed that ash and peanut combined reduced soil bulk density and increased aggregate stability and porosity.Ayeni, (2011) reported that a combined application of reduced quantities of poultry manure and NPK fertilizer gave better residual effect on soil nutrient content and maize yield than fertilizer alone.

Combining organic inputs with synthetic amendments would reduce amount of synthetic fertilizer needed and amount of nutrients contained in the synthetic fertilizers may be more efficiently utilized (Vanlauwe*et al.,* 2002). Also a combination of organic and synthetic amendments was reported to improve crop yield, soil fertility levels or both (Palm *et al.,* 1997; Vanlauwe*et al.,* 2002; Odunze*et al.,* 2012).Again Ayeni (2011) reported increases in the **soil pH, organic matter**, total N, Bray-1- P and exchangeable Mg and K values of soils treated with organic wastes combined (combination of poultry manure, oil palm sludge and urea), while mineral fertilizer alone reduced the values of these **soil properties.**Vanlauwe *et al*., (2001) put at about 50% the cost of inorganic fertilizer that would be saved should the smallholder farmer combine the use of inorganic fertilizers with organic inputs. Extensive economic analysis of on-farm experiments by Ugbabe *et al.*, (2007) show that the combined organic manure and mineral fertilizer applications are profitable.

Kulkarne and Kulkarne, (1982) suggested that the common problems associated with both chemical fertilizer and organic manure when singly applied could be eliminated by integrating the good qualities in each material in order to achieve a better interaction effects. There is therefore no justification in wasting scarce resources on chemical fertilizer, which does not justify the ends. Given that cost of procuring chemical fertilizers in Nigeria is beyond the reach of the smallholder farmers, the ISFM approach will ensure cost reduction because only small quantity of chemical fertilizers is required with organic manure (Ayeni, 2011)**.**

Combining organic and mineral inputs have been advocated as a sound management principle for smallholder farming in the tropics since none of them is usually available in sufficient quantities and both inputs are needed in the long term to sustain soil fertility and crop production (Vanlawe *et al*., 2001).Many studies in SSA have reported positive interactions between inorganic fertilizer and organic manure, with the benefits of manure increasing with decreasing soil fertility (Zingore*et al*., 2008; Mtambanengwe and Mapfumo, 2005)**,** and Zingore (2011) suggested that when soils are degraded; as is the case in the NGS of Nigeria, restoration of soil fertility through balanced fertilization and organic matter additions is necessary to achieve high crop productivity.

2.4.2 Innovative cereal-legume cropping systems

Legume integration into farming systems is an important component of ISFM because of their potential to fix nitrogen, hence reducing farmers' costs for purchase of nitrogen fertilizers. Also because of their ability to improve the soil physical and chemical attributes as well as provide protein supplements for poor families (Latif *et al.*, 1992).Nitrogen is the most important nutrient element required for crop production especially for cereals in the northern Guinea savanna, which was reported to dominate cultivated land in the world (Myers, 1988), and the ability of legumes to fix atmospheric nitrogen is one of their most important benefit. The various legume-based technologies; such as rotations of cereal crops with grain legumes, improved fallows, alley cropping, and green manures were advocated as viable options for providing supplementary N to cereal crops through biological N fixation (Giller*et al.*, 1997). In addition, Zingore (2011) reported that groundnuts can double yields of subsequent season maize crop without fertilizer, but gave more additional grain yield when fertilizer was used on the maize. Intercropping maize with grain legumes offers opportunities to improve overall productivity of both crops, and ensure that legumes benefit from fertilizer targeted to maize. Intercrops can result in increased grain output over maize alone, both with and without fertilizers (Snapp and Silim, 2002).

2.4.3 Utilization of improved germplasm

The utilization or not of improved germplasm can have very serious effects in crop yield and yield parameters irrespective of other soil fertility management approaches. For instance Carsky *et al.*, (1999) reported lower recovery efficiency of nitrogen in maize following soybean genotype (TGx 1660-19F) than maize following natural fallow in the northern Guinea savanna of Nigeria. And Yusuf *et al.*, (2009b) attributed this to the genetic difference in the soybean cultivar used. To a large extent, field legume production in Africa is dominated by the cultivation of low-yielding, traditional varieties that agricultural planners seek to replace with high-yielding, determinate varieties. (Sanginga and Woomer, 2009). Key to the success of ISFM practices in the northern Guinea savanna (NGS) Nigeria, particularly the cereal-legume systems is the availability of improved, desirable seeds and their accompanying technology to smallholder farmers. The redirection of soil management practice is best conducted in conjunction with the adoption of improved crop varieties that have been specially bred to meet rural household needs (DeVries and Toenniessen, 2001).Nutrient response to fertilizer application distinguishes soils into two types: responsive soils; in which crop productivity responds to fertilizer, and poor, less-responsive soils; in which crop productivity responds minimally or not respond to fertilizer due to other constraints besides the nutrients contained in the fertilizer (Vanlawe *et al.*, 2010). To this end therefore, the application of fertilizer to improved germplasm on responsive soils will boost crop yield and improve the agronomic efficiency of fertilizer relative to traditional varieties. In this way, the new cropping systems that involve higher-yielding staple foods grown in conjunction with new and improved legumes in rotations and intercrops can raise the living standard of African small-scale farmers while improving the soils upon which their future depends.

2.4.4 Soil fertility gradients in smallholder farms

Constraints to crop production can vary substantially between fields within a single farm creating what is often referred to as 'soil fertility gradients' (Tittonell *et al.*, 2005; Vanlauwe *et al.*, 2006). Soil fertility varies considerably at the farm and landscape levels in many smallholder farming systems in Africa, leading to variable crop productivity and crop response to additions of fertilizer and organic nutrient resources (Zingore *et al*., 2007).Such fertility gradients can have reasonable impact on fertilizer response and an important aspect of local adaptation is the adjustments of inputs used along existing soil fertility gradients. Problems of declining soil fertility are widespread in SSA, largely as a consequence of continued cultivation of crops with low levels of nutrient inputs (Zingore, 2011), typical of practices in smallholder farms. Complex variability in soil fertility between fields on the same farm or between farms differing in access to resources for crop production results from inherent variation in soils (Zingore, 2011), and that smallholder farmers typically have limited amounts of nutrient resources that are preferentially used on fields closest to homesteads, hence steep gradients of decreasing soil fertility with increasing distance from homesteads (Prudencio, 1993). There is a generalized trend of decreasing soil fertility in SSA (Stoorvogel *et al*., 1993), but rates of change in soil nutrient stocks differ between farms and fields within farms (Zingore, 2011).Adjusting for site-specific soil conditions is a last requirement for maximizing AE because of the variability found in farming systems at different scales.

2.5 Evaluating the Integrated Soil Fertility Management (ISFM).

2.5.1 Soilquality

Soil microbial activities, nutrient availability and release pattern, soil moisture content are among factors that highlight soil quality, and these are some of the conditions the ISFM practices will create in cropping systems where they are used. Agricultural activities such as rotation and fertilizer application have been observed to have significant implication for microorganism present in the soil (Hengeveld, 1996). Besides living plants, roots and organisms, soil microbial biomass (SMB) is a living portion of soil organic matter. Soil microbial biomass is considered to act both as agent of biochemical changes in soil and as a repository of plant nutrients such as nitrogen (N) and phosphorus (P) in agricultural ecosystems (Jenkinson and Ladd, 1981). The changes in soil organic carbon contents are directly associated with changes in microbial biomass carbon and biological activity in soil. The soil microorganisms are sensitive to changes in the surrounding soil reported Schinner and Sonnletner, (1996) andhave been shown that the microbial population changes after fertilization (Hyman *et al.*, 1990). Fertilizer can directly stimulate the growth of microbial populations as a whole by supplying nutrient and may affect the composition of individual microbial communities in the soil (Khonje *et al.*, 1989).Organic materials can even lead to better response to soil microbial activities as observed by Nakhro and Dkhar, (2010) who reported significant fungal and bacterial population growth with organic materials than inorganic fertilizers. Response to changes in input of organic materials is quicker in soil microbial biomass than in soil organic matter as a whole (Powlson and Jenkinson, 1981). Microbial biomass contains labile fraction of organic C and N, which are mineralized rapidly after the death of microbial cells. Soil microbes are typically C-limited (Smith and Paul, 1990); lower microbial biomass in soils from conventional agroecosystems is often caused by reduced organic carbon content in the soil (Fliebach and Mader, 2000). The quality and quantity of organic inputs are the most important factors affecting microbial biomass and community structure (Peacock *et al.*, 2001). Organic input applications increased nutrients status, microbial activity and productive potential of soil while the use of only chemical fertilizers in the cropping system resulted in a poor microbial activity and productive potential of the soil (Kang et al., 2005).

2.5.2 Efficiency of inputs use

One of the expectations of the full adoption of the ISFM is that crops will more efficiently utilize applied inputs and increasethe agronomic benefits of applied inputs. Novoa and Loomis, (1981) and Cassman *et al.*, (2002) outlined a number of simple indices that are frequently used in agronomic research to assess the efficiency of applied nutrients. Namely, recovery efficiency (RE) or uptake efficiency, agronomic efficiency (AE), physiological efficiency (PE), partial factor productivity (PFP), among others. Crop yield (Y) and plant nutrient accumulation/uptake (U) which typically increase with increasing nutrient addition (F) and gradually approach a ceiling, are important parameters used in estimating these indices. De Witt, (1992) reports that at low levels of nutrient supply, rates of yield increase and nutrient uptake are large because the nutrient of interest represents the primary factor limiting growth. As nutrient supplies increase, incremental yield gains become smaller because yield determinants other than that nutrient become more limiting as the yield potential is approached.Applying organic resources in conjunction with mineral fertilizers increases AE and, in many cases contributes additional nutrients. Agronomic efficiency is also improved through better nutrient retention and improved nutrient release patterns, which is related to improved soil physical and biological properties. Crop yield and AE are affected by so many factors including uptake and utilization efficiencies and by soil organic matter resulting from biomass production and recycling. Uptake efficiency is defined as the efficiency with which a nutrient is assimilated into the crop, whereas the utilization efficiency describes the efficiency with which a crop transforms assimilated nutrients into yield.

Very few studies have been conducted to evaluate the N use efficiency of cropping systems in the NGS of Nigeria(Carsky *et al.*, 1999). N uptake, N agronomic efficiency and N uptake efficiency were reported by Yusuf *et al.*, (2009b) to be significantly higher in legume-maize rotation than the continuous maize system, attributing this to the diversity and quality of crop residues in the legume-maize rotation. Several studies have accordingly reported higher uptake efficiencies in rotation than in monocultures (Huang et al., 1996; Lopez-Bellido and Lopez-Bellido, 2001; Cassman, 2001).Several research findings have recommended ISFM options for increasing soil fertility and agronomic efficiency of applied inputs (Sanginga and Woomer, 2009; Vanlauwe*et al*., 2010).

2.5.3 Crop yields

Low cereal yields in the SSA have largely been attributed to low use of organic and mineral nutrient resources, which has also resulted in negative nutrient balances (Smaling *et al.*, 1993).Results from FAO Fertilizer Program show average response of 750 kg maize grain ha^{-1} to medium NPK applications (FAO, 1989)**.** Low crop yield trends also hold for grain legumes whose average yields have stagnated at about0.7ton ha^{-1} against a potential of up to 3 tons ha^{-1}.These low crop yields have led to increased food insecurity, poverty and malnutrition in most parts of SSA, which are likely to worsen as the population continues to grow.Mutegi and Zingore, (2014) reported that in demo trials of maize-soybean rotations established by the Millennium Village Project (MVP) in 2010 in Uganda, show-casing good agronomic practices with various levels of manure and fertilizer combinations, maize crop yields for plots with organic and inorganic fertilizers ranged between 1.9 and 4.0 t ha^{-1} which was between 50% and 200% higher than yields from farmer practice. Across two soybean cropping seasons in the same trials, average soybean yields from the improved technology plots ranged between 1.2 and 1.8 tons/ha; this was between 50% -100% higher than yields from the farmer practice.Mutegi and Zingore, (2014)also reported that improved cereal-legume intercrop technologies in Kenya increased maize yield by between 2.8 and 3.3 tons/ ha (300%), and in between 1.0and 1.3 tons of legume grains in comparison to the baseline of 0.7 tons/ha.Agbim and Adeoye, (1991) and Nottidge *et al*., (2005)have reported that the use of inorganic fertilizer in combination with organic materials gives higher and sustainable crop yields than using either inorganic fertilizer or animal manure alone.

2.5.4 Profitability of input use

One of the most obvious factors that could explain low fertilizer use in Africa relative to other regions in the world relates to profitability. As described by Yanggen *et al.*, (1998), the financial incentives for farmers to use fertilizer are influenced by three parameters:

i. The technical response to fertilizer use, measured by the units of output (O) produced from one unit of nutrient (N) input (the O/N ratio).

ii. The relationship between output price and fertilizer price, expressed in units of output needed to purchase one unit of fertilizer nutrient (P_N/P_O).

iii. The value-cost ratio (VCR), which is simply the ratio of the technical response to fertilizer use and the nutrient/output price ratio, or (O/N) / (P_N/P_O).

Some simple "rules of thumb" can be invoked in interpreting the values taken on these parameters. According to Morris *et al.*, (2007), using international export prices, P_N/P_O has generally ranged over the past 20 years between 2 and 3 for wheat.The ratio is generally lower for rice (because rice is more expensive than wheat in global markets) and higher for maize and other coarse grains (because maize and coarse grains are generally cheaper).The lower the ratio, the higher the profitability (Yanggen *et al.*, 1998). The O/N ratio for maize would have to be in the region of 7-10 or higher to provide adequate incentive to make fertilizer use more attractive (Morris *et al.*, 2007). Value cost ratio is a good indicator of financial attractiveness of an intervention (Kaizzi*et al.*, 2011) and a minimum VCRabove 2 is considered profitable. A value cost ratio of 1 implies that the returns are equal to the inputs and therefore there is no livelihood improvement from investment, while a value of less than 1 implies losses of human, financial and capital resources. Therefore, value cost ratio of more than 2 is required for an investment to be attractive in SSA (Kaizzi *et al.*, 2011).

Meanwhile, the following range of values were reported by Yanggen *et al.,* (1998) for maize in the West African region; yield response (O/N ratio) 0-54, price incentives (P_N/P_O ratio) 1.9-5.1and value cost ratio (VCR) 1.5-28. An economic analysiscarried out on data from 10 projects implementing different types of the ISFM options from across eastern, southern and western Africa yielded value cost ratio (VCR) values of more than 2 (Mutegi and Zingore, 2014).Value-to-cost ratios (VCR) for West African countries varied between 1.1 and 8.9; usually above the required minimum ratio of 2 (Vanlauwe and Giller 2006).

CHAPTERTHREE

3.0 MATERIALS AND METHODS

3.1 Nitrogen Response Experiment

3.1.1 SiteDescription

The experiment was conducted in the wet seasons of 2012 and 2013 on a smallholder farm in Pampaida Ikara, northern Guinea savanna (NGS) of Nigeria. Pampaida is located at latitude $11^0$32’.16N and longitude $08^0$16’.19E. The northern Guinea Savanna has a mono modal rainfall pattern with a mean annual rainfall of 1011±161mm concentrated almost entirely in the five months (May/June–September/October) of the cropping season (Oluwasemire and Alabi, 2004). The soil was classified as TypicHaplustalf (Ogunwole*et al*., 2001) or Chromic Cambisols according to the FAO system of soil classification (FAO, 2001). The soils are inherently low in fertility, due to low organic matter and cation exchange capacity, and the dominance of low activity clays (LAC) (Odunze, 2003).

3.1.2 Treatment and Experimental Design

The treatments in this experiment consisted of five levels of nitrogen thus;

0 kg N ha^{-1} (0N)

30 kg N ha^{-1} (30N)

60 kg N ha^{-1} (60N)

90 kg N ha^{-1} (90N)

120 kg N ha^{-1} (120N)

The treatments were arranged in a randomized complete block design (RCBD), replicated four times as shown in Fig. 3.1.

3.1.3 Agronomic Practices

(1) Land preparation: Each experimental area wasmarked out from the farmer's field, and ridging was done with animal traction at 0.75m apart after the old ridges had been flattened with hoe.Plot size for the experiment was 6 x 5m.

(2)Planting: Test crop for the experiment was maize and the variety used was Oba 98. Oba 98 is a top cross quality protein maize adapted to the northern Guinea savanna with yield potentials of 6.5 – 8.0 t ha^{-1}. Maize was planted at 0.25 mwithin row and about 0.75 m between rows on the ridges and was thinned to one plant per stand two weeks after planting (2WAP).

(3) Fertilizer Application: Atplanting, a basal application of 40 kg ha^{-1}P and K as Single Super Phosphate(18% P_2O_5) and Muriates of Potash(60% K_2O) were applied to maize in treatments 1 and 2. Inorganic N fertilizer was applied as NPK 15:15:15 and ureain split doses at two weeks after planting (one third of the rates) and at six weeks after planting (the remaining two third). The fertilizers were applied by banding about 5 cm away from the plants.

(4) Weeding: The crops were weeded two times before harvest. The first weeding was carried out at about two weeks after planting while the second weeding was done at about six weeks after planting. The first weeding was done manually using hoe while the second weeding was done with animal traction.

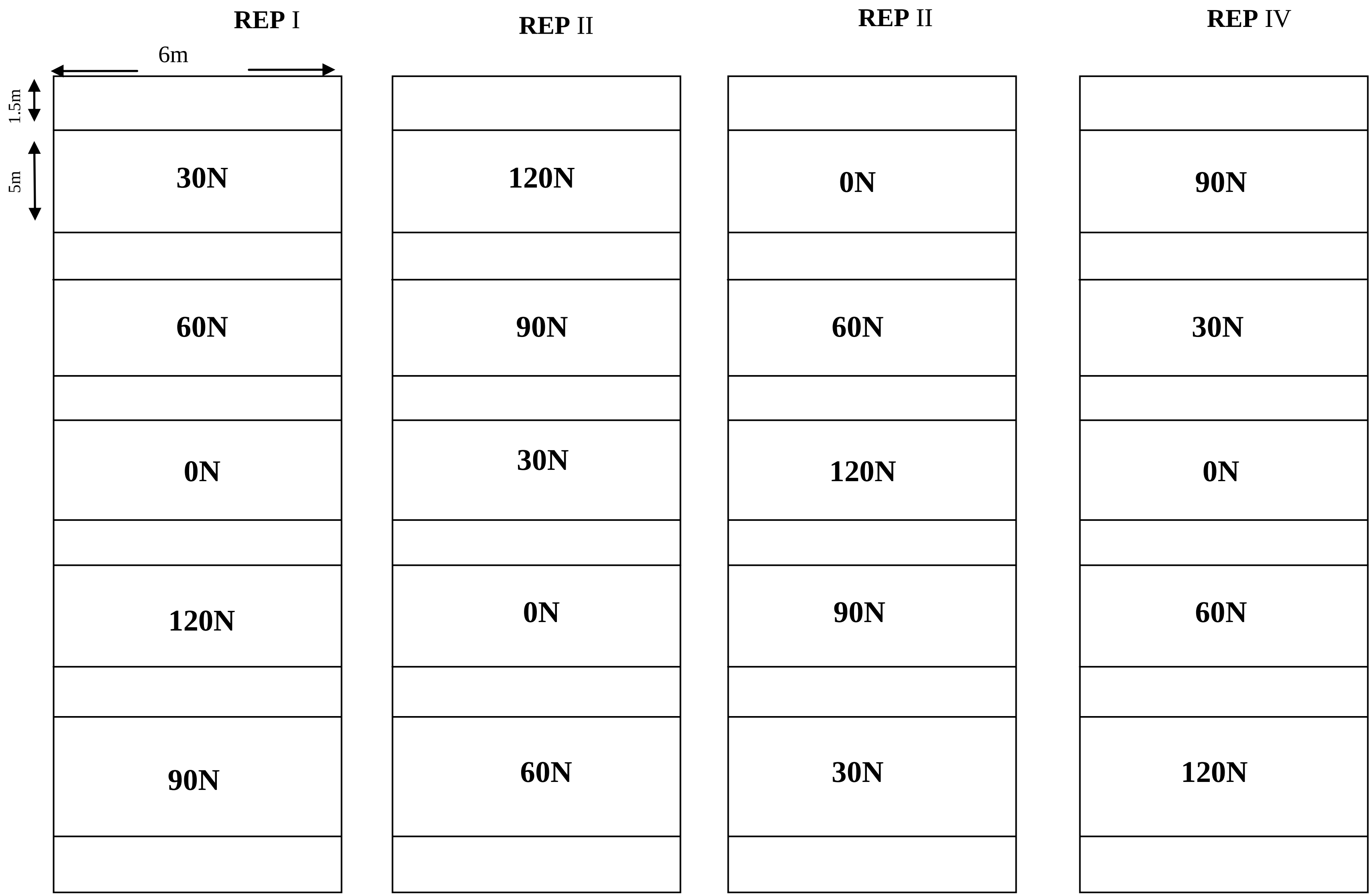

Fig 3.1: Field layout for nitrogen response experiment

(5) Harvesting: At maturity, plants were harvested fromeach plot by leaving the two (2) outermost ridges or rows on either side of the plot. From each of the four middle rows, three (3) maize stands (representing approximately 0.5m) were discarded from both ends of the row. All maize plants included in the net plot were cut at above ground level and the cobs harvested. Number of plants and cobs harvested, and weight of cobs and stovers were recorded right on the field. Ten (10) cobs and stover samples were randomly sub-sampled, weighed and recorded for each net plot.

3.1.4 Soil Sampling and Analyses

Soil samples were collected before each year's planting using systematic random sampling technique. At a depth of 0 -15cm, samples were collected using auger for physical and chemical analysis of the inherent nutrient status and characterization of the fields. Four (4) soil samples were taken at random from each plot, bulked to form a composite sample from which sub samples were taken and prepared for analyses. Samples were air-dried, sieved using 2-mm mesh sieve and bagged in polythene bags and used foranalyses.

Particle size distribution was determined by the hydrometer method, as described by Gee and Bauder (1986). Soil pH was determined electrometrically with a soil/solution ratio of 1:2.5 (Hendershot*et al.*, 1993). Total nitrogen was determined by the micro-kjeldahl digestion method (Bremner and Mulvaney, 1982) and organic carbon as described by Nelson and Sommers (1982). Organic matter was calculated by multiplying organic carbon by the "Van Bemmelen factor" of 1.72. Carbon: Nitrogen ratio (C/N) was computed by dividing organic carbon by total nitrogen. Available phosphorus was extracted by the Bray I method (Olson and Sommers, 1982). Exchangeable Ca^{2+}, Mg^{2+}, K and Na^{+} were extracted using 1N ammonium acetate buffered at pH 7.0 as described by Chapman, (1965), then exchangeable Ca^{2+} and Mg^{2+} were determined by

EDTA complexometric titration while exchangeable K^+ and Na^+ were estimated by flame photometry (Jackson, 1958). As described by McLean, (1982), exchangeable acidity was determined by titration method. Effective Cation Exchange Capacity (ECEC) wasestimated by summation method (summation of all the exchangeable acids and exchangeable bases).

3.1.5 Yield and Yield Components Analysis

Plant heights were taken before harvest using a metre rule to measure from the shoot at above ground level to the base of the last maize leaf (just before the tarsal). Sub-sampled cobs and stoversharvested were taken to the laboratory and dried to about 13% moisture content. After drying, the cobs were shelled and the weight of grains and husks were taken and recorded. Moisture content of grains were also taken and recorded. The sub-sampled stover weights after drying were also taken. In the laboratory, these samples were washed with distilled water to remove adhering soils and dirt, put in envelops and oven dried at 65°C until a constant weight is obtained. After oven drying, they were ground and passed through a 0.5mm sieve. Thereafter, total nitrogen accumulated in grains and stovers was determined using the micro-Kjeldahl digestion method (Bremner and Mulvaney, 1982). Results obtained were used for the calculation of the following nitrogen use efficiencies and harvest index (Fageria*et al.* 2010).

Agronomic Efficiency of Nitrogen (AEN) $= \frac{Gf - Gu}{Na} =$ (kg/kg)

Where Gf = the grain yield of fertilized plot (kg)

Gu = the grain yield for the unfertilized plot (kg)

Na = the quantity of N applied (kg)

Physiological Efficiency of Nitrogen (PEN) = $\frac{Yf-Yu}{Nf-Nu}$(kg/kg)

Where; Yf = total biological yield (grains + stalks) of a fertilized plot (kg)

Yu = total biological yield (grains + stalks) of unfertilized plot (kg)

Nf = Nutrient accumulation of the fertilized plot (kg)

Nu = Nutrient accumulation of the unfertilized plot (kg)

Recovery Efficiency of Nitrogen (REN) =$\frac{Nf-Nu}{Na} \times \frac{100}{1}$(%)

Where; Na = the quantity of N applied (kg)

Nf = Nitrogen accumulation of the fertilized plot (kg)

Nu = Nitrogen accumulation of the unfertilized plot (kg)

Nitrogen Use Efficiency (NUE) =$PEN \times REN$ (kg kg^{-1})

Grain Harvest Index (HI) = Grain yield / above ground biomass

Profitability of fertilizer use was estimated using Value Cost Ratio (VCR), Output-Input (O/I) ratio and Input-Output price (P_N/P_O) ratio (Morris *et al*., 2007).

VCR is given by the relation

Marginal Revenue / Total cost of fertilizers.

Where; Marginal Revenue = (Target yield – Control) x Price of 1kg of grain

Total cost of fertilizers = Quantity of each fertilizer x Price of each fertilizer).

O/I ratio is given by the relation

Quantity of grain harvested (kg ha^{-1})/ Quantity of fertilizer applied (kg ha^{-1}).

P_N/P_O ratio is given by the relation

Total cost of applied fertilizer / Total Revenue.

Where Total Revenue = quantity of grain harvested (kg) X Price of 1 kg grain

3.1.6 Statistical Analysis

Data collected were subjectedtoanalysisofvariance(ANOVA)using the GLMprocedureofSAS(SAS, 1999).Wherethe F-ratioswere found tobesignificant,treatment means were separated using theDuncan Multiple Range Test (DMRT).

3.2. Combined Inorganic Fertilizer and Manure Experiment

3.2.1 SiteDescription

The experimentwas conducted in the wet seasons of 2012 and 2013 onthree smallholder farms located in Pampaida, Saulawa and Fulani Sule in Ikara, northern Guinea savanna (NGS) of Nigeria. Farm I was in Pampaida, located at latitude $11^0$32′.16N and longitude $08^0$16′.19E, farm II was in Saulawa, located at latitude $11^0$34′.25N and longitude $08^0$12′.04E and farm III was in Fulani Sule, located at latitude $11^0$20′.33N and longitude $08^0$10′.43E.The northern Guinea Savanna has a mono modal rainfall pattern with a mean annual rainfall of 1011±161mm concentrated almost entirely in the five months (May/June–September/October) of the cropping season (Oluwasemire and Alabi, 2004). The soil was classified as TypicHaplustalf (Ogunwole*et al.*, 2001) or ChromicCambisols according to the FAO system of soil classification (FAO, 2001).

The soils are inherently low in fertility, due to low organic matter and cation exchange capacity, and the dominance of low activity clays (LAC) (Odunze, 2003).

3.2.2 Treatment and Experimental Design

The treatments in this experiment consisted of five levels of nitrogen combined with 2.5 t ha^{-1} sheep and goat manure and one 2.5 t ha^{-1}sheep and goat manure thus;

0 kg N ha^{-1} No N fertilizer (0N)

30 kg N ha^{-1}+ 2.5 t ha^{-1}sheep and goat manure (30NSGM)

60 kg N ha^{-1}+ 2.5 t ha^{-1}sheep and goat manure (60NSGM)

90 kg N ha^{-1}+ 2.5 t ha^{-1}sheep and goat manure (90NSGM)

120 kg N ha^{-1}+ 2.5 t ha^{-1}sheep and goat manure (120NSGM)

0 kg N ha^{-1}+ 2.5 t ha^{-1}sheep and goat manure (0NSGM)

The treatmentswere arranged in a randomized complete block design (RCBD), replicated four times as show in Fig. 3.2, and repeated in the three smallholder farmsin Pampaida, Saulawa and Fulani Sule.

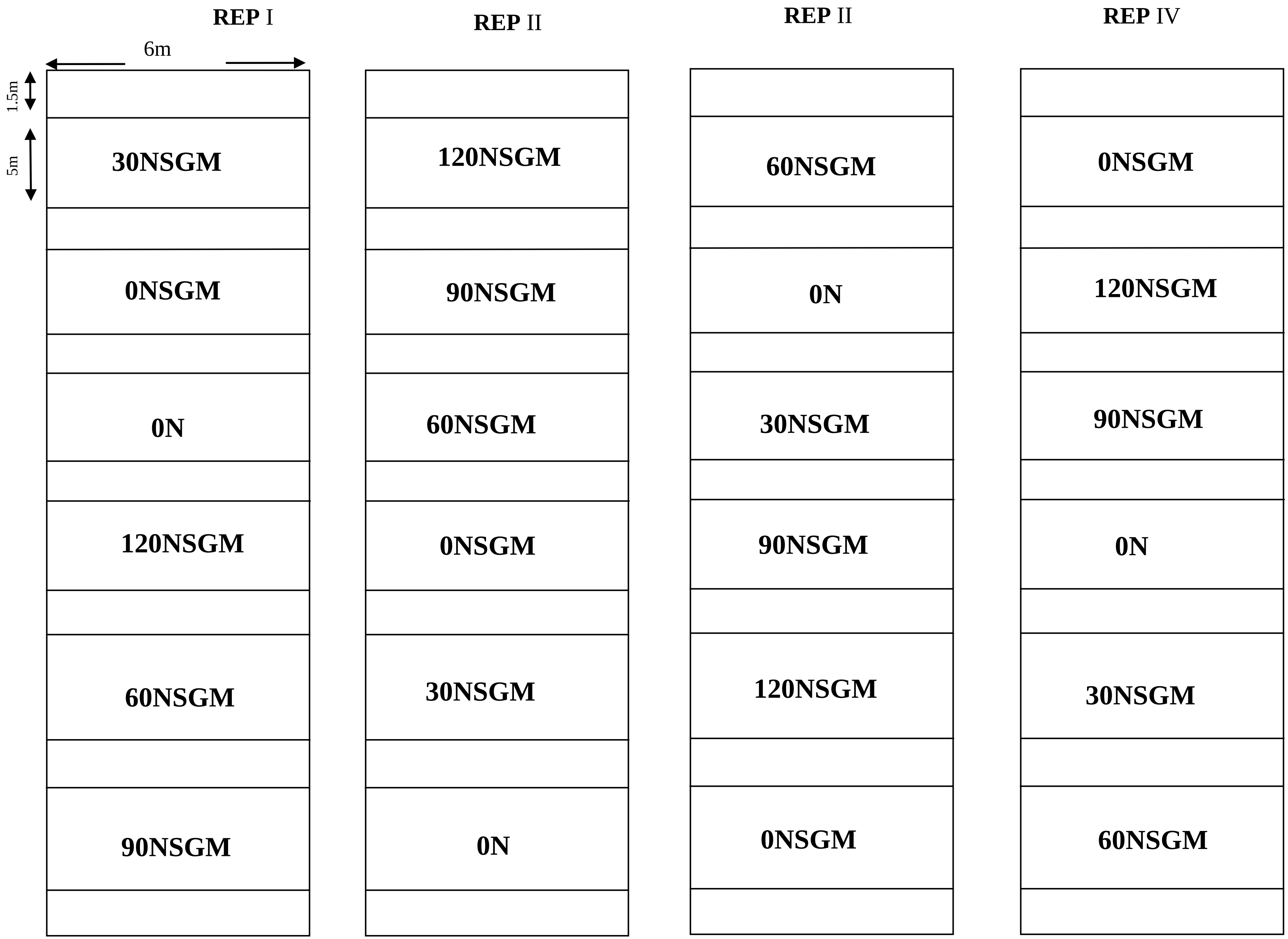

Fig 3.2: Field layout for combined inorganic fertilizer and manure experiment

3.2.3 Agronomic Practices

(1) Land preparation: Each experimental area was marked out from the farmer's field, and ridging was done with animal traction at approximately 0.75m apart after the old ridges had been flattened with hoe.Plot size for the experiment was 30 m^2 (6 x 5m).

(2)Planting: Test crop for the experiment was maize and the variety used was Oba 98. Oba 98 is a top cross quality protein maize adapted to the northern Guinea savanna with yield potentials of 6.5 – 8.0 t ha^{-1}. Maize was planted at 0.25 mwithin row and about 0.75 m between rows on the ridges and was thinned to one plant per stand two weeks after planting (2WAP).

(3) Fertilizer Application: At planting, 40 kg ha^{-1}P and K as Single Super Phosphate(18% P_2O_5) and Muriates of Potash(60% K_2O) were applied to maize in treatments 1 and 2. Inorganic N fertilizer was applied in split doses at two weeks after planting (one third of the rates) and at six weeks after planting (the remaining two third of the rates) as NPK 15:15:15 and urea. The fertilizers were applied by banding about 5 cm away from the seedling. Manure used for the experiment was sheep and goat manure, which was sourced from the Sheep and Goat Department of the National Animal Production Research Institute (NAPRI), Shika, Kaduna State. The manure was applied on dry weight bases by broadcasting on designated plots before ridging was done.

(4) Weeding: The crops were weeded two times before harvest. The first weeding was carried out at about two weeks after planting while the second weeding was done at about six weeks after planting. The first weeding was done manually using hoe while the second weeding was done with animal traction.

(5) Harvesting: At maturity, plants were harvested from each plot by leaving the two (2) outermost ridges or rows on either side of the plot. From each of the four middle rows, three (3) maize stands (representing approximately 0.5m) were discarded from both ends of the row. All maize plants included in the net plot were cut at above ground level and the cobs harvested. Number of plants and cobs harvested, and weight of cobs and stovers were recorded right on the field. Ten (10) cobs and stover samples were randomly sub-sampled, weighed and recorded for each net plot.

3.2.4 Soil Sampling and Analyses

Soil samples were collected before each year's planting using systematic random sampling technique. At a depth of 0 -15cm, samples were collected using auger forphysical and chemical analysis of the inherent nutrient status and characterization of the fields. Four (4) soil samples were taken at random from each plot, bulked to form a composite sample from which sub samples were taken and prepared for analyses. A portion of the samples collected in 2013 was preserved fresh for soil microbial biomass analyses. The remaining samples were air-dried, sieved using 2-mm mesh sieve and bagged in polythene bags and used foranalyses.

Particle size distribution was determined by the hydrometer method, as described by Gee and Bauder (1986). Soil pH was determined electrometrically with a soil/solution ratio of 1:2.5 (Hendershot*et al.*, 1993). Total nitrogen was determined by the micro-kjeldahl digestion method (Bremner and Mulvaney, 1982) and organic carbon as described by Nelson and Sommers (1982). Organic matter was calculated by multiplying organic carbon by the "Van Bemmelen factor" of 1.724. Carbon: Nitrogen ratio (C/N) wascomputed by dividing organic carbon by total nitrogen. Available phosphorus was extracted by the Bray I method (Olson and Sommers, 1982). Exchangeable Ca^{2+}, Mg^{2+}, K and Na^{+} were extracted using 1N ammonium acetate buffered at pH

7.0 as described by Chapman, (1965), then exchangeable Ca^{2+} and Mg^{2+} were determined by EDTA complexometric titration while exchangeable K^{+} and Na^{+} were estimated by flame photometry (Jackson, 1958).As described by McLean, (1982), exchangeable acidity was determined by titration method. Effective Cation Exchange Capacity (ECEC) wasestimated by summation method (summation of all the exchangeable acids and exchangeable bases).The extractable micro nutrients such as zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu) were extracted with 0.1NHCL and determined by atomic absorption spectrophotometer.

3.2.5 Soil microbial biomass determination

Soil microbial biomass carbon and nitrogen were estimated by the fumigation extraction method (Brookes *et al.,* 1985; Sparling and West, 1998) using field-fresh moist 2mm sieved soil samples and 10 g of samplewas weighed into a cup and placed in a desiccator. A second sample (10 g) was weighed into another cup and immediately fumigated in a desiccator using reagent-grade ethanol-free chloroform. Water-saturated filter paper was placed in the desiccator to keep the samples moist, while the desiccators were covered air-tight, placedin a dark place and left for 72 hours. After 72 hours, the desiccators were opened to allow the chloroform to dissipate, and then all samples were removed and immediately extracted with 0.5M K_2SO_4 as was done with the unfumigated sample.

The extractable carbon and nitrogen in the both fumigated and unfumigated extracts were determined by the Walkley and Black (Nelson and Sommers, 1982) and micro-kjedahl(BremnerandMulvaney, 1982) methods respectively. Soil microbial biomass carbon was estimated by multiplying the difference in extractable C between the unfumigated and fumigated samples by a conversion factor of 2.64 (Vance *et al.,* 1987). Microbial biomass nitrogen was calculated by multiplying the difference in extractable N between the unfumigated and fumigated samples by a conversion factor of 1.46 (Brookes *et al.*, 1985).

3.2.6 Yield and Yield Components Analysis

Plant heights were taken before harvest using a metre rule to measure from the shoot at above ground level to the base of the last maize leaf (just before the tarsal). Sub-sampled cobs and stovers harvested were taken to the laboratory and dried to about 13% moisture content.After drying, the cobs were shelled and the weight of grains and husks were taken and recorded. Moisture content of grains were also taken and recorded. The sub-sampled stover weights after drying were also taken.In the laboratory, these samples werewashed with distilled water to remove adhering soils and dirt, put in envelops and oven dried at 65^{o}C until a constant weight is obtained.After oven drying, they were ground and passed through a 0.5mm sieve. Thereafter, total nitrogen accumulatedin grains and stovers was determined using the micro-kjeldahl digestion method (Bremner and Mulvaney, 1982). Results obtained were used for the calculation of the following nitrogen use efficiencies and harvest index (Fageria*et al.* 2010).

Agronomic Efficiency of Nitrogen (AEN) $= \frac{Gf - Gu}{Na} =$ (kg/kg)

Where Gf = the grain yield of fertilized plot (kg)

Gu = the grain yield for the unfertilized plot (kg)

Na = the quantity of N applied (kg)

Physiological Efficiency of Nitrogen (PEN) = $\frac{Yf - Yu}{Nf - Nu}$(kg/kg)

Where; Yf = total biological yield (grains + stalks) of a fertilized plot (kg)

Yu = total biological yield (grains + stalks) of unfertilized plot (kg)

Nf = Nutrient accumulation of the fertilized plot (kg)

Nu = Nutrient accumulation of the unfertilized plot (kg)

Recovery Efficiency of Nitrogen (REN) $= \frac{Nf - Nu}{Na} \times \frac{100}{1}$ (%)

Where; Na = the quantity of N applied (kg)

Nf = Nitrogen accumulation of the fertilized plot (kg)

Nu = Nitrogen accumulation of the unfertilized plot (kg)

Nitrogen Use Efficiency (NUE) $= PEN \times REN$ (kg kg^{-1})

Grain Harvest Index (HI) = Grain yield / above ground biomass

Profitability of fertilizer use was estimated using Value Cost Ratio (VCR), Output-Input (O/I) ratio and Input-Output price (P_N/P_O) ratio (Morris *et al*., 2007).

VCR is given by the relation

Marginal Revenue / Total cost of fertilizers.

Where; Marginal Revenue = (Target yield – Control) x Price of 1kg of grain

Total cost of fertilizers = Quantity of each fertilizer x Price of each fertilizer).

O/I ratio is given by the relation

Quantity of grain harvested (kg ha^{-1})/ Quantity of fertilizer applied (kg ha^{-1}).

P_N/P_O ratio is given by the relation

Total cost of applied fertilizer / Total Revenue.

Where Total Revenue = quantity of grain harvested (kg) X Price of 1 kg grain

3.2.7 Statistical Analysis

Data collected were subjectedtoanalysisofvariance(ANOVA)using the GLMprocedureofSAS(SAS, 1999).Wherethe F-ratioswere found tobesignificant,treatment means were separated usingthe Duncan Multiple Range Test (DMRT).

3.3 Maize-Legume Cropping System Experiment

3.3.1 SiteDescription

The experiment was conducted in the wet seasons of 2012 and 2013 on three smallholder farms located in Pampaida, Saulawa and Fulani Sulein Ikara, northern Guinea savanna (NGS) of Nigeria. Farm I was in Pampaida, located at latitude $11^0$32'.16N and longitude $08^0$16'.19E, farm II was in Saulawa, located at latitude $11^0$34'.25 N and longitude $08^0$12'.04E and farm III was in Fulani Sule, located at latitude $11^0$20'.33N and longitude $08^0$10'.43 E. The northern Guinea Savanna has a mono modal rainfall pattern with a mean annual rainfall of 1011±161mm concentrated almost entirely in the five months (May/June–September/October) of the cropping season (Oluwasemire and Alabi, 2004). The soil was classified as TypicHaplustalf (Ogunwole*et al*., 2001) or Chromic Cambisols according to the FAO system of soil classification (FAO, 2001). The soils are inherently low in fertility, due to low organic matter and cation exchange capacity, and the dominance of low activity clays (LAC) (Odunze, 2003).

3.3.2 Treatment and Experimental Design

The treatments in this experiment consisted of five maize-legume cropping systems thus;

Soybean/maizerotation+ cowpeas relay (SBMZRT)

Groundnut/maizerotation + cowpeas relay (GNMZRT)

Maize-soybeanstrip cropping (SBMZSP)

Maize-groundnutstrip cropping (SBMZSP)

Continuous maize-cowpea intercrops (CTMZCPInt).

The treatments were arranged in a randomized complete block design (RCBD), replicated four times as shown in Fig. 3.3, and repeated in the three smallholder farms in Pampaida, Saulawa and Fulani Sule.

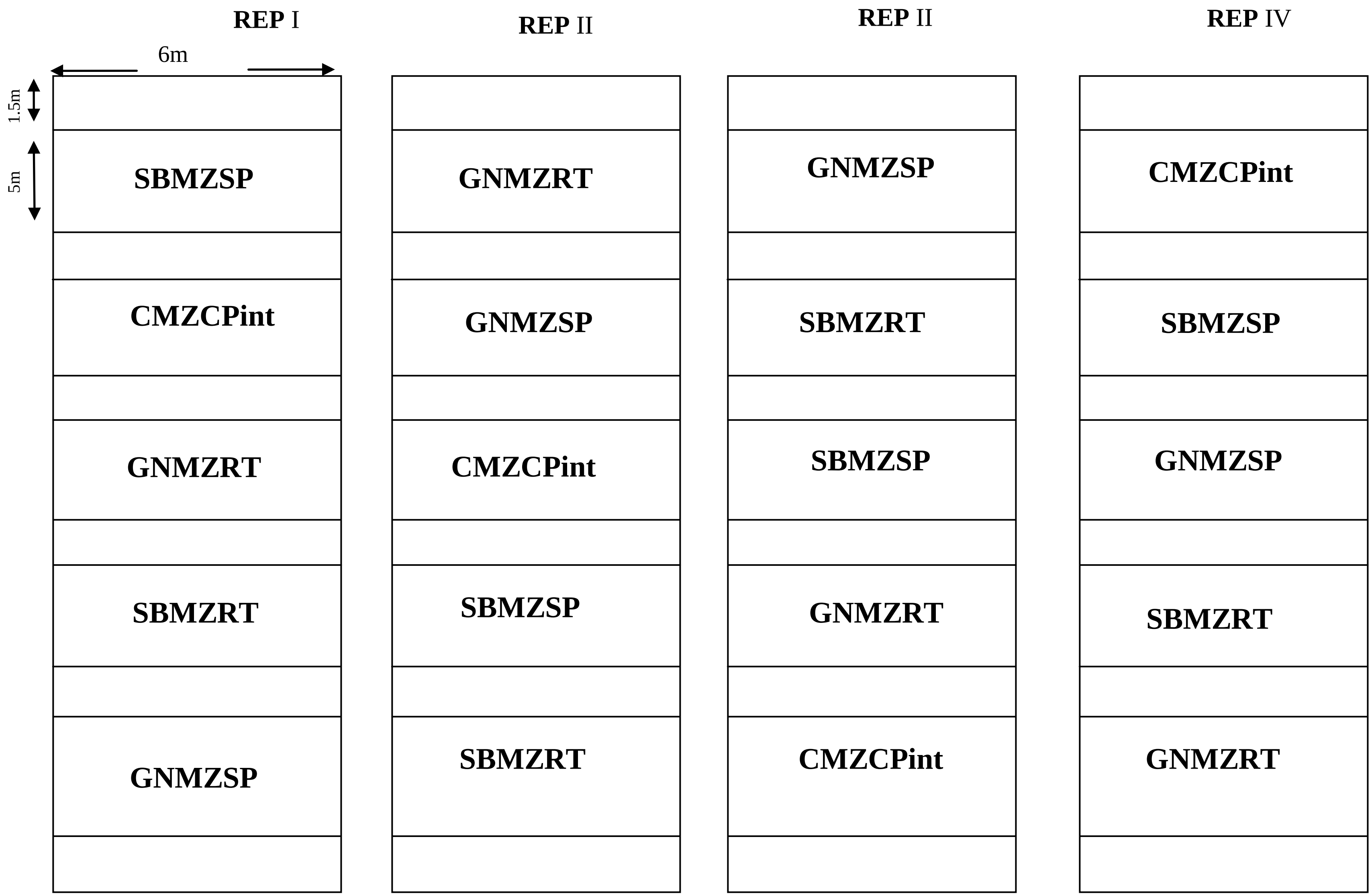

Fig 3.3: Field layout for maize-legumes cropping system experiment

3.3.3 Agronomic Practices

(1) Land preparation: Each experimental area was marked out from the farmer's field, and ridging was done with animal traction at approximately 0.75m apart after the old ridges had been flattened with hoe.Plot size for the experiment was (30 m^2 (6 x 5m).

(2)Planting: Test crops for the experiment were maize, soybean, groundnut and cowpea. The varieties used were Oba 98 maize, TGx 1448-2E soybean, Samnut 23 groundnut and Sampea-11 cowpea. Oba 98 is a top cross quality protein maize adapted to the northern Guinea savanna with yield potentials of 6.5 – 8.0 t ha^{-1}. SAMPEA-11 is an improved cowpea variety with photosensitive dual purpose and resistant to common disease. It is adaptable to the northern Guinea savanna and has a yield potential of about 1.6 t ha^{-1}. TGX 1448-2E is a compact and erect early-maturing soybean variety that is resistant to shattering. It is bred for the forest and savanna agro-ecologies, with potential yield of 1.5 – 2.5 t ha^{-1}.

Maize was planted at 0.25 mwithin row and about 0.75 m between rows on the ridges and was thinned to one plant per stand two weeks after planting (2WAP). Soybean was planted at 0.1 m within row and 0.75 m between rows at the rate of one plant per stand. Groundnut was planted at 0.2 m within row and 0.75 m between rows and at a rate of one plant per stand. Cowpea was spaced at 0.25 m by 0.75 m at a rate of one plant per stand. In the treatments involving rotation, the legumes (soybean and groundnut) were planted in the 2012 planting season while maize was planted on the same plots in 2013. Treatments involving strip and intercrop were arranged in a 2:2 pattern for maize and legumes such that the first four ridges were planted with maize while the other four ridges were planted with legume.

(3) Fertilizer Application: Atplanting, a basal application of 40 kg ha^{-1}P and K as Single Super Phosphate(18% P_2O_5) and Muriates of Potash(60% K_2O) were applied to maize and legumes.90 kg ha^{-1} inorganic N fertilizer was applied as NPK 15:15:15 and urea to maize in split doses at two weeks after planting (one third of the 90 kg N ha^{-1}) and at six weeks after planting (the remaining two third). The fertilizers were applied by banding about 5 cm away from the plant.

(4) Weeding: The crops were weeded two times before harvest. The first weeding was carried out at about two weeks after planting while the second weeding was done at about six weeks after planting. The first weeding was done manually using hoe while the second weeding was done with animal traction.

(5) Harvesting: At maturity, maize plants were harvested fromeach plot by leaving the two (2) outermost ridges or rows on either side of the plot for the maize in rotation, whereas for the maize in strips, maize plants were harvested from the two (2) inner rows of the maize strip. From each of the four middle rows for maize in rotation and the two inner rows for the maize in strip cropping, three (3) maize stands (representing approximately 0.5m) were discarded from both ends of the row. All maize plants included in the net plot were cut at above ground level and the cobs harvested. Number of plants and cobs harvested, and weight of cobs and stovers were recorded right on the field. Ten (10) cobs and stover samples were randomly sub-sampled, weighed and recorded for each net plot.A quadrant of $1.5m^2 \pm 0.5m$ was placed in the legume plots and eight cowpea, soybean and groundnut plants each were harvested. Afterharvest, the pods where separated from the haulms, weighed separately and taken to the laboratory for further drying to about 12% moisture content and their weight was taken again. Whereas the haulm weight after drying was taken as haulm yield, grain yield was obtained by manually cracking the pods of groundnuts, cowpea and soybean, and separating the grains from the shells.

3.3.4 Soil Sampling and Analyses

Soil samples were collected before each year's planting using systematic random sampling technique. At a depth of 0 -15cm, samples were collected using auger for physical and chemical analysis of the inherent nutrient status and characterization of the fields. Four (4) soil samples were taken at random from each plot, bulked to form a composite sample from which sub samples were taken and prepared for analyses. A portion of the samples collected in 2013 was preserved fresh for soil microbial biomass analyses. The remaining samples were air-dried, sieved using 2-mm mesh and bagged in polythene bags and used foranalyses.

Particle size distribution was determined by the hydrometer method, as described by Gee and Bauder (1986). Soil pH was determined electrometrically with a soil/solution ratio of 1:2.5 (Hendershot*et al.*, 1993). Total nitrogen was determined by the micro-kjeldahl digestion method (Bremner and Mulvaney, 1982) and organic carbon as described by Nelson and Sommers (1982). Organic matter wascalculated by multiplying organic carbon by the "Van Bemmelen factor" of 1.724. Carbon: Nitrogen ratio (C/N) was computed by dividing organic carbon by total nitrogen. Available phosphorus was extracted by the Bray I method (Olson and Sommers, 1982). Exchangeable Ca^{2+}, Mg^{2+}, K and Na^{+} were extracted using 1N ammonium acetate buffered at pH 7.0 as described by Chapman, (1965), then exchangeable Ca^{2+} and Mg^{2+} were determined by EDTA complexometric titration while exchangeable K^{+} and Na^{+} were estimated by flame photometry (Jackson, 1958). As described by McLean, (1982), exchangeable acidity was determined by titration method. Effective Cation Exchange Capacity (ECEC) wasestimated by summation method (summation of all the exchangeable acids and exchangeable bases).The extractable micro nutrients such as zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu) were extracted with 0.1N HCL and determined by atomic absorption spectrophotometer.

3.3.5 Soil microbial biomass determination

Soil microbial biomass carbon and nitrogen were estimated by the fumigation extraction method (Brookes *et al.,* 1985; Sparling and West, 1998) using field-fresh moist 2mm sieved soil samples and 10 g of sample was weighed into a cup and placed in a desiccator. A second sample (10 g) was weighed into another cup and immediately fumigated in a desiccator using reagent-grade ethanol-free chloroform. Water-saturated filter paper was placed in the desiccator to keep the samples moist, while the desiccators were covered air-tight, placed in a dark place and left for 72 hours. After 72 hours, the desiccators were opened to allow the chloroform to dissipate, and then all samples were removed and immediately extracted with 0.5M K_2SO_4 as was done with the unfumigated sample.

The extractable carbon and nitrogen in the both fumigated and unfumigated extracts were determined by the Walkley and Black (Nelson and Sommers, 1982) and micro-kjedahl(BremnerandMulvaney, 1982) methods respectively. Soil microbial biomass carbon was estimated by multiplying the difference in extractable C between the unfumigated and fumigated samples by a conversion factor of 2.64 (Vance *et al.,* 1987). Microbial biomass nitrogen was calculated by multiplying the difference in extractable N between the unfumigated and fumigated samples by a conversion factor of 1.46 (Brookes *et al.,* 1985).

3.3.6 Yield and Yield Components Analysis

Plant heights were taken before harvest using a metre rule to measure from the shoot at above ground level to the base of the last maize leaf (just before the tarsal).Sub-sampled cobs and stovers harvested were taken to the laboratory and dried to about 13% moisture content.After drying, the cobs were shelled and the weight of grains and husks were taken and recorded.

Moisture content of grains were also taken and recorded. The sub-sampled stover weights after drying were also taken. In the laboratory, these samples were washed with distilled water to remove adhering soils and dirt, put in envelops and oven dried at 65^{o}C until a constant weight is obtained. After oven drying, they were ground and passed through a 0.5mm sieve. Thereafter, total nitrogen accumulated in grains and stovers was determined using the micro-kjeldahl digestion method (Bremner and Mulvaney, 1982). Results obtained were used for the calculation of the following nitrogen use efficiencies and harvest index (Fageria*et al.*, 2010).

Agronomic Efficiency of Nitrogen (AEN) $= \frac{Gf - Gu}{Na} =$ (kg/kg)

Where Gf = the grain yield of fertilized plot (kg)

Gu = the grain yield for the unfertilized plot (kg)

Na = the quantity of N applied (kg)

Physiological Efficiency of Nitrogen (PEN) = $\frac{Yf - Yu}{Nf - Nu}$(kg/kg)

Where; Yf = total biological yield (grains + stalks) of a fertilized plot (kg)

Yu = total biological yield (grains + stalks) of unfertilized plot (kg)

Nf = Nutrient accumulation of the fertilized plot (kg)

Nu = Nutrient accumulation of the unfertilized plot (kg)

Recovery Efficiency of Nitrogen (REN) $= \frac{Nf - Nu}{Na} \times \frac{100}{1}$(%)

Where; Na = the quantity of N applied (kg)

Nf = Nitrogen accumulation of the fertilized plot (kg)

Nu = Nitrogen accumulation of the unfertilized plot (kg)

Nitrogen Use Efficiency (NUE) = $PEN \times REN$ (kg kg^{-1})

Grain Harvest Index (HI) = Grain yield / above ground biomass

Profitability of fertilizer use was estimated using Value Cost Ratio (VCR), Output-Input (O/I) ratio and Input-Output price (P_N/P_O) ratio (Morris *et al*., 2007).

VCR is given by the relation

Marginal Revenue / Total cost of fertilizers.

Where; Marginal Revenue = (Target yield – Control) x Price of 1kg of grain

Total cost of fertilizers = Quantity of each fertilizer x Price of each fertilizer).

O/I ratio is given by the relation

Quantity of grain harvested (kg ha^{-1})/ Quantity of fertilizer applied (kg ha^{-1}).

P_N/P_O ratio is given by the relation

Total cost of applied fertilizer / Total Revenue.

Where Total Revenue = quantity of grain harvested (kg) X Price of 1 kg grain

3.3.7 Statistical Analysis

Data collected were subjectedtoanalysisofvariance(ANOVA)using the GLMprocedureofSAS(SAS, 1999).Wherethe F-ratioswere found tobesignificant,treatment means were separated usingthe Duncan Multiple Range Test (DMRT).

CHAPTER FOUR

4.0 RESULTS

4.1 Initial Physical and Chemical Properties of the Soils.

The results of some of the physical and chemical properties of the soils of the study area are presented on Table 4.1. The results show that the soils were dominated by sand sized particles, as the textural class was sandy loam. The soils had near neutral pH, although the pH in $CaCl_2$for Saulawa declined slightly in 2013 to slightly acidic. Organic matter was low as is the case with most savanna soils.The mean total N was 0.67 g kg^{-1}in 2012 and 0.71 g kg^{-1} in 2013. Effective CEC for the soils were 4.03cmol kg^{-1} for Pampaida, 5.28cmol $kg^{-1}$for Saulawa, and 4.03cmol kg^{-1} for Fulani Sule.Mean Available P for the three locations was 14.14 $mgkg^{-1}$after the first planting season, while average exchangeable K for the three farms was 0.28 cmol kg^{-1}.

Table 4.1: Effects of imposed treatments between 2012 and 2013 on the soil properties of three farms inIkara, NGS Nigeria.

Soil properties	Soil content		
	Pampaida	Saulawa	Fulani Sule
Sand (g kg^{-1})	785.31	594.10	660.70
Silt (g kg^{-1})	149.19	321.59	273.87
Clay (g kg^{-1})	65.50	84.33	65.44
Textural class	Loamy Sand	Sandy Loam	Sandy Loam
pH(H_2O)	6.79	5.77	6.61
pH($CaCl_2$)	6.02	5.15	6.08
Organic Matter (g kg^{-1})	8.07	8.14	10.40
Total Nitrogen (g kg^{-1})	0.81	0.68	0.83
Av. Phosphorus (mg g^{-1})	8.68	23.49	16.88
C:N ratio	7.84	7.13	7.57
Exch. Bases (cmol kg^{-1})			
Ca^{2+}	2.33	1.08	2.63
Mg^{2+}	0.89	0.79	0.94
K^{+}	0.10	0.62	0.12
Na^{+}	0.67	1.42	0.26
Exch. Acidity (cmol kg^{-1})	0.18	0.31	0.14
Effective CEC	3.72	4.20	3.71
Base Saturation	0.49	0.30	0.49
Ext Micronutrients (mg kg^{-1})			
Mn	10.58	15.45	31.74
Cu	21.10	42.02	4.06
Fe	40.49	25.10	45.05
Zn	5.19	2.81	7.34

4.2 Soil Microbial Biomass Carbon (SMB_C) and Nitrogen (SMB_N)

4.2.1 Effects of combined fertilizer and organic manure on SMB_C and SMB_N

The results of microbial biomass carbon and nitrogen as affected by combined fertilizer and organic manure application are presented in Table 4.2. The results show that combining N-fertilizer and organic manure increased soil microbial biomass carbon (SMB_C) and soil microbial biomass nitrogen (SMB_N). While SMB_C seemed to increase with increasing rate of nitrogen, the pattern was not regular with SMB_N. However, 90 kg N ha^{-1} maintained the highest SMB_N for all three locations and combined except in Pampaida where the highest SMB_N resulted from 120 kg N ha^{-1}. SMB_C varied from 65.54mg kg^{-1} in the N unfertilized plot in Saulawa, to 200.72 mg kg^{-1} in the 120 kg N ha^{-1} fertilized plot in Fulani Sule. SMB_N ranged from 6.50 in the N-unfertilized plot in Fulani Sule to 20.75 mg kg^{-1} in the 120kg N ha^{-1}fertilized plot in Saulawa. Mean SMB_C and N are 130.63 and 11.95 mg kg^{-1} respectively. Soil microbial biomass C:N ratio ranged from 10.3:1 to 10.9:1 with a mean C:N ratio of 10.6:1.

4.2.2 Effects of maize-legume cropping systems on SMB_C and SMB_N

Results of $SMB_C$and SMB_Nas affected by maize-legume cropping systems are presented in Table 4.3. The results show that SMB_C was affected by cropping systems and locations. In Pampaida, SMB_C ranged from 106.02 to 196.63 mg kg^{-1} with a mean of 149.83 mg kg^{-1}.The range was 9.22 to 184.34 mg kg^{-1} in Saulawa and 99.12 to 196.53 mg kg^{-1} in Fulani Sule. Their respective means were 149.51 and 141.08 mg kg^{-1}. In all locations, maize after soybean and groundnut gave higher SMB_C followed by maize-soybean and maize-groundnut strips. Continuous maize-cowpea intercrop returned the lowest SMB_C. In the combined analysis, the pattern was similar as plots where maize was cropped after soybean had 191.17 mg kg^{-1} SMB_Cwhich was higher than those obtained in plots where maize was cropped after groundnut (169.32 mg kg^{-1}) and maize-soybean strip which were statistically similar. Although the SMB_C from maize after groundnut plots were statistically similar with maize after soybean and maize-soybean strip, it was significantly higher than the SMB_C obtained from maize-groundnut strip (124.26 mg kg^{-1}) and continuous maize-cowpea intercrop which were statistically the same. The SMB_C due to maize after groundnut and soybean contributed the most percentages (3.59 and 3.55) to total organic carbon in the soil. Maize after soybean contributed the most to SMB_N in Pampaida and Fulani Sule (18.00 and 19.25 mg kg^{-1}), whereas the case was different in Saulawa where the most contribution to SMB_N (17.50 mg kg $^{-1}$) came from plots where maize was cropped after groundnut plot. In all three locations, however, the continuous maize-cowpea intercrop returned the least contribution to $SMB_{N.}$ In the combined analysis, maize after soybean and groundnut significantly contributed the most to SMB_N (17.83 and 16.50 mg kg^{-1} respectively). They were followed by maize-soybean strip whose contribution to SMB_N was significantly better maize-groundnut strip. The least contribution came from the continuous maize-cowpea intercrop.

The most percentage contribution of $SMB_N$to total nitrogen was from maize-soybean strip (1.72) whereas the least was from the maize after soybean (1.22). SMB_C to N ratio ranged from 10.82 to 10.26. The lowest MBC: MBN ratio was in maize after groundnut whereas the highest and poorest came from maize-soybean strip.

Table 4.2: The influence of combined N fertilizer and organic manure on soil microbial biomass carbon and nitrogen in Pampaida, Saulawa and Fulani Sule, 2013

Treatments	Soil Microbial Biomass C (mg kg^{-1})			Soil Microbial Biomass N (mg kg^{-1})			SMBC/SMBN ratio
N fertilizer + SG Manure	Pampaida	Saulawa	Fulani Sule	Pampaida	Saulawa	Fulani Sule	
0N	94.22c (2.22)	65.54e (1.33)	69.64c (1.38)	7.25d (1.06)	8.00c (1.14)	6.50e (1.00)	10.55
M	139.28b (2.97)	122.89c (2.17)	94.22c (1.86)	11.50c (1.32)	8.00c (1.57)	9.75d (1.63)	12.18
30NM	102.41c (2.42)	94.22d (1.77)	122.89b (2.33)	16.00b (1.57)	15.50b (1.96)	14.75c (1.87)	6.91
60NM	135.18b (2.59)	126.99c (2.49)	143.37b (2.85)	18.00a (2.09)	17.50b (2.19)	18.50b (2.61)	7.51
90NM	126.99b (2.57)	159.76b (3.01)	184.34a (3.86)	21.00a (1.75)	19.50ab (3.00)	24.50a (2.55)	7.25
120NM	176.15a (3.57)	192.53a (3.37)	200.72a (3.99)	19.50a (2.87)	20.75a (2.73)	17.50b (2.69)	9.86
Mean	129.04	126.99	135.86	18.65	17.85	18.30	7.15
SE±	25.27	24.87	28.12	3.25	3.00	2.75	

Means of treatment set followed by unlike letters are significantly different at 5% level of significance using Duncan Multiple Range Test.
Values in parenthesis are calculated as percentages of total organic C and N of the plots
M = Manure, N = Nitrogen fertilizer, SMBC = Soil Microbial Biomass Carbon, SMBN = Soil Microbial Biomass Nitrogen, SG = Sheep and Goat.

Table 4.3: Influence of maize rotation with soybean and groundnut, strip cropping with soybean and groundnut, and continuous maize-cowpea intercrop on soil microbial biomass carbon and nitrogen in Pampaida, Saulawa and Fulani Sule in 2013.

Treatments	Soil Microbial Biomass C (mg kg^{-1})			Soil Microbial Biomass N (mg kg^{-1})			SMBC/SMBN ratio
Maize-Legume Cropping Systems	Pampaida	Saulawa	Fulani Sule	Pampaida	Saulawa	Fulani Sule	
Maize after Soybean	196.63a (4.69)	184.34a (3.04)	192.53a (3.26)	18.00a (1.08)	16.25b (1.45)	19.25a (1.18)	10.72
Maize-Soybean Strip	143.37ab (2.96)	155.66a (2.59)	147.47ab (2.64)	14.25ab (1.93)	12.75b (1.63)	14.25b (1.64)	10.82
Maize after Groundnut	180.24a (4.25)	176.15a (3.40)	151.57ab (3.20)	16.00a (1.2)	17.50a (1.77)	16.00b (1.43)	10.26
Maize-Groundnut Strip	122.89ab (2.50)	135.18ab (2.53)	114.70b (2.32)	12.75b (1.52)	11.25b (1.46)	11.25c (1.34)	10.58
Continuous Maize-Cowpea Intercrop	106.02b (2.42)	96.22b (1.69)	99.12b (1.71)	11.00c (1.21)	8.20 (1.09)	9.00d (1.76)	10.68
Mean	149.83	149.51	141.08	14.40	13.19	13.95	10.60
SE±	24.29	18.04	19.08	2.75	3.00	2.75	

Means of treatment set followed by unlike letters are significantly different at 5% level of significance using Duncan Multiple Range Test.
Values in parenthesis are calculated as percentages of total organic C and N of the plots
SMBC = Soil Microbial Biomass Carbon, SMBN = Soil Microbial Biomass Nitrogen.

4.3 Effects of the SoleInorganic N Fertilizer Vs. Combined Inorganic N Fertilizer and Manure on Maize Yields and Yield Parameters.

4.3.1 Stover and grain yields

Results of stover and grain yields as influenced by sole inorganic N and manure combined with inorganic N are presented in Table 4.4. The results show that inorganic N fertilizer alone significantly influenced stover yields at the three farms. Increasing levels of N from 30 to 60kgN ha^{-1} had no significant effect on stover yield. Further increase to 90 kgN ha^{-1} led to a significant increase but was at par with 120 kg ha^{-1} N level.Combining N and manure application also had significant effect on stover yield in all locations as yields increased with increasing N levels. Yields ranged from 826 kg ha^{-1} to 4899 kg ha^{-1} with a mean of 3267 kg ha-^{1}. At Pampaida and Saulawa, there were increases with every level of N applied whereas at Fulani Sule, there were no significant yield increases when N level was increased from 30 to 60 kg N ha^{-1} and from 90 to 120 kg N ha^{-1}.The results also show that combined inorganic N and manure gave 8% more stover yield than sole inorganic N.

Grain yield was affected byfertilizer application at especially at higher doses with grain yield significantly increasing when N level was increased from 90 to 120 kg N ha^{-1}, with sol inorganic N application. The results further show that combined inorganic N fertilizer and manure application had significant effect on grain yield when Nlevel increased to 60 kg ha^{-1} except in Fulani Sule where only the increase of N level to 90 kg ha^{-1}significantlyincreased yield. Although there were yield increases when N level was raised to 90 and 120 kg ha^{-1}, these increases were not significant except in Fulani Sule.The difference between grain yield from plots that received fertilizer alone and fertilizer combined with organic manure is shown in Fig.4.1, showing that every N level increase resulted in a significant increase in grain. The combined application of fertilizer and organic manure relative to fertilizer alone increased grain yield by 32% in Pampaida, 27% in Saulawa and 35% in Fulani Sule, and there was significant improvement from 2.89 t ha^{-1} when inorganic N fertilizer alone was applied to 5.58 t ha^{-1} when combined with manure.

4.3.2 Nitrogen uptake

Treatment effects on nitrogen uptake are presented in Table 4.5. In the sole inorganic N treatment, nitrogen uptake was significant withthe addition of 60 kg N ha^{-1} in Pampaida, and a further increase to 120kg N ha^{-1} resulted in another significant N uptake. However in Saulawa and Fulani Sule, only the increase of N level from 90 to 120kg N ha^{-1} significantly improved N uptake. In the combined analysis however, uptake increased significantly with every level increase in N fertilizer. Combining inorganic N with manure significantly affected nutrient uptake when N level was raised to 120kg N ha^{-1} in Pampaida. In Fulani Sule and Saulawa however, there was no significant difference in uptake with each successive level increase in N fertilizer applied. Significant increase in uptake was observed only when N level was increased from 30 to 90kg N ha^{-1}in Saulawa, but in Fulani Sule when it was further raised to 120kg N ha^{-1}, there was no significant improvement. Thus with combined inorganic N and manure, nitrogen uptake increased by 26% in Pampaida, 9% in Saulawa and 25% in Fulani Sulecompared tosole inorganic N.Figure4.2 shows the combined effects of sole inorganic N and inorganic N combined with manure on the nitrogen uptake of maize in the three farms. The results show that the combined analysis corroborated the results in the three sites as uptake increased from 45.74kg ha^{-1} with sole fertilizer treatment alone to 68.99kg ha^{-1} when N was combined with sheep and goat manure.

4.3.3 Agronomic efficiency of Nitrogen

Results of the effects of fertilization and manuring on the agronomic efficiency of nitrogen (AEN) are presented in Table 4.5, showing that application of fertilizer alone increased AEN as N levels decreased. However, only 30kg N ha^{-1} significantly improved AEN in all the locations. With the combined application of inorganic N fertilizer with manure, the trend differed in Pampaida with AEN increasing with N levels while in other locations it followed no specific pattern.A linear relationship between N applied and grain yield and which describes increase in maize yield per unit N applied for the three farms combined is illustrated in Fig. 4.3. From the relationship, it can be observed that 1 kg of N applied with 2.5 t ha^{-1} manure gave 2.02 kg of maize grain, whereas without manure it gave 1.86 kg of maize grain. The gap widened as N level increases from such that with 30 kg N ha^{-1}, grain yield from inorganic N with manure was better by more than 48%. The figure also shows that agronomic efficiency of N improved from 23.25 kg kg^{-1} when inorganic N was applied alone to 45.5kg $kg^{-1}$when it was applied with manure, representing a 95% improvement.Fig. 4.4is a conceptual linear maize response to N fertilization showing the two ways by which the ISFM option of applying inorganic N in combination with manure increases the benefit of fertilizer application. Whereas A is the nutrients supplied by the N fertilizer applied, B represents the additional nutrients from the ISFM option which resulted in additional yield increase (C). As a result of manure addition, there was an improvement AEN which also resulted to yield increase (D). At 20 kg N ha^{-1} for instance, inorganic N applied alone gave about 2.20 tons of maize per hectare whereas at the same rate the combined N fertilizer and manure gave 3.0 t ha^{-1}. When the N level was increased to 40 kg N ha^{-1}, sole fertilizer gave 2.3 t ha^{-1} whereas the ISFM option gave 4.0 t ha^{-1}. With the highest N rate use in this study, maximum grain yield from fertilizer alone is 3.94t ha^{-1}, while the ISFM option gave 8.0 tons per hectare.

Table4.4: Stover and grain yields as affected by mineral N fertilizer alone and mineral N fertilizer combined with manure in Pampaida, Saulawa and Fulani Sule in 2013.

Treatments	Stover Yield (kg ha^{-1})			Grain Yield (t ha^{-1})		
Mineral N alone	Pampaida	Saulawa	Fulani Sule	Pampaida	Saulawa	Fulani Sule
0	419d	874d	584d	1.72d	1.72d	1.62d
30	2709c	2709c	2709c	2.63c	2.63c	2.63c
60	3179bc	3179bc	3179bc	3.00bc	3.00bc	3.00bc
90	4076ab	4076ab	4076ab	3.28b	3.28b	3.28b
120	4634a	4634a	4634a	3.93a	3.93a	3.93a
Mean	3004	3095	3037	2.91	2.91	2.91
SE±	333.2	335.84	330.21	0.17	0.17	0.17
N + 2.5 t SGM ha^{-1}						
0	826d	1143d	1203c	2.28e	2.15d	2.37d
30	2848c	2941c	2942b	3.73d	3.71c	4.25c
60	3183c	3208c	3086b	5.35bc	5.30b	5.32bc
90	4382b	4419b	4578a	6.52ab	5.83ab	6.93b
120	4787a	4899a	4858a	7.92a	6.93a	9.73a
Mean	3205	3322	3273	5.16	4.78	5.72
SE±	391.24	344.13	371.43	0.46	0.37	0.78

Means of treatment set followed by unlike letters are significantly different at 5% level of significance using Duncan multiple range test (DMRT).
N = Nitrogen SGM = Sheep and Goat Manure.

Table 4.5: Nitrogen uptake and agronomic efficiency of nitrogen as affected by sole mineral N fertilizer and mineral N fertilizer combined with sheep and goat manure in Pampaida, Saulawa and Fulani Sule in 2013.

Treatment	Nitrogen Uptake (kg ha^{-1})			Agronomic Efficiency of Nitrogen (kg kg^{-1})		
N alone	Pampaida	Saulawa	Fulani Sule	Pampaida	Saulawa	Fulani Sule
0	11.31d	15.83c	13.58d	0	0	0
30	44.79c	42.82b	26.09cd	35.22a	30.23a	33.62a
60	46.20c	53.30b	41.44bc	23.68b	21.25b	22.94b
90	56.27b	55.03b	52.51b	18.95c	17.32c	18.45c
120	66.92a	85.96a	74.03a	19.95c	18.37c	19.22c
Mean	45.1	50.58	41.53	24.36	21.79	23.56
SE±	2.53	3.89	5.12	1.31	1.31	1.31
N + 2.5 t SGM ha^{-1}						
0	40.01d	34.39c	37.10c	0	0	0
30	55.98cd	47.16bc	52.70bc	43.28b	39.92b	57.72a
60	77.44bc	77.90a	73.96ab	47.27a	44.82a	46.35b
90	94.95b	86.33a	91.92a	45.03a	37.43b	48.39b
120	128.41a	68.93ab	99.16a	45.40a	37.28b	58.01a
Mean	79.36	62.94	70.97	45.24	39.86	51.37
SE±	8.6	8.54	11.26	3.20	3.20	3.20

Means of treatment set followed by unlike letters are significantly different at 5% level of significance using Duncan multiple range test (DMRT).
N = Nitrogen SGM = Sheep and Goat Manure

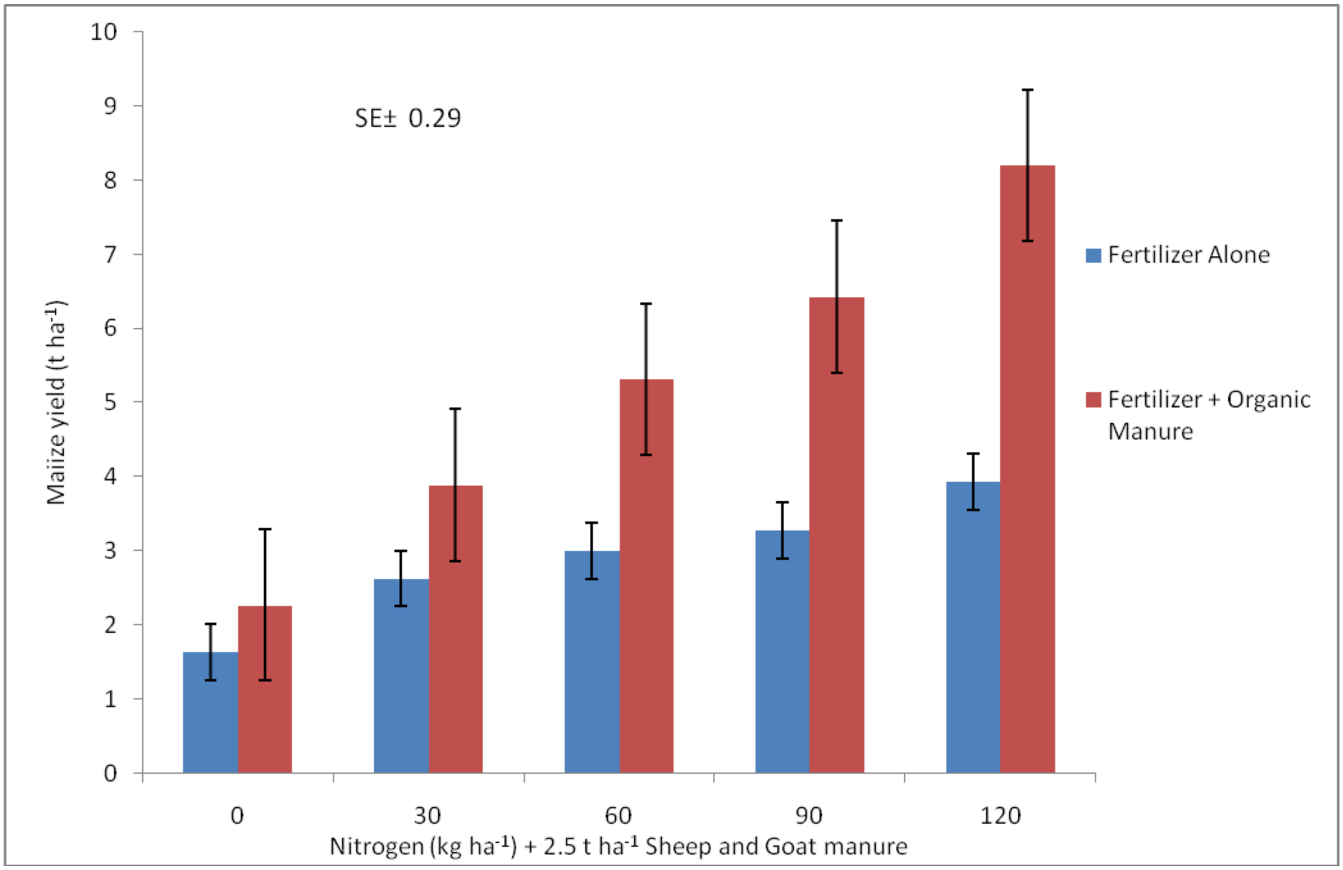

Fig. 4.1: Maize grain yield as affected by fertilizer alone and combined fertilizer + Sheep and Goat manure in Ikara, NGS**.**

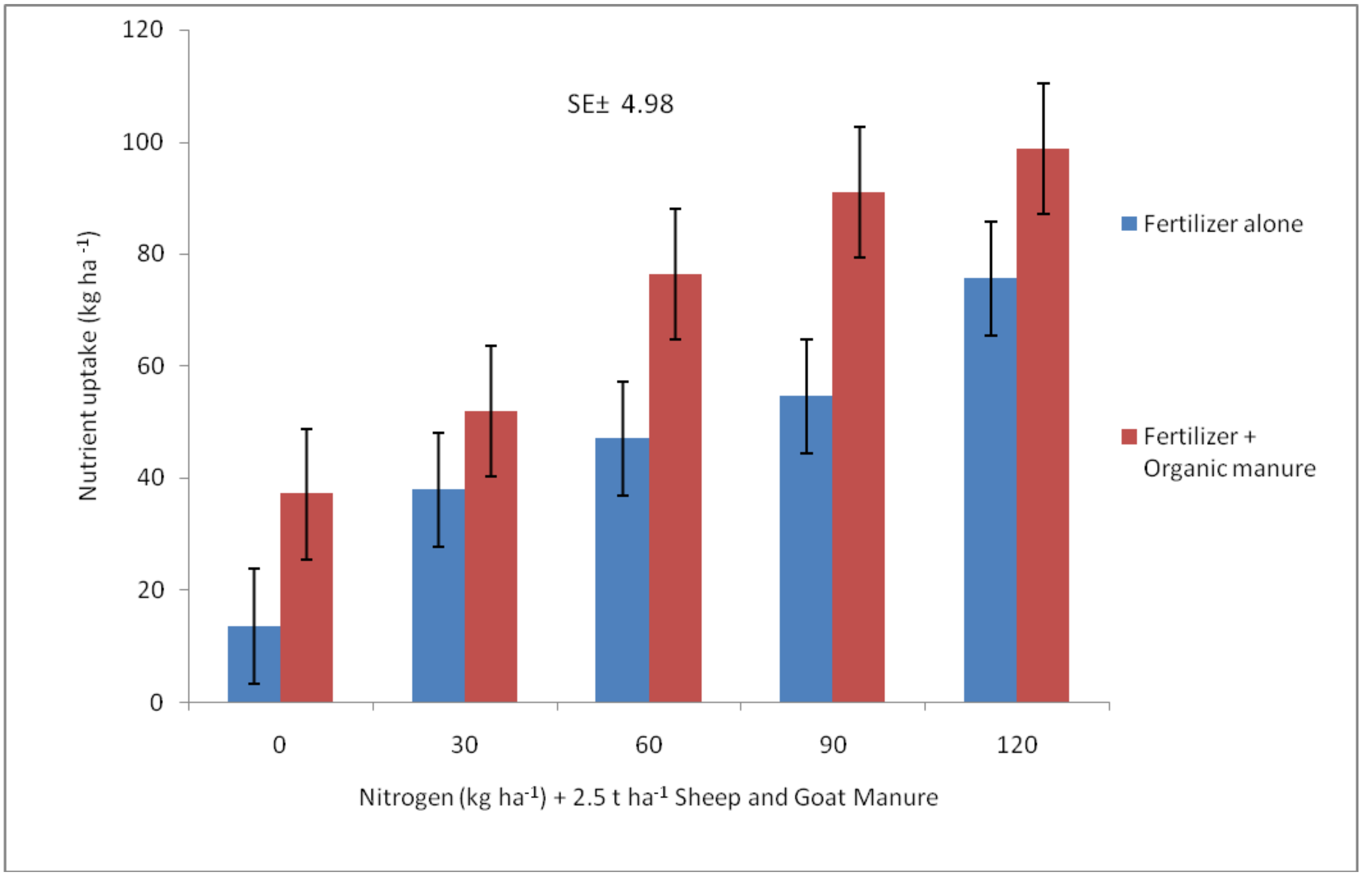

Fig. 4.2 Effect of fertilizer applied alone and fertilizer combined with manure on the nutrient uptake of maize in Ikara, NGS Nigeria

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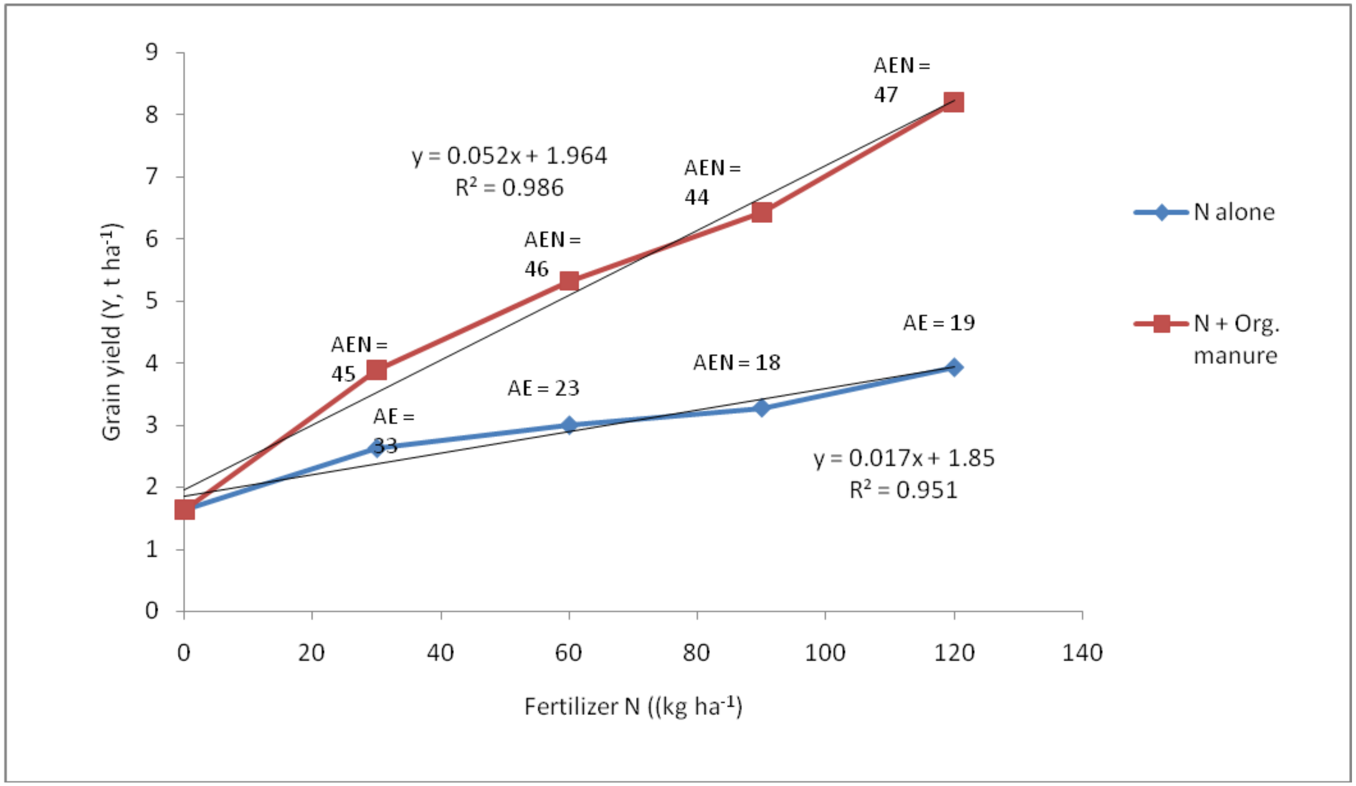

Fig. 4.3: Relationship between maize grain yield, nitrogen rates and the agronomic efficiency of nitrogen (AEN) as affected by inorganic N fertilizer alone and in combination with manure in Ikara, northern Guinea savanna (NGS) Nigeria.

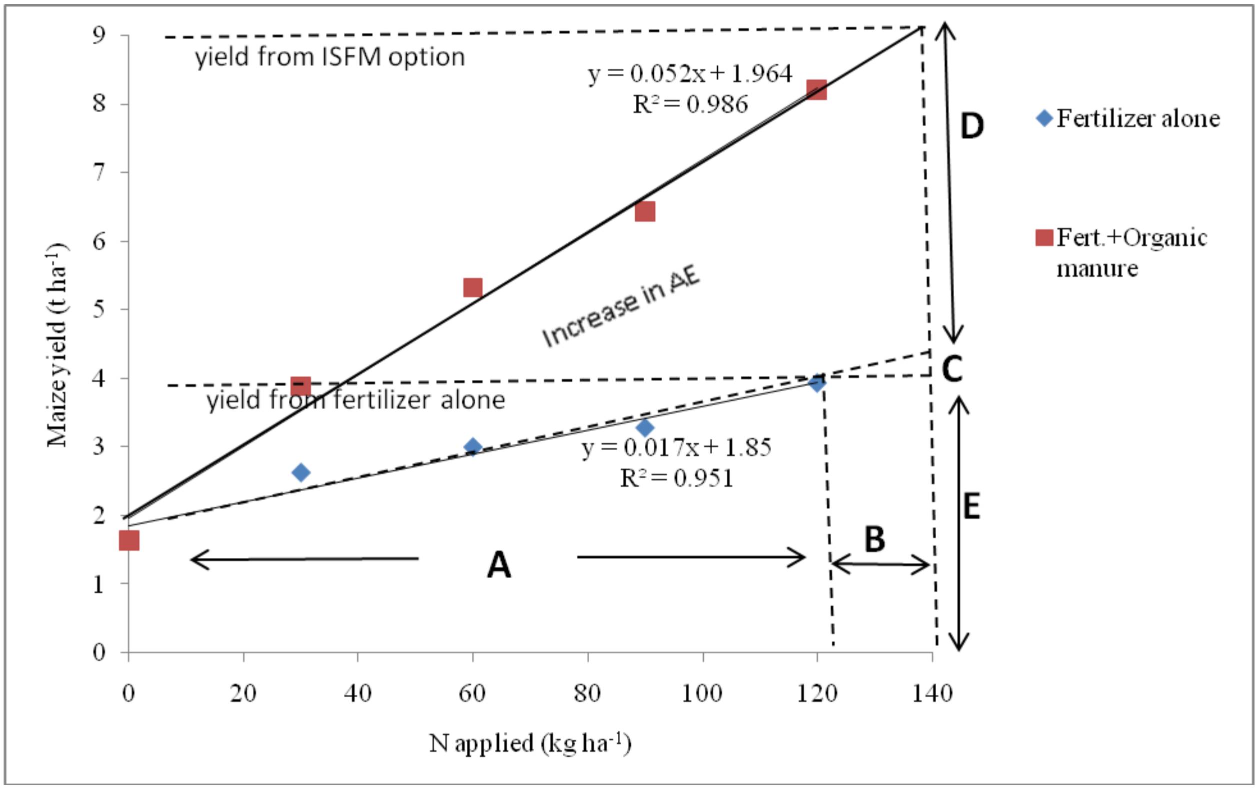

Fig. 4.4: Conceptual diagram of the yield increase from improved agronomic efficiency (AE) of combined fertilizer and organic manure application

A = Nutrient supplied by N fertilizer

B = Additional nutrients available as a result of the combined application of N fertilizer and manure.

C = Yield increase from additional nutrient supplied.

D = Yield increase as a result of improved agronomic efficiency.

4.3.4 Physiological efficiency of Nitrogen

Results of the effects of N fertilization with and without manure on the physiological and uptake efficiencies of N are presented in Table 4.6. The results show that in Pampaida, with sole inorganic N fertilizer, physiological efficiency (PEN) increased with increasing N levels and with significant improvement when N level was increased from 30kg N $ha^{-1}$to 120kg N ha^{-1}. A similar trend was observed at 60 kg N ha^{-1} and 90kg N ha^{-1}. In Saulawa PEN increased with N levels up to 90 kg Nha^{-1}, and reduced as the level was further increased to 120kg N ha^{-1}, whereas in Fulani Sule, there was no significant effect of N levels on the physiological efficiency. When inorganic N was applied in combination with manure, PEN increased with increase in N levelsas was observed in N without manure, but this time in all the farms. There was however no significant effect except in Saulawa where only the maximum increase of N level up to 120kg N ha^{-1} significantly increased PEN. Physiological efficiency of N was higher with combined fertilizer and organic manure than with fertilizer alone by 164% in Pampaida, and over 600% and 200%in Saulawa and Fulani Sule respectively. In the combined analysis, physiological efficiency increased from 12.5 kg kg^{-1} with fertilizer alone to 48.99 kg kg^{-1} with fertilizer combined with organic manure (Fig 4.5 and 4.6). The linear equation shows maize response to a unit uptake of N, and with sole N fertilizer a unit uptake of grain translated to 1.23 units of maize yield, whereas it was 2.33 with inorganic N combined with manure. When N level was increased to 30 kg N, a huge gap of up to 61% was established between yieldsresponses to N uptake with inorganic N combined with manure as against when it is applied alone.

4.3.5 **Nitrogen uptakeefficiency**

For uptake efficiency, the result shows that with N fertilizer alone, nitrogen uptake efficiency (NUpE) increased with decreasing N levels except in Fulani Sule where the reverse was the case.

There was a significant increasewhen N levels was reduced to 30kg N ha^{-1} in Pampaida and Saulawa, but there was no significant effect of N levels on NUpE in Fulani Sule. With inorganic fertilizer combined with manure,NUpE reduced with increasing levels of N, with Pampaida showing a significant improvement in NUpE when N level was reduced from 60 to 30kg N ha^{-1}. In Saulawa, significant effect on NUpE was observed when N level was reduced from120kg N ha^{-1} to 60kg N ha^{-1} which was statistically similar to NUpE at 30 kg N ha, yet with varying N levels, no significant effect was observed in Fulani Sule. When the three locations were combined, there was significant improvement on NUpE as N levels fail from 120kg N ha^{-1} to 30kg N ha^{-1}, with statistically similarity observed among the N levels. Nitrogenuptake efficiency was higher with combined inorganic N and manure application (0.74kg kg^{-1}) relative to inorganic N alone (0.59kg kg^{-1}) as shown in Fig. 4.6.

4.3.6 Harvest Index

Results of harvest index as affected by mineral N fertilizer alone and mineral N fertilizer combined with manure are presented in Table 4.7. The result shows that harvest index (HI) decreased with increasing N levels, and showed no significant effect with the different N levels. When manure was incorporated however, the trend was different as HI increased with increasing levels of N. There was no significant effect by N levels except in Saulawa where HI was significantly reduced as N was reduced to 30kg N ha^{-1}, whereas the other N levels gave statistically similar effects on HI. Harvest index was higher with combined inorganic N and manure by 26% in Pampaida, 24% in Saulawa and 25% in Fulani Sule. Combined analysis showed an improvement from 0.48 when inorganic N was applied without manure to 0.8 when it was combined with 2.5 t ha^{-1} manure.

Table 4.6: Effect of fertilization and manuring on physiological efficiency and uptake efficiency of nitrogen

Treatments	Physiological Efficiency of N (kg kg^{-1})			Recovery Efficiency of N (kg kg^{-1})		
	Pampaida	Saulawa	Fulani Sule	Pampaida	Saulawa	Fulani Sule
Inorganic N (kg ha^{-1})						
0	0	0	0	0	0	0
30	10.82b	5.01b	26.51	1.12a	0.90a	0.42b
60	17.74ab	7.68ab	22.48	0.58b	0.62b	0.46ab
90	18.04ab	12.55a	18.12	0.50c	0.44c	0.43b
120	22.21a	9.35ab	17.01	0.46c	0.58b	0.50a
Mean	17.20	6.92	16.82	0.66	0.64	0.45
SE±	8.40	1.62	5.46	0.04	0.04	0.04
Inorganic N(kg ha^{-1}) + manure (2.5 t ha^{-1})						
0	0	0	0	0	0	0
30	43.42	52.56b	51.79	0.90a	0.73a	0.84a
60	59.3	53.75b	52.58	0.83b	0.78a	0.75b
90	61.52	61.02b	56.95	0.76c	0.64b	0.74b
120	57.63	103.07a	81.22	0.84b	0.38c	0.67c
Mean	45.35	54.08	48.51	0.83	0.63	0.75
SE±	8.40	8.40	10.71	0.05	0.05	0.05

Means of treatment set followed by unlike letters are significantly different at $P < 0.05$ using Duncan multiple range test (DMRT).

Table 4.7: Effects of fertilization and manuring on nitrogen use efficiency and harvest index.

Treatments	Harvest Index (%)		
	Pampaida	Saulawa	Fulani Sule
Inorganic N (kg ha^{-1})			
0	0.75a	0.65a	0.71a
30	0.42b	0.43b	0.43b
60	0.42b	0.42b	0.42b
90	0.41b	0.41b	0.41b
120	0.42b	0.42b	0.42b
Mean	0.49	0.47	0.48
SE±	0.02	0.02	0.02
Inorganic N(kg ha^{-1}) + manure (2.5 t ha^{-1})			
0	0.81	0.72b	0.73
30	0.82	0.72b	0.8
60	0.81	0.80a	0.8
90	0.83	0.83a	0.81
120	0.87	0.84a	0.85
Mean	0.83	0.78	0.8
SE±	0.02	0.02	0.02

Means of treatment set followed by unlike letters are significantly different at $P < 0.05$ using Duncan multiple range test (DMRT).

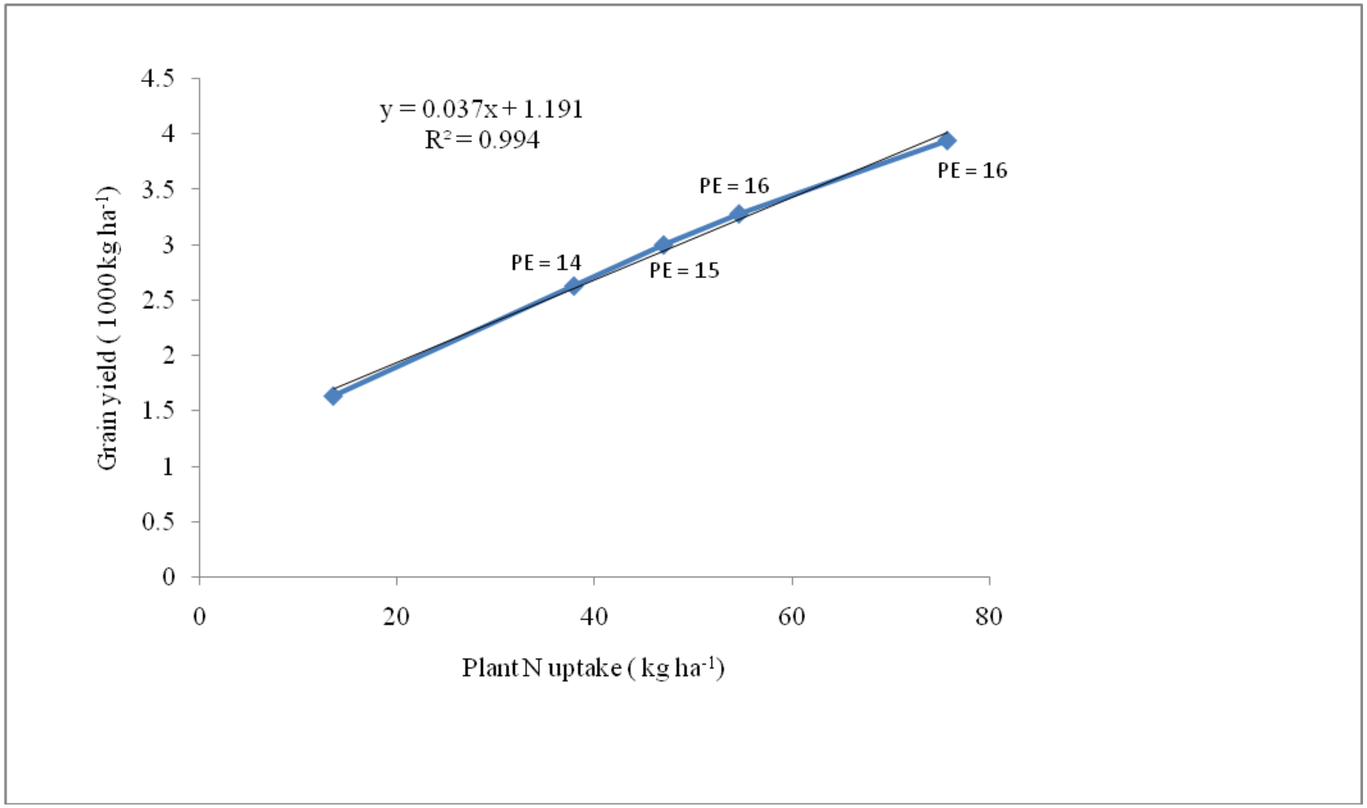

Fig. 4.5: Relationship between grain yield, plant N uptake and the physiological efficiency of fertilizer at five different rates of N applied alone in Pampaida, Saulawa and Fulani Sule combined.

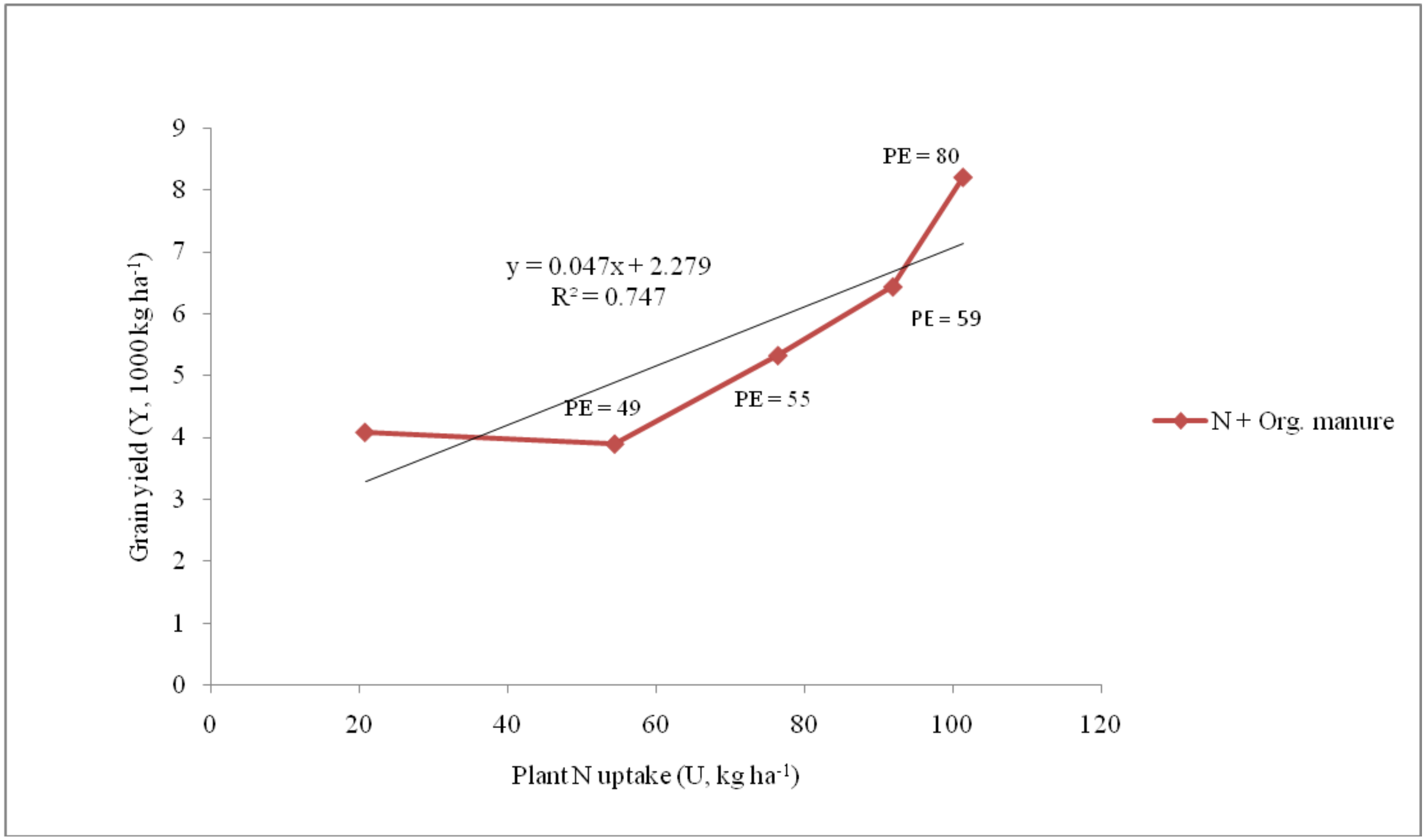

Fig. 4.6:Relationship between grain yield, plant N uptake and the physiological efficiency of fertilizer at five different rates of N applied in combination of manure in Pampaida, Saulawa and Fulani Sule combined.

4.4 Effects of Maize-Legume Systems on the Maize Yields and Yield Parameters

4.4.1 Maize yields

The results of maizestover yields as affected by maize rotation with soybean (SBMZRT) and groundnut (GNMZRT), maize strip cropping with soybean (SBMZSP) and groundnut (GNMZSP), and continuous maize cowpea intercrop (CTMZCPInt) are presentedin Table 4.8. The results show that maize stover yield ranged from 1054kg ha^{-1} to 2328kg ha^{-1}, with a mean of 1570kg ha^{-1}. SBMZSP gave the significantly highest yield (2329kg ha^{-1}) followed by GNMZSP with 1947kg ha^{-1}which was significantly higher than the rest. There was no significant difference between stover yields from SBMZRT (1249 kg ha^{-1}), GNMZRT (1268 kg ha^{-1}) and CMZCPint (1055 kg ha^{-1}). With respect to the different farms, the 1731kg ha^{-1}obtained from Fulani Sule was the highest maize stover yield which was statistically the same as 1687kg ha^{-1}in Saulawa. These two were significantly higher than 1289kg ha^{-1}recorded at Pampaida.Maize grain yields ranged from 2810 to 7790 kg ha^{-1} with the mean grain yield of 5940kg ha^{-1}. There was no significant difference in the grain yields from all treatments except the CMZCPint which was significantly lower than the rest. With respect to location, grain yields showed no significant difference.

4.4.2 Nitrogen Uptake

Nitrogen uptake in maize-legume systems ranged from 40.66 to 111.58kgha^{-1}(Table 4.9). The mean nitrogen uptake was 90.13kgha^{-1}. There was no significant difference in nutrient uptake between all the treatments except the CMZCPint (40.66kgha^{-1}) which had a significantly lower uptake than the rest. A similar trend was observed when combined analysis was carried out.Nitrogen uptake was affected by location as significantly higher uptake was observed in Pampaida (103.69 kg ha^{-1}) than in Saulawa (85.12 kg ha^{-1}) and Fulani Sule (81.60 kg ha^{-1}), which were statistically the same. Agronomic efficiency of nitrogen (AEN) ranged from 16.5 to

63.74 kg kg^{-1}, with a mean AEN of 49.51 kg kg^{-1}. All treatments showed no significant difference in AEN except the CMZCPint (16.50 kg kg^{-1}) which had a significantly lower than the other treatments. With respect to location, AEN was better in Pampaida (53.18 kg kg^{-1}) and Fulani Sule (53.18 kg kg^{-1}) than in Saulawa which recorded a significantly lower efficiency (42.17kgkg^{-1}).

4.4.2 Harvest Index of Maize.

The result of the effects of maize rotation with soybean (SBMZRT) and groundnut (GNMZRT), maize strip cropping with soybean (SBMZSP) and groundnut (GNMZSP), and continuous maize cowpea intercrop (CTMZCPInt) on harvest index (HI) is presented in Table 4.10. The result shows that harvest index in these maize-legume systems ranged from 0.72 to 0.81%, with a mean of 0.76%. Maize after soybean (0.81%) and after groundnut (0.80%) gave the highest HI which were significantly higher than the rest. There were no significant differences in the HI of the other treatments.In terms of location, Pampaida recorded a significantly higher HI (0.78%) than the other two locations which both recorded 0.75% harvest index.

Table 4.8: Maize yields as affected by maize-legume systems

Treatments	Stover Yield (kg ha^{-1})				Grain Yield (t ha^{-1})			
	Pampaida	Saulawa	Fulani Sule	Combined analysis	Pampaida	Saulawa	Fulani Sule	Combined analysis
Maize-Legume Cropping Systems								
SBMZRT	1041b	1032b	1675b	1249c	6.48a	6.60a	7.79a	6.96a
SBMZSP	2122a	2567a	2297a	2329a	6.98a	6.07a	6.62a	6.55a
GNMZRT	1090b	1090b	1625b	1268c	6.15ab	6.13a	7.49a	6.59a
GNMZSP	1372b	2483a	1986ab	1947b	6.26ab	5.98a	6.84a	6.36a
CMZCPint	821b	1268b	1075c	1055c	3.59b	2.81b	3.31b	3.23b
Mean	1289	1688	1732	1570	5.89	5.52	6.41	5.94
SE±	184	213	121	122	0.85	0.6	0.78	0.4

Means in the same column followed by unlike letters are significantly different at $P < 0.05$ levels of significance using Duncan Multiple Range Test

SBMZRT = Soybean/Maize Rotation, SBMZSP = Soybean-Maize Strip Cowpea relay, GNMZRT = Groundnut/Maize Rotation
GNMZSP = Groundnut-Maize Strip Cowpea relay, CMZCPint = Continuous Maize-Cowpea intercrop

Table 4.9: Effects of maize-legume systems on nitrogen uptake and agronomic efficiency of nitrogen.

Treatments	Nitrogen Uptake (kg ha^{-1})				Agronomic Efficiency of Nitrogen (kg kg^{-1})			
	Pampaida	Saulawa	Fulani Sule	Combined analysis	Pampaida	Saulawa	Fulani Sule	Combined analysis
Maize-Legume Cropping Systems								
SBMZRT	133.33a	102.62a	98.79a	111.58a	68.50a	54.22a	68.50a	63.74a
SBMZSP	102.59a	88.09a	87.94a	92.87a	55.55a	48.25a	55.55a	53.12a
GNMZRT	133.33a	108.38a	83.15a	109.06a	65.16a	48.98a	65.16a	59.77a
GNMZSP	104.55a	85.55a	99.37a	96.49a	57.99a	47.32a	57.99a	54.43a
CMZCPint	42.30b	40.93a	38.73b	40.66b	18.70b	12.10b	18.70b	16.50b
Mean	103.69	85.12	81.6	90.13	53.18	42.17	53.18	49.51
SE±	14.45	10.45	9.22	6.47	8.62	6.65	8.62	4.02

Means in the same column followed by unlike letters are significantly different at $P < 0.05$ levels of significance using Duncan Multiple Range Test

SBMZRT = Soybean/Maize Rotation, SBMZSP = Soybean-Maize Strip Cowpea relay, GNMZRT = Groundnut/Maize Rotation GNMZSP = Groundnut-Maize Strip Cowpea relay, CMZCPint = Continuous Maize-Cowpea intercrop

Table 4.10: Effects of maize-legume systems on nitrogen use efficiency and harvest index

Treatments	Nitrogen Use Efficiency (kg kg^{-1})				Harvest Index (%)			
	Pampaida	Saulawa	Fulani Sule	Combined analysis	Pampaida	Saulawa	Fulani Sule	Combined analysis
Maize-Legume Cropping Systems								
SBMZRT	46.67a	30.11a	46.09a	40.96a	0.82	0.82a	0.79a	0.81a
SBMZSP	38.56a	26.54a	36.12a	33.74a	0.73	0.70b	0.71b	0.72b
GNMZRT	43.43a	25.21a	43.71a	37.45a	0.81	0.80a	0.79a	0.80a
GNMZSP	40.15a	25.89a	37.32a	34.45a	0.76	0.69b	0.74ab	0.73b
CMZCPint	9.73b	12.55b	8.27b	10.18b	0.8	0.72b	0.71b	0.74b
MEAN	35.7	24.06	34.3	31.36	0.78	0.75	0.75	0.76
SE±	6.38	2.93	6.61	2.98	0.03	0.01	0.02	0.01

Means followed by different letter(s) in a column are significantly different at $P < 0.05$.
SBMZRT = Soybean/Maize Rotation, SBMZSP = Soybean-Maize Strip Cowpea relay, GNMZRT = Groundnut/Maize Rotation
GNMZSP = Groundnut-Maize Strip Cowpea relay, CMZCPint = Continuous Maize-Cowpea intercrop

4.4.3 Physiological and Uptake Efficiencies of Nitrogen.

The results of physiological efficiency of nitrogen (PEN) and uptake efficiency of nitrogen (NUpE) as affected maize rotation with soybean (SBMZRT) and groundnut (GNMZRT), maize strip cropping with soybean (SBMZSP) and groundnut (GNMZSP), and continuous maize cowpea intercrop (CTMZCPInt) is presented inTable 4.11. The results show that PEN ranged from 14.41 to 38.56 kg kg^{-1}, with a mean PEN of 33.39 kg kg^{-1}. All treatments showed statistically similar PEN. Fulani Sule (44.60 kg kg^{-1}) represented the best PE in terms of location, but it did not differ significantly from the PEN obtained at Pampaida (35.20 kg kg^{-1}) and Saulawa (20.36 kg kg^{-1}). Nitrogen uptake efficiency (NUpE) ranged from 0.3 to 1.08 kg kg^{-1}, with a mean NUpE of 0.85 kg kg^{-1}. All treatments showed no significant difference in NUpE except the CMZCPint (0.3 kg kg^{-1}) which was significantly lower than the others. Combined analysis gave a similar trend. Pampaida gave the highest NUpE (1.03 kg kg^{-1}) which was significantly higher than 0.77 kg kg^{-1}(Saulawa) and 0.76 kg kg^{-1}(Fulani Sule) which was statistically similar.

Table 4.11: Physiological efficiency uptake efficiency of nitrogen as affected by maize-legume cropping systems.

Treatments	Physiological Efficiency of N (kg kg^{-1})				Recovery Efficiency of N (kg kg^{-1})			
	Pampaida	Saulawa	Fulani Sule	Combined	Pampaida	Saulawa	Fulani Sule	Combined
Maize-legume cropping systems								
SBMZRT	34.74	32.04	47.75	38.18	1.36a	0.96a	0.95a	1.08a
SBMZSP	37.14	33.61	43.74	38.16	1.01a	0.80a	0.83a	0.88a
GNMZRT	32.65	25.08	57.95	38.56	1.38a	1.03a	0.77a	1.06a
GNMZSP	39.46	33.67	39.75	37.62	1.04a	0.77a	0.95a	0.92a
CMZCPint	32.01	-22.6	33.81	14.41	0.34a	0.28b	0.28b	0.30b
Mean	35.2	20.36	44.6	33.39	1.03	0.77	0.76	0.85
SE±	6.93	21.01	9.75	8.34	0.16	0.12	0.1	0.07

Means followed by different letter(s) a column are significantly different at $P < 0.05$.
SBMZRT = Soybean/Maize Rotation, SBMZSP = Soybean-Maize Strip Cowpea relay, GNMZRT = Groundnut/Maize Rotation
GNMZSP = Groundnut-Maize Strip Cowpea relay, CMZCPint = Continuous Maize-Cowpea intercrop

4.5 Profitability of Fertilizer Use

The profitability of nitrogen fertilizer use in sole application, combined inorganic N application with manure, as well as for the maize-legumes cropping systems in maize production was evaluated using Value Cost Ratio (VCR), Output-Input (O/I) ratio, and Input-Output price (P_N/P_O) ratio. The results are shown in Table 15. Value cost ratio represents the ratio of revenue from grain to the total cost of fertilizer applied.

Value Cost Ratio ranged from 1.33 to 1.73, while the mean VCR is 1.54 with sole inorganic N application. Ratio was highest at Fulani Sule (1.56) while Pampaida and Saulawa recorded the same ratio (1.45). In all locations, VCR was higherat 30 kg Nha^{-1}and 120 kg N ha^{-1}.With combined inorganic N and manure application, VCR ranged from 2.73 to 5.65 with a mean VCR of 3.75. 120 kg N ha^{-1} in Fulani Sule gave the highest VCR, while the lowest was with 30 kg N ha^{-1} in Saulawa. Unlike in sole inorganic N application, VCR increased with N levels. In the maize-legume cropping systems, VCR ranged from 0.96 to 5.44 having a mean of 3.79. The highest ratio was obtained from the soybean after maize in Fulani Sule whereas continuous maize cowpea relay in Saulawa recorded the least ratio.

Values of O/I ratio ranged from 8.75 to 13.16 with a mean of 10.12 for maize cultivated with sole inorganic N fertilizer. O/I ratio decreased with increasing N levels with 30 kg N ha^{-1}giving the highest O/I ratio (13.16). With the combined inorganic N fertilizer and manure, the ratio ranged from 14.13 to 22.22 with a mean O/I of 16.5. Unlike in the sole inorganic N application, O/I ratios here followed no specific pattern but 120 and 30 kg N ha^{-1} maintained the highest ratios at all locations and when combined.O/I ratio ranged from 7.49 to 20.75 with a mean of 15.82 with the maize-legume cropping systems. Maize after soybean in Fulani Sule gave the widest O/I ratio, whereas the narrowest was recorded in the continuous maize cowpea intercrop in Saulawa. Also maize-soybean systems gave higher ratios than maize-groundnut in all locations and when combined except Fulani Sule.

Input-output price ratio for maize production under sole inorganic N application ranged from 0.24 to 0.35with a mean value of 0.31. Values increased with increasing N-levels, but 120 kg N ha^{-1} was slightly lower than 90 kg N ha^{-1} which gave the highest P_N/P_O ratio. When inorganic N fertilizer was combined with manure, ratios were much lower and ranged from 0.15 in 120 kg N ha^{-1}in Fulani Sule to 0.21 in 90 and 120 kg N ha^{-1}in Saulawa. The mean P_N/P_O was 0.19. The results further show that in the maize-legume systems, P_N/P_Oratio ranged from 0.15 to 0.40 with a mean of 0.21.

Table 4.12: Effects of sole inorganic N fertilization, manuring in combination with inorganic N and maize-legume cropping systems on the profitability of fertilizer use in maize production.

	VCR				O/I				P_N/P_O			
Treatments	Pampaida	Saulawa	Fulani Sule	Combined analysis	Pampaida	Saulawa	Fulani Sule	Combined analysis	Pampaida	Saulawa	Fulani Sule	Combined analysis
Inorganic N (kg ha^{-1}).												
0N												
30N	1.45	1.45	1.61	1.58	13.16	13.16	13.16	13.15	0.24	0.24	0.24	0.24
60N	1.33	1.33	1.44	1.42	9.66	9.66	9.66	9.67	0.32	0.32	0.32	0.32
90N	1.38	1.38	1.47	1.45	8.75	8.75	8.75	8.74	0.35	0.35	0.35	0.35
120N	1.65	1.65	1.73	1.72	9.81	9.81	9.81	9.81	0.34	0.34	0.34	0.34
Mean	1.45	1.45	1.56	1.54	10.34	10.34	10.34	10.34	0.31	0.31	0.31	0.31
Inorganic N (kg ha^{-1}) + manure (2.5 t ha^{-1})												
0N												
30N	2.75	2.73	3.60	3.09	15.71	15.64	17.89	16.40	0.20	0.20	0.17	0.19
60N	3.41	3.37	3.48	3.47	15.39	15.25	15.30	15.31	0.20	0.20	0.20	0.20
90N	3.88	3.32	4.30	3.88	15.80	14.13	16.80	15.58	0.19	0.21	0.18	0.19
120N	4.32	3.63	5.65	4.57	18.09	15.84	22.22	18.72	0.18	0.21	0.15	0.18
Mean	3.59	3.26	4.26	3.75	16.25	15.21	18.05	16.50	0.19	0.20	0.17	0.19
Maize-legume cropping systems												
SBMZRT	4.20	4.31	5.44	4.69	17.26	17.59	20.75	18.54	0.17	0.17	0.15	0.16
SBMZSP	4.63	3.83	4.41	4.34	18.58	16.16	17.64	17.46	0.16	0.19	0.17	0.17
GNMZRT	3.91	3.89	5.17	4.37	16.39	16.34	19.95	17.56	0.18	0.18	0.15	0.17
GNMZSP	4.00	3.76	4.61	4.17	16.67	15.94	18.23	16.95	0.18	0.19	0.17	0.18
CMZCPint	1.64	0.96	1.49	1.41	9.55	7.49	8.81	8.62	0.32	0.40	0.34	0.35
Mean	3.68	3.35	4.22	3.79	15.69	14.71	17.07	15.82	0.20	0.23	0.20	0.21

VCR = Value cost ratio, O/I = Output-Input ratio, P_N/P_O = Input-Output Price ratio, SBMZRT = Soybean/Maize Rotation, SBMZSP = Soybean-Maize Strip Cowpea relay, GNMZRT = Groundnut/Maize Rotation
GNMZSP = Groundnut-Maize Strip Cowpea relay, CMZCPint = Continuous Maize-Cowpea intercrop

CHAPTER FIVE

5.0 DISCUSSION

5.1 Physical and Chemical Properties of the Soils Studied.

The soils of the three farms had pH ranges between slightly acidic (6.8) to strong acidity (5.15) which are within the range of 4.8-8.2 reported by Jones and Wild (1975) for soils of the region. Organic matter (8.87 g kg^{-1}) was low for savanna soils, it was however higher than the 5.8 g kg^{-1}reported by Abdu *et al.* (2007) for soils of Ikara.Total nitrogen averaged 0.77 g kg^{-1} for all farms which is also considered low for savanna soils. Yet it is up to 15% increase from 2012 before the treatments were imposed. This gain in N is attributable to added N benefits from the biological nitrogen fixation (BNF) by legumes in some of the treatments imposed in this study, as well as to increased biological activities as a result of organic manure incorporation. These values are higher than the 0.51 g kg^{-1}reported as mean for soils in the Nigerian savanna (Jones and Wild, 1975), it agrees with the 0.70gkg^{-1} reported by Abdu *et al.* (2007) for Ikara, in the northern Guinea savanna.

Based on FAO soil taxonomy (1991), effective CEC for the soils were low; 4.03cmol kg^{-1} for Pampaida; 5.28cmol $kg^{-1}$for Saulawa, and 4.03cmol $kg^{-1}$for Fulani Sule. Mean available P for the three locations was moderate 14.14 mgkg^{-1}but much higher than the 7.0mgkg^{-1} reported by Abdu *et al.*, (2007).At 0.28 cmol kg^{-1}, which was the average exchangeable potassium obtained for the three locations after the first planting season, exchangeable potassium was

5.2 Soil Microbial Biomass Carbon and Nitrogen

Soil microbial biomass carbon and nitrogen significantly increased at higher N levels in the combined application of manure and inorganic N fertilizer. The combined application of N fertilizer and organic manure had a stabilizing and favorable short-term effect on SMB_C and N, and results from Goladi and Agbenin (1997) show that with continuous treatment, the long term effects will be even better. The organic manure provided the carbon source for energy which is evident in the strong correlation between organic carbon and the soil microbial biomass in this study, while N served as the nutrient substrate for increased microbial activity (Goladi and Agbeni, 1997). The $SMB_C$was responsible for between 1.06 to 3.99% of the soil organic carbon. These values are a bit short of the 4.0-6.5% reported by Franzluebbers *et al*. (1995) and the 17.5% and 6.5% recorded by Goladi and Agbenin (1997) for N-fertilized with dung and NPK with dung respectively in long-term experiments. SMB_Caligned closely with SMB_N representative of their correlation (r=0.665), implying that as reported by Franzluebbers et al. (1995), N immobilization is related to microbial biomass activity.

Microbial biomass C: N ratio of 8:1 to 15:1 were similar to the range 8:1 to 11:1 reported by Goladi and Agbenin (1997) for the Northern Guinea Savanna Nigeria soils, but lower than the 13:1 to 16.5:1 reported for some tropical agro ecosystems by Mazzarino *et al.* (1993). The C:N ratio reflected the variation in the organic carbon and nitrogen input.

5.3 Nitrogen uptake

N uptake was found to be largely affected by nitrogen levels in all locations and when combined. Combined application of inorganic N fertilizer with manure increased N uptake even though a significant difference in uptake between the N levels was only observed when N was raised to 120kgN ha^{-1} in Pampaida. This can be attributed to improved soil conditions that led to reduced

N immobilization by soil organism as a result of sheep and goat manure addition.Vanlauwe *et al.,* (2011) reported that manure and compost are unlikely to result in lasting N immobilization since these materials have gone through a decomposition phase before application to the maize.In Fulani Sule and Saulawa however, there was no significant difference in uptake with each successive level increase in N fertilizer applied.

The astronomic increase in the world population expected in the next three decades (UN-DESA, 2015) without an equivalent increase in the size of land means that the land available to each farmer is will reduce considerably. Because of its peculiar climate, cereals and legumes remain the dominant crop cultivated in the northern Guinea savanna (NGS) ecological zone. The use of inorganic fertilizer on maize and other crops remain a daunting task for smallholder farmers in the northern Guinea savanna (NGS) because of their low economic status, and for the very few who can afford inorganic fertilizers, its continuous has not translated to economic benefit. The results from this experiment showed that maize cultivated with a combined inorganic N fertilizer and manure application utilized nitrogen better than maize cultivated with fertilizer alone. This can be attributed to incorporation of organic manure which created a better soil condition; increase in nutrient availability, retention and release, better soil structure, and improved soil physical and biological properties (Okalebo *et al.,* 2003, Hudson, 1994, Sangina and Woomer, 2009). Soil moisture condition is another factor as affirmed by Barrios *et al*., (1997). All these can only mean an improved soil healthtranslatingto better yield, which are benefits derived from adopting a sustainable soil management approach like ISFM.

5.4 Agronomic Efficiency of Nitrogen

Sole inorganic N fertilizer application showed a notable effect on agronomic efficiency of N across the three locations, decreasing with increasing Nlevels. This is consistent with the observations of Yusuf *et al.*, (2009b) and Fofana *et al.;* (2004) who reported reducedagronomic efficiency of N with increasing N fertilizer rates. The trend can be attributed to fact thatat lower rates, N represented the primary nutrient limiting growth but at higher levels, some other factors or nutrients became more important yield determinant than N (de Witt, 1992). And according to Singh *et al*., (2001) N limitation is one of the major constraints to cereal productivity in the sub-Saharan Africa.There were no significant differences observed between 60, 90 and 120 kgN ha^{-1} indicating that applying beyond 30 kgN ha^{-1}fertilizers alone represented a poor management practice.With combined inorganic N fertilizer and manure, there were significant increases in AEN of maize as against inorganic N alone. Many researchers have reported similarly that inorganic fertilizers alone, even though they contain the major nutrients, lack the minor nutrients essential for crop growth, whereas organic sources contain these (Vanlauwe and Sangina, 1995; Cadisch and Giller 1997).Combining inorganic fertilizer with sheep and goat manure had a substantial impact on the AEN and in some locations, a deviation in the trends observed with fertilizer alone, where AEN was increasing with decreasing N levels. Again this can be attributed to the alleviation of other crop growth constraints besides N by the manure (Vanlauwe *et al.;* 2011). An increase in soil organic matter contentenabled improved nutrient retention, turnover and availability (Sanginga and Woomer, 2009). In addition, the sheep and goat manure may have counteracted soil acidity and Al toxicity (Pypers*et al.;* 2005).The ISFM approach of combining inorganic fertilizer application with available organic inputs, embodies these benefits to increase crop yields right from inception and when fully adopted, smallholder farmers in the northern

Guinea savanna Nigeria can expect to maintain high productivity every other cropping season, since their farms would benefit from better nutrient availability, moisture retention, and high soil organic matter resulting in better agronomic efficiency.

The AEN of 45.49 kg kg^{-1} obtained in this study was better than the 42 kg kg^{-1} reported by Frink *et al.*; (1999) for USA and the 27 kg kg^{-1} reported by Yusuf *et al.;* (2009b) for the NGS Nigeria. These differences are attributable to the better nutrient retention and improved nutrient release pattern(Sanginga and Woomer, 2009). However our AEN figure was lower than the 57 kg kg^{-1} reported by the same researchers for USA, and we can associate this differences with the improvement in the indigenous N supply from net mineralization of soil organic matter, atmospheric N inputs, and biological N_2 fixation (BNF) over the past two decades in the USA (Yusuf *et al*., 2009b).

With the maize-legume systems, maize after soybean and groundnut and maize in strip with soybean and groundnut improved agronomic efficiency better than continuous intercropping of maize with cowpea. There was however no significant differences both between and among maize after legumes and maize in strip with the legumes, and this was similar to results obtained by Yusuf *et al.,* (2009b) with maize after TGx1448-2E and other legumes.

5.5 Physiological Efficiency of Nitrogen

Physiological efficiency of nitrogen (PEN) was barely influenced by Nlevels, with the PEN increasing with increasing N levels as expected. There were significant differences among the N levels in Pampaida and Saulawa farms, but not in Fulani Sule and in combined analysis. This is totally consistent with the results obtained by Yusuf et al. (2009b). The deviations may be attributed to the differences in management practices in these farms before the treatments were imposed.

With the combined application of inorganic N and manure, significant differences were observed in Saulawa and in combined, but not in Pampaida and Fulani Sule, implying that combining inorganicN fertilizer with manure improved the physiological efficiency by 36.5 kg kg^{-1} representing a 74%. This can be attributed to improved N concentration in the grain due to higher N uptake. Yusuf *et al.*, (2009b) identified N concentration as one of the genetic factors that govern physiological efficiency.

5.6 Nitrogen Uptake Efficiency

Nitrogen uptake efficiency (NUpE) was significantly affected by N fertilizer levels, increasing with decreasing N levels implying that there were more N losses at higher N levels. The huge gap observed in NUpEwhen inorganic N was applied alone and when it was combined with manure can be attributed to the lower grain yield returned by fertilizer alone as against inorganic N combined with manure (Cassman *et al.*, (2002). The average NUpE obtained in this study irrespective of treatments and locations was 73%. Thiswas better than the 42% reported for developed countries by Raun and Johnson (1999), and the 54% obtained by Yusuf et al. (2009b) for the Northern Guinea Savanna of Nigeria.

As observed earlier, NUpE declined with increasing N fertilizer levels even though grain yields and N uptake were increasing with increasing N fertilizer levels. Yusuf *et al.*, (2009b) suggested that this trend may be an indication that N response was poor. However a better way to look at it is to agree with Huggins and Pan (2003) who submitted that decreasing NUpE at higher N fertilizer levels may be due to greater losses from the system. This therefore means that smallholder farmers must be careful when adopting recommendations with higher N-fertilizer dose, since this will be economically unwise andan unsustainable way to go for low-income farmers.

5.7 Maize Grain Yield

Grain yield was significantly increased at high N levels in the three locations, even though the combined analysis showed that every N level increase resulted in a significant increase in grain yield. Bearing in mind that Ologunde and Ogunlela; (1984) had submitted that for maximum maize grain yield to be realized in the Northern Guinea Savannah of Nigeria, addition of 120 kgN ha^{-1} of inorganic fertilizer is required, this study confirms that inorganic N is very important for maize production in the NGS agro ecological zone. The positive response observed in maize yield due to Napplication confirms the importance of N in maize nutrition. Adetunji (1991) reported a strong dependence of maize yield on N content of some Nigerian soils. Gallaher *et al.*,(1992) also reported increases in maize grain yield due to N-application rates.

Data showed that suitable management practices play major role in maize production in the study area. Agbim and Adeoye, (1991), Nottidge *et al*., (2005) have shown that, it is the use of inorganic fertilizer in combination with organic materials that gives higher and sustainable crop yields than using either of them alone.

The average grain yield obtained when inorganic N fertilizer was combined with manure was still short of the expected optimum yield from the maize variety used (Oba 98) which is 6.5 to 8 tha^{-1}. This can be attributed to the fact that the optimum fertilizer recommendation of 150kgN ha^{-1} for hybrid maize was not attained and also to the fact that the trial is only in its second season. Previous management practices of continuous cultivation,typical of smallholder farms in this AEZ, have led to a considerably low residual supply. This justifies the ISFM approach for improving soil health and productivity. The optimum fertilizer rate for hybrid maize was not included in this experiment because it would represent an expensive option since experiments were conducted with the mindset of smallholder farms and to test the effects of these ISFM options.Vanlauwe *et al.*, (2001) have reported that mineral inputs are often too expensive for smallholders to be applied at optimal rates.

5.8 Profitability of Fertilizer Use

5.8.1 Value Cost Ratio

The value cost ration (VCR) was better in combined inorganic N and manure application than the sole inorganic N application. This is attributable to the higher grain yield and better agronomic efficiency of nitrogen obtained in former due to added nutrients supply from manure.From the result of this study, the use of fertilizer alone was not profitable in any location including Fulani Sule which gave the highest VCR of 1.56. Although they had acceptable O/N ratio of 7-10 or above (Morris *et al.*, 2007), their mean VCR (1.54) did not meet the threshold of≥2 (Morris *et al*., 2007). With combined inorganic and organic manure, VCR averaged 3.75 in the three locations with the Fulani Sule the most profitable (4.26) and Saulawa the least profitable (3.26). Maize production with combined inorganic and organic manure was more profitable (3.75) than with sole fertilizer (1.54) which was not profitable. Wallys, (2003) and Ugbabe *et al.*, (2007) reported similar results. This is attributable to better AEN and higher grain yields recorded in the former. (Tables 4 and 5). The potency of the claims by the Integrated Soil Fertility Management (ISFM) technology, that the combined application of inorganic and organic manure offer added benefit (Vanlauwe *et al.*, 2010) as a result of the complementarities between the two sources of fertilizer (Sanginga and Woomer, 2009),has been confirmed by this study. Given that cost of procuring chemical fertilizers in Nigeria is relatively beyond the reach of the smallholder farmers, this study agrees with Ayeni, (2011) that the integrated soil fertility management approach will ensure cost reduction because only small quantity of chemical fertilizers is required with home-availableanimal manure**.**

It was also observed that in all locations, the cost of inputs was higher in the combined inorganic and organic manure application than in the sole fertilizer application because cost implications of the sheep and goat manure used were taken into consideration, yet the higher grain yields in the former was enough to pay off the extra cost incurred in inputs. Therefore for smallholder farmers who would rely on available organic resources (at little or no monetary cost to them) as recommended in the ISFM, the cost will be much reduced and the VCR and by implication profitability will become even much higher.Again despite the lower mean cost incurred in fertilizer use in the maize-legume systems (estimated to be NGN 40,201), VCR ratio was still higher in the combined inorganic and organic manure (estimated mean costwas NGN 60,659).

5.8.2 Output-input ratio and input-output price ratio

Trends of the O/I and P_N/P_O ratios in the combined inorganic N and manure application were similar. The better ratio for maize production with the combined inorganic N and manure application relative to inorganic N alone is attributable to better nutrient uptake that resulted in higher grain yields. In this study, the O/I ratio for both treatments were above the threshold (>3) as set by Morris *et al.*, (2007), implying that maize production on each of them is profitable. But the combined inorganic and organic manure application is a better option since it had a higher O/I ratio in all location than the sole fertilizer application.

The lower P_N/P_O in the combined inorganic and organic manure application is an indication of higher profitability since Yanggen *et al*., (1998), the lower the P_N/P_O ratio the higher the profitability.

CHAPTER SIX

6.0 SUMMARY AND CONCLUSION

6.1 Summary

A field experiment was carried out in 2012 and 2013, repeated on three smallholder farms in Pampaida, Saulawa and Fulani Sule all in Ikara, northern Guinea savanna Nigeria. The experiment was to determine the effects of the sole inorganic N fertilizer application, combined application of inorganic N fertilizer with manure, and maize-legumes (groundnut, cowpea and soybean) in rotation and in strips, on N uptake, maize grain yields, nitrogen use efficiency and nitrogen uptake efficiency. It also determined the effect of combined application of inorganic N fertilizer with manure and the maize-legume systems on the microbial biomass carbon and nitrogen and the soil microbial biomass C:N ratio of soils. Treatments included 2.5 t ha^{-1} of sheep and goat manure applied in combination with 5 rates of N fertilizer (0, 30, 60, 90, and 120), maize cultivated after groundnut and soybean, maize intercropped with groundnut and soybean each with cowpea relay, continuous cowpea intercrop and five N-response trials with 5 rates of N (0, 30, 0, 90, and 120 kg n ha^{-1}). The experiment was arranged in a RCBD and replicated four times in each location. N fertilizer sources used where NPK 15:15:15 and Urea applied in two split doses at 10 days after planting (DAP) and 35 days after planting (DAP). Soil samples were taken before land preparation was done on each plot and were subjected to routine analysis. Fresh soil samples were also used to determine the soil microbial biomass Carbon and Nitrogen.

At harvest, maize stover and grain were sampled and weighed and extrapolated per plot. Concentrations of N in grain and stover were also determined in the laboratory. N uptake, agronomic efficiency, N recovery efficiency, harvest index and physiological efficiency and N use efficiency were computed using appropriate formulas.

The economic profitability of fertilizer use for each treatment was estimated using the Value Cost Ratio (VCR), the output-input ratio (O/I) and input-output price ratio (P_N/P_O).

From the study, the findings were:

1. The combined application of inorganic N fertilizer with manure and the maize-legume cropping systems contributed up to 3.77 % of total organic carbon and 2.97% of total nitrogen of the soils by improving soil microbial biomass.
2. Nitrogen fertilizer is important for maize production in the northern Guinea savanna (NGS) Nigeria.
3. Nitrogen fertilizer alone is neither sufficient nor sustainable for smallholder farming in the NGS Nigeria.
4. Combined application of inorganic N fertilizer with sheep and goat manure increased maize yield significantly compared to sole inorganic N fertilizer application.
5. The five cropping systems used in this study improved grain yield and physiological efficiency in the respective order; Maize after soybean (SBMZRT) > Maize after groundnut (GNMZRT) > Soybean-maize strip cowpea relay (SBMZSP) > Groundnut - maize strip cowpea relay (GNMZRSP) > Continuous maize-cowpea intercrop (CTMZCPint) and GNMZRT > SBMZRT > SBMZSP > GNMZSP > CMZCPint, while agronomic efficiency and uptake efficiency of nitrogen were both improved in the order SBMZRT > GNMZRT > SBMZSP > GNMZSP > CMZCPint.

6. Agronomic and uptake efficiencies of nitrogen are amenable or responsive to improved soil management practices.
7. The combined application of inorganic N fertilizer with manure and the maize-legume cropping systems resulted in improved AE of N, grain yield, N uptake and NUpE by maize.
8. The combined application of inorganic N fertilizer with manure and the maize-legume cropping systems were significantly more profitable in maize production than sole inorganic N fertilizer application in smallholder farms in the northern Guinea savanna of Nigeria.

6.2 Conclusion

Information obtained in the study showed that;

1. Added to the established benefits of cereal-legume systems and combined application of fertilizers with organic manure to the soil, these management practices also contribute to the soil organic carbon and total nitrogen by increasing soil microbial biomass carbon and nitrogen.

2. Compared to current practices in smallholder farms, the combined application of fertilizers with home-available organic inputs can increase nutrient use efficiency (NUE) by up to 300% and agronomic efficiency by up to 95%. With the maize-legume systems used in this study, the figures can be as much as 200% and 100% respectively.

3. Cultivating maize in rotation and strips with grain legumes and with fertilizer applied in combination with organic manure are more profitable in smallholder farms of the northern Guinea savanna, Nigeria than with sole inorganic N fertilizer application.

RECCOMMENDATIONS FOR FURTHER RESEARCH

1. Studies should be carried out to understand the effects of the ISFM approaches (treatments applied in this study) on the nutrient composition of grains produced, so as to understand how ISFM is improving or otherwise, the quality of diets which is the final end of the whole effort in soil fertility management.
2. More detailed socio-economic analysis of the ISFM adoption which include the wellbeing of farmers or livelihood as affected by improved productivity due to adoption of better soil fertility management approach, need to also be researched.
3. It will be important to study to the role of gender in soil fertility management and in the management of improved soil productivity for a better livelihood among smallholder farmers.

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