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**Use of Locally Available Amendments to Improve Acid Soil
Properties and Maize Yield in the Savanna Zone of Mali**

By

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OCTOBER, 2014

**Use of Locally Available Amendments to Improve Acid Soil
Properties and Maize Yield in the Savanna Zone of Mali**

A Thesis submitted to the Department of Crop and Soil Sciences, Faculty of
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DOCTOR OF PHILOSOPHY

IN

SOIL SCIENCE

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DECLARATION

I hereby declare that this submission is my own work toward the PhD and that, to the best of my knowledge, it contains no material previously published for the award of any other degree of the University, except where due acknowledgment has been made in the text.

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ABSTRACT

Soil acidity is a major constraint to crop production in the Savanna zone of Mali. The high cost of lime makes it an unrealistic option for resource poor farmers. This thesis addresses the challenges associated with soil acidity management by using locally available materials in three studies.

A laboratory study was carried out to investigate the liming potential of the following locally available materials: Cattle manure (CM), sheep manure (SM), goat manure (GM), poultry manure (PM), Sabunjuma compost (SC), maize residue (MS), ash from maize straw (AM), Tilemsi rock phosphate (TPR), and lime of Tokouto (TL) as control. The AM had the highest initial pH and proton consumption capacity, MS the highest OC content, SC the highest N content, TL the highest CCE and sum of basic cation. Soil pH and basic cations were increased while exchangeable acidity was decreased by addition of all amendments and the effect was greater at the higher rate of application. In terms of lime equivalence, the addition of 20 mg g⁻¹ of AM, MS, PM, CM, GM and SM were equivalent to 2.25, 0.02, 0.33, 1.15, 1.05, 0.05 mg g⁻¹ of Ca(OH)₂ in increasing soil pH respectively at least in the short period of this experiment. The high initial pH, base cation and proton consumption capacity also contributed to raise pH of ash, animal or compost amended soil.

A first field experiment was carried out to assess the effect of dolomite lime and kraal manure application on growth and yield of maize as well as soil properties in an acid soil (pH= 4.8). The experiment consisted of four rates of lime (L0 =0, L1=325, L3=650 and L4=1300 kg ha⁻¹) and four rates of kraal manure (M0= 0, M1=1.25, M2=2.5, M3=5 Mg ha⁻¹). The addition of lime at 325 kg ha⁻¹ and manure at 1.25 Mg ha⁻¹ increased soil pH above 5.5 (critical level for Al toxicity), increased soil exchangeable Ca, Mg, K and available P but decreased exchangeable acidity for sole and combined application leading to increased maize growth and yields. The increases in grain yield following the

addition of lime were 19, 25 and 34 % in 2012 as compared to 23, 22 and 23 % in 2013 by the application of 25, 50 and 100 % of LR respectively. Manure increased grain yield in the order of 19, 12 and 36 % (2012) as compared to 31, 21 and 49 % (2013) respectively with the addition of 1.5, 2.5 and 5 Mg ha^{-1} . The combined use of 100 % LR+5 Mg ha^{-1} produced the highest yield of 4000-5542 kg ha^{-1} . Exchangeable acidity was negatively correlated to maize growth and yields highlighting its detrimental effect. The sole application of 25 % of LR (3.14-4.32), 1.25 Mg ha^{-1} of manure (4.25-6.9) and the combination of 25LR+1.25M (2.36-4.16) were the most economically viable.

A second field trial was conducted to evaluate the effect of the combined application of lime and fertilizer on soil acidity and growth and yield of maize. The experiment consisted of two methods of lime application (Broadcasting and Banding), two methods of fertilizer application (Banding and Spot) and four rates of lime (L0 = 0, L1 = 325, L3 = 650 and L4 = 1300 kg ha^{-1}). Banding of lime had no significant effect on soil pH, exchangeable acidity, and exchangeable K. Application of lime increased soil pH, exchangeable Ca and Mg, and available P, but decreased exchangeable acidity. Spot application of fertilizer had no significant ($P>0.05$) effect on soil pH, exchangeable Ca, Mg and K and available P. Exchangeable acidity was negatively correlated to maize growth and yields. Spot application of fertilizer increased maize height, biomass and grain yields. The grain yield was increased by 32 % with the spot application of fertilizer as compared to the banding in 2013. Application of 25, 50 and 100% of LR increased grain yield respectively by 22, 25, and 35 % in 2012 and 22, 25 and 40 %, in 2013. Lime banding had the highest net benefit compared to broadcasting and the margins were 57250 and 92500 F CFA. The net benefit for spot application of fertilizer was higher than the banding and the margins were 92750 and 220750 F CFA. Application of 25 % of LR had the highest net benefit (675250-757250 F CFA). The best combination was broadcasting of lime + spot application of fertilizer+25 % of LR with the cumulative net benefits of 722750 and 962500 F CFA.

DEDICATION

I dedicate this thesis to my parents, Bafing Samaké and Tenin Sangaré, who have been an inspiration throughout my life, and always supported my dreams and aspiration, but unfortunately will be unavailable to witness the culmination of this work due to their demise.

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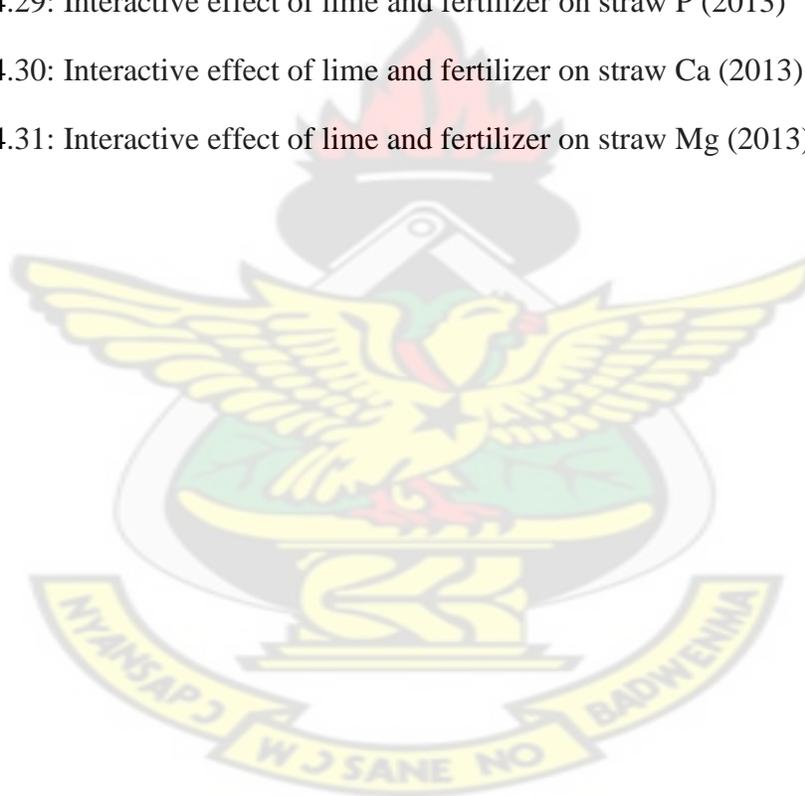
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LIST OF ACRONYMS

Acronym	Meaning
ACI	Agence de cession immobilière
ADSS	Acidity decision support system
Al mono	Aluminium monomeric
Alt	Aluminium total
AM	Ash from maize straw
AP	After planting
Av. P	Available phosphorus
BdF	Banding application of fertiliser
BdL	Banding of lime
BrL	Broadcasting of lime
CCE	Carbonate calcium equivalent
CEC	Cation exchange capacity
CFA	Communauté Financière d'Afrique
CM	Cattle manure
CRRA	Centre Regional de Recherche Agronomique
DAP	Diammonium phosphate
DM	Dry matter
DNA	Deoxyribonucleic acid
DTPA	Diethylene triamine pentaacetic acid
ECEC	Effective cation exchangeable capacity

Echan.Acid	Exchangeable acidity
ECOFIL	Economie des filières
FAO	Food and agriculture organisation of the United Nations
FM	Fertiliser method of application
FYM	Farm yard manure
GIS	Geographic information system
GM	Goat manure
IER	Institut d'Economie Rural
ISFM	Integrated soil fertility management
Labo-SEP	Laboratoire Sol-Eau-Plante
LM	Lime method of application
Lr	Lime rate
LR	Lime requirement
LSD	Least significant difference
MS	Maize straw
NFB	Net farm benefit
NFI	Net farm income
NPV	Net present value
OC	Organic carbon
OM	Organic matter
PCC	Proton consumption capacity
PET	Potential evapo-transpiration
PIRT	Projet d'inventaire des ressources terrestres

PM	Poultry manure
PR	Phosphate rock
PROFEBA	Production de fertilisants bacteriens
SC	Sabunjuma compost
SM	Sheep manure
SMP	Shoemaker-McLean-Pratt
SOC	Soil organic carbon
SOM	Soil organic matter
SPF	Spot application of fertiliser
T.P	Total phosphorus
TAS	Target aluminium saturation
TL	Toukoto lime
T.N	Total nitrogen
TPR	Tilemsi phosphate rock
UN	United Nation
UNESCO	United Nations Educational and Scientific Cooperation
VCR	Value cost ratio
WAP	Weeks after planting

CHAPTER ONE

1.0. INTRODUCTION

West African agriculture has many difficulties to feed the population (World Bank, 2006) due to the imbalance between growth rates of cereals grain (1%) and population (3%) (UN, 2001). Previously, drought was considered as the most limiting factor, but nowadays soil fertility problems particularly soil acidity and associated factors are the major setbacks to crop production (Sumner and Noble, 2003; Bationo *et al.*, 2005).

Sahelian soils are naturally susceptible to acidification due to their inherent low buffering capacity (Wilding and Hossner, 1989). These susceptible soils may become extremely acidic by improper management practices (Van der Pol, 1992; Mulungu, *et al.*, 2013). Acid soil represents about 50% of the total arable land in the world (vonUexküll *et al.*, 1995) and constitutes about 22-27 % of the soil in tropical Africa (Pandey and Gardener, 1992; Malcolm and Andrew, 2003). In Mali, soil acidity is widespread, covering about 55 % of the cotton region (Doumbia *et al.*, 2003), and 22% of irrigated lands (Ballo, 2005). The consequences of soil acidity on crop production are very alarming. Herrero-Estrella (2003) reported that the yield losses of various crops induced by Al toxicity and associated factors ranged from 25 to 80 %.

The low crop productivity in acid soils is mainly attributable to Al toxicity and nutrient deficiencies particularly P, Ca, Mg and Mo (Harter, 2002; Zheng, 2010). Optimum growth and efficient use of fertilizer nutrients require the addition of lime for rehabilitating acid soils. Whilst it continues to be accepted as essential step to effective agricultural production, liming is not a common practice in West Africa. The high

application rates and expense and the low primary price of crop production make lime use inaccessible for most farmers with very limited capital (Doumbia *et al.*, 1998; Gigou, 1998). Moreover, a significant fraction of lime can be lost through erosion or uptake by weeds and create best condition for their development and increase the cost of production. A credible alternative to lime is the use of cheaper local amendments (manure, rock phosphate, ash, crop residue, etc), which can be available at low cost to most semi-subsistence farmers (Haynes and Mokolobate, 2001). The rationale for the use of organic amendments as a management strategy is based on the fact that they do not only provide a substantial amount of plant nutrients, but also have a significant liming effect on soil acidity (Wong and Swift, 2003, Tang *et al.*, 2007). Indeed, these organic amendments have been proposed as alternatives to traditional lime (Shen and Shen, 2001; Hayes and Mokolobate, 2001).

Manure is the most common amendment used by farmers to improve soil properties and crop yield but the quantity and the quality are limiting factors to the use of this resource (Vanlaume and Giller, 2006; Kisinyo *et al.*, 2014). The lime of Toukoto (dolomite) is now a cheap locally available source of Ca and Mg at the disposal of Malian farmers. However, the application of lime at required rate is not economically viable for many poor farmers (Gigou, 1998). The combined application of lime and manure at reduced rate could be an interesting alternative for controlling soil acidity while improving crop productivity at a reasonable cost. Nevertheless, a plethora of studies has compared separately the liming effects of lime and manure (Whalen *et al.*, 2001; Naramabuye, 2004), but few have investigated their combined effect (Opala, 2011). Even with the few studies that have examined the combined effects, they have been involved with high

levels of organic materials which may not be feasible for farmers. Furthermore, no study has been done to evaluate the effect of combined application of lime and manure at reduced rate on acid soil properties, crop yield and the economic benefits on maize.

The method of application can significantly influence the efficiency of lime and mineral fertilizer (Opala *et al.*, 2007). Several studies have proved the superiority of both banding and spot application to broadcasting (Bagayoko *et al.*, 2011), but there are conflicting reports on the superiority of spot application over banding in increasing maize yield (Buresh *et al.*, 1997). Until now, no study has been done to evaluate the precision application of fertilizer and lime at low rate on grain yield and the financial return.

The present study is to fill these gaps by linking agronomic performance to financial returns. The overall objective of this research was to develop technologies for sustainable soil fertility managements that improve crop production at reasonable cost.

The specific objectives were as follows:

1. Evaluate the liming potential of some locally available resources on a sandy acidic soil properties;
2. Determine the appropriate rate of lime for localized application;
3. Evaluate the combined effect of the application of lime and manure on some selected soil properties and maize yield;
4. Evaluate the efficiency of localized application of lime and fertilizer on some selected soil properties and maize yield;
5. Assess the financial returns of the application of lime and manure and the precision application of lime and fertilizer on maize.

The above specific objectives were formulated to test the following hypotheses:

- i. Local resources (manures, cereal ash and rock phosphate) have potential to correct soil acidity and provide crop nutrient.
- ii. The localized application of lime and fertilizer on maize does not cause soil nutrient depletion and would improve maize yield.
- iii. Optimal combination of low rate of agricultural lime and animal manure improves maize yield and soil fertility.



CHAPTER TWO

2.0

LITERATURE REVIEW

2.1 Causes of soil acidity in the Sahelian zone of West Africa

Soil erosion and acidity are the main frequent forms of soil degradation in West Africa. However, soil erosion, particularly water erosion, has received more research attention than soil acidity mainly because of the more visible effect of erosion. Acid soils are common in humid region because of the leaching of basic cations and salts by high rainfall (Brady and Weil, 1999) leaving behind more stable materials rich in iron and aluminium oxides. In this way, the low rainfall regimes in Sahel region (500-1000 mm) would not favour the acidification of soil because of the limited leaching of base cations (Gigou, 1998). However, the majority of semiarid and sub humid soils of west Africa are frequently strongly acid, less fertile, low buffered, and characterised by the dominance of sesquioxides and kaolinite with few weatherable mineral reserves (Wilding and Hossner, 1989). According to Wilding and Hossner (1989), this acidity may be attributed to (i) the indigenous acidity of the parent materials, (ii) the development of acidity in soils weathered under wetter paleoclimates, (iii) leaching of bases from shallow soil systems under contemporaneous climates with concomitant development of acidity, and (iv) vector dynamics between base renewal to surface horizons and base loss to lower subsoil by leaching under contemporaneous climates. In other words, soil acidity is the result of natural weathering processes that are accelerated in wet regions. Other soils become acidic by the number of process and the acidity problem appears to increase with time in West Africa. Because of the low potential cation exchange capacity, soil fertility is restricted in the topsoil to the SOM which

declines about five times faster and under cultivation renders soil more susceptible to degradation (Steiner, 1994 as cited by Hieper, 2002). The acidified soils are more frequent than naturally acid soils (Harter, 2002). This acidification results as a side effect of widespread nutrient imbalance in cultivated lands. According to Pieri (1987), nutrient losses by erosion, runoff, the use of fertilizers and intensive organic matter mineralisation are considered as the main causes of a negative balance of Ca and Mg. Moreover, some factors such as development of new technology, introduction of tillage, use of mineral fertilizer, intensive crop production, reduction of fallow systems, none restitution of crop residue and cultivation of marginal land increase west African soil acidification.

The removal of basic cations by crop harvesting and the use of acidifying fertiliser are considered as the main cause of soil acidification in West Africa (Smaling and Baun, 1996; Vanlauwe and Giller, 2006). Harvesting of crop has its effect on soil acidity development because crops absorb lime-like element as cations for their nutrition. The roots of high-yielding grain and forage crops remove basic cations from the soil and release hydrogen into soil solution to maintain an ionic charge balance within the tissue. The removal of crop residues which are rich in basic cations from the field is responsible for acidity. In this way, the soil acidity developed faster in continuous cropping with high plant biomass than those with high grain yield (Van der Pol, 1992). The use of acidifying fertilizer especially nitrogen (Diammonium Phosphate and Urea), has been often blamed as responsible of West African soil acidification (Harter, 2002; Lungu and Dynoodt, 2008). The most popular source of nitrogen is Urea and its decomposition consumes protons as follows: $\text{CO (NH}_2)_2 + 2\text{H}^+ + 2\text{H}_2\text{O} \longrightarrow 2\text{NH}_4^+ +$

H₂CO₃. Indeed, two hydrogen ions are consumed for each urea molecule decomposed and increase pH in the surrounding soil, but the ammonium ion is then converted to nitrate releases through biological process two (2) hydrogen ions in to the soil solution as illustrated by this equation: $\text{NH}_4^+ + 2\text{O}_2 \longrightarrow \text{NO}_3 + \text{H}_2\text{O} + 2\text{H}^+$ (Harter, 2002). The two hydrogen ions are very active and known to be “acid” in soil solution (Haynes and Mokolobate, 2001). Another effect of nitrogen fertilizer has been to increase bases removal by increasing bases uptake and crop yield.

Soil acidity is characterised by low pH and the abundance of acidic cations (H, Al, Fe, and Mn) on system colloid soil solution. The low pH affects significantly the fixation and the availability of soil nutrients such as N, P, K, S, B, Mo, etc. The abundance of acidic cations on system colloid soil solution can be toxic to crop growth and leads to reduced crop yield. Many cases of Al toxicity have been reported in tropical soils particularly in the semiarid and sub humid zones of West Africa. The decomposition of the soil organic matter stops when the Al content is high in soil with pH less than 4.5 (Helyar and Porter, 1989). Gigou (1997) reported that in some acidic areas in Southern part of Mali (Konobougou and Nogolasso) cotton plant did not grow at all or the growth was stunted due to Al toxicity or the imbalance of basic cations. Doumbia *et al.* (1998) observed a poor early growth of sorghum (*Sorghum bicolor*) in acidic sandy soil of Cinzana characterized by leaf yellowing, purpling of leaves and death of the leaf tip. In extreme cases, seedlings become completely brown and the roots show necrotic spots and do not grow below the first 10 or 15 cm of topsoil and the plant dies. The same symptoms were observed in other sorghum growing regions in Mali. Doumbia *et al.* (1998) concluded that P deficiency and Al toxicity were some of the major causes of

this soil problem. Pichot *et al.* (1981) observed similar case of poor early sorghum growth in Plinthic Paleustafs of Burkina Faso. Al toxicity reduced growth and declined maize (*Zea Mays L*) yield (Collet *et al.*, 2000) and resulted in poor root development and low sugarcane (*Saccharum officinarum*) yield under irrigation (Namaro, 1983). Oluwatoyinbo *et al.* (2005) observed in Nigerian acidic soils a remarkable stunted plant growth and decreased Okra (*Abelmoschus esculentus*) yield both in field and greenhouse experiments.

2.2 Mechanisms for the poor fertility of acidic soils

The soil acidity results generally to low soil fertility and consequently to poor crop growth and low yield. These negative effects on crop development may be due to the combination of factors such as the toxicities of Al, Mn, H coupled with the deficiencies or the unavailabilities of P, Ca, Mg and Mo (Yost, 2000). These factors can act independently or together, and can promote or inhibit the survival and function of rhizobia, mycorrhiza, and other microorganisms (Helyar and Porter, 1989). However, at $\text{pH} \leq 5.5$, Al-toxicity is the main stress factor for plants (Langer *et al.*, 2009). As soil acidity increases, soil surfaces become less negatively charged, and the soil cation-retention mechanism by which exchangeable bases are held is less effective. Thus, these cation are easily moved downward by water beyond the root zone (Uchida and Hue, 2000). Furthermore, the negatively charged ions, such as P and Mo are strongly tied up by the Al and Fe components of acid soils, thereby becoming unavailable for plant uptake. Thus, the leaching of cations and binding of anions thereby result in nutrient impoverishment.

Other serious problems in acid soil are the abundance of soluble aluminium and manganese due to mineral dissolution by acidity. Exchangeable Al and Mn are beneficial to plant at low level (Lidon and Barreiro, 2002) but they can be very injurious when their concentrations are higher in soil. The exchangeable Al and Mn increases greatly in acid soil at pH values less than 5.0. The high level of aluminium and manganese are toxic to plant growth, but Al toxicity is considered as the main factor limiting crop growth in acid soils (Mattiello *et al.*, 2010). The toxic effects of Al on plant growth are well known and attributed to several physiological pathways, but the precise mechanism has not yet been understood (Poschenrieder *et al.*, 2008). However, proposed mechanisms of Al toxicity include: Al interaction with the root cell wall, Al disruption of plasma membrane and the membrane transport processes, and inhibition of mineral uptake and metabolism, especially Ca, P and Mo (Lidon and Barreiro, 2002).

Aluminium in excess harms crop by deterioration or stopping of root growth and this is the most serious consequence of Al toxicity (Tabuchi and Matsumoto, 2001). This symptom of Al toxicity is related to the linkage of Al to carboxylic groups of pectins in root cells (Klimashevsky and Dedov, 1975) or to the switching of cellulose synthesis into callose accumulation (Teraoka *et al.*, 2002), to Al inhibition of mitosis in the root apex (Liu and Jiang, 2001) implicating blockage of DNA synthesis (Horst *et al.*, 1983), aberration of chromosomal morphology and structure (Liu and Jiang, 2001) occurrence of anaphase bridges and chromosome stickiness (Liu and Jiang, 2001) and to Al-induced programmed cell death in the root-tip triggered by reactive oxygen species (Pan *et al.*, 2001). As result, the plants are not able to absorb water and nutrients normally and will appear stunted and exhibit nutrient deficiency symptoms, especially those for

phosphorus (Wang *et al.*, 2006) and become sensitive to drought stress (Carver and Ownby, 1995). In maize root tips, Al induces a rapid change in cell number and positioning (Doncheva *et al.*, 2005), and recent evidence suggests that DNA damage and interference with cell-cycle progression and cell differentiation are the primary causes of root growth inhibition due to Al toxicity (Rounds, 2008). On the other hand, manganese toxicity first shows up in plant tops rather than roots. The susceptibility to Mn toxicity and symptoms vary widely among species and are often specific to a particular species (Uchida and Hue, 2000). According to Hue and Ikawa (2011), stunted, crinkled, and chlorotic leaves are the symptoms of Mn toxicity in soybeans.

In sum the final affect of Al and Mn toxicity leads to complete crop failure or significant yield loss. Often the field will appear to be under greater stress from pests, such as weeds, because of the poor condition of the crop and its inability to compete. Several studies have showed the high correlation between poor crop growth and Al saturation (Costa *et al.*, 2003). The yields of several tropical crops were reduced by 60 % or above in soil with Al saturation greater than 60 % (Kamptrah, 1984). Davis-carter, (1989) found that exchangeable Al was the primary cause for poor early growth of pearl millet (*Pennisetum americanum* K. Schum) in buffered sandy soil of Niger. Gallordo *et al.* (1999) observed a decreased of barley grain yield by 50 % in acid soil while liming increased wheat shoot weight and grain yield by 60 % for sensitive genotype and 32 % for tolerant genotype.

The Subsoil acidity can limit drastically the growth and yield of crops. Indeed, insufficient Ca limits root elongation into the subsoil therefore limiting the soil volume explored and crop access to soil water; resulting to shallow rooting, drought

susceptibility, and poor use of subsoil nutrients (Mengel *et al.*, 2001; Tang *et al.*, 2001). The Al saturation in subsoil of weathered acid soil could be higher than top soil Al saturation and this dramatic change results in shallow rooting that leads to extreme sensitivity to even short drought periods (Loss *et al.*, 1993). Other factors that can be associated with acid soil infertility include: biological organisms (nematodes, termites), restrictive subsoil layers (claypans, ironpans, silt pans, plow pans), soil erosion, zones of low moisture retention, and other soil physical and chemical properties (Scott-Wendt *et al.*, 1988a).

2.3 Crop tolerance to soil acidity

The tolerance of a plant to soil acidity is the ability of this plant to grow well in soil with low pH or with low level of Ca, Mg and P in soil solution (Kamprath and Foy, 1985). The tolerance of maize to factors related to soil acidity is of prime concern in West Africa because: (i) crop production is the main activity for the majority of the population, (ii) acid soils occur over a large area of West Africa, and (iii) maize is one of the major crops grown in that region and the most cultivated in Africa.

The optimum pH for a particular crop is not easy to characterise. However, a soil pH range of 6 to 7 is accepted to be desirable from the standpoint of optimum availability of most crop nutrients. Response to varying pH in the field is influenced not only by the susceptibility of the crop to H⁺ injury and to various deficiencies at low and high pH, but also by large pH-dependent changes in the solubility of Al, P, Mn, Fe, Zn, Cu, and Mo (Mengel and Kirkby, 1987). The use of Al tolerant plant would be a less expensive, sustainable and more environmental friendly alternative to counteract soil acidity. Many cases of Al tolerance have been reported in tropical soils particularly in West

Africa. In earlier study, Walker *et al.* (1975) found that millet forage yield did not significantly change when the pH of sandy clay loam soil was successively increased to 5.4, 5.5, 5.6, 6.3, and 7.1. Also, Locascio and Hochmuth (2002) showed that application of 4.5 Mg ha⁻¹ increased watermelon (*Citrullus lanatus*) yield only by 10 % in the first growing season and had no effect in the second season. Other workers such as Dierolf *et al.* (1999) reviewed an international literature on crop tolerance to Al toxicity and concluded that the relative yield for maize at 25, 50 and 75 % aluminium saturation varied between 66 and 95, 37 and 95, and 8 and 77 % respectively, emphasizing the unpredictable and complex nature of crop tolerance to soil acidity. Most recently three comprehensive studies were conducted in South Africa to provide biophysical soil acidity guidelines for maize production. Relationships between relative yield and pH (KCl) as well as relative yield and acid saturation were established for the 0-0.15 m soil layer (Farina and Channon, 1991). The acid saturation threshold value, above which significant maize yield losses will occur, was established for highly and less weathered soil at 20 % (Farina and Channon, 1991). Differences in Al tolerance may be attributed to tolerant cultivars having the ability to reduce the Al activity in the rhizosphere.

In general, crops such as sorghum, millet, corn, tea and upland rice are considered as more tolerant; while maize, sweet potato, sugar cane, cotton, are more sensitive to soil acidity. However, this tolerance varies greatly among varieties within the same species (Ma *et al.*, 2001; Raman *et al.*, 2010). Indeed, The *et al.* (2006) reported that Al-tolerant maize variety gave 61 % higher grain yield than the Al-sensitive variety, and with lime treatment, yield improvement of 208 and 82 % was obtained for Al sensitive and Al-tolerant varieties of maize, respectively. In many plants, Al tolerance appears to closely

coincide with the ability to tolerate low P levels in nutrient solutions, either in the presence or absence of Al (Kamprath and Foy, 1985). On the other hand, it has been suggested that in some soils the main factor limiting plant growth, is not Al *per se* but low Ca concentrations in acidic sub soils (Brady and Weil, 1999).

The crop tolerance to Mn toxicity varies among and between plant species. Fageria (2001) reported that maize is more tolerant to Mn than wheat and soybean. It was also observed that Mn toxicity was alleviated by high levels of Ca (Horst *et al.*, 2010) and Mg (Silva *et al.*, 2001) indicating that Mn concentration changes in a similar manner as Al concentration or that exchangeable acidity is not an ideal indicator to relate to plant performance and that Mn saturation will probably lead to better relationships. The critical Al saturation tolerance varies with crops. Table 2.1 shows the critical Al saturation and corresponding soil pH values of some crops where acute toxicity symptoms are most likely to occur.

Table 2.1: Critical levels of Al saturation and corresponding soil pH of selected crops

Crops	Critical Al saturation (%) (90% maximum yields)	pH (1:1, H ₂ O)
Maize	>20	<5.2
Cowpea	>30	<5.0
Soy bean	>15	<5.5
Sugarcane	>15	<5.5
Cotton	>10	<5.5
Cassava	>40	<5.0

Source: Kamprath (1980)

2.4 Mechanisms of plant tolerance to aluminium

Because of the limiting impact of soil acidity on world crop production, understanding the mechanisms and genes conferring tolerance to acid soil stress has been a focus of intense research interest over the past decade. The first research identifying and quantifying crop tolerance of soils with low pH came from the tropics (Silva, 1976 as cited by Boyer, 1976).

Sanchez (1976) listed the following physiological mechanisms as associated with tolerance or sensitivity to aluminium among or within species: (i) differences in root morphology: root systems of some Al-tolerant varieties keep developing and are not injured in the root tips or laterals in acid soils, (ii) changes in pH of the root rhizosphere: some Al-tolerant varieties increase the pH of the growth medium, whereas sensitive ones decrease it. Such changes are believed to be a result of differential cation-anion uptake, secretion of organic acids, carbon dioxide, and bicarbonate, (iii) lower translocation of Al to the plant top: several tolerant species and varieties accumulate Al in the roots, but translocate it to the tops at a lower rate than sensitive varieties. However, several tree and fern species that are adapted to acid soils conditions accumulate large amounts of Al in their tops, (iv) aluminium in the roots does not inhibit the uptake and translocation of Ca, Mg, and K in tolerant varieties, whereas it does so in sensitive varieties. Varietal tolerance to Al in wheat and barley is related to Ca uptake and translocation; in sorghum, to K, (v) High plant Si concentration is associated with Al tolerance in certain rice varieties, and (VI) aluminium-tolerant varieties do not inhibit P uptake and translocation as much as susceptible varieties or species. Also, many Al-tolerant species or varieties are also tolerant of low P concentrations.

According to Yost (2000), many authors have pointed out that tolerance of toxic conditions in soils of low pH has the components of both tolerance (the presence of the toxic element within the plant) and of avoidance or exclusion (prevention of the toxic element from entering the plant). Maron *et al.* (2008) compared gene expression in two maize genotypes with contrasting Al tolerance and found that several genes involved in processes such as cell wall remodelling, response to oxidative stress. Several other studies have addressed the role of organic compounds in the detection and avoidance (malate) and tolerance (cytosol, proteins, mucilage) of Al toxicity. In Al-tolerant maize, exudation of Al-induced flavonoid type phenolics catechin and quercetin from 10 mm root tip is reported (Kidd *et al.*, 2001). The organic acids excreted by root tips are also involved in detoxification of Al in the rhizosphere eg malic acid for wheat and citric acid for maize and snapbean genotypes (Delhaize and Ryan, 1995). The release of organic acids protects the root apex by chelating Al in the rhizosphere (Wang *et al.*, 2006), thus rendering it non-phytotoxic. The genes which transport citric acid and confer Al tolerance are “MATE” for sorghum (Magalhaes *et al.*, 2007) and ZmMATE1 for maize (Maron *et al.*, 2013).

2.5 Lime requirement of soil

Lime requirement (LR) can be defined as the quantity of an agricultural limestone needed to bring a soil to a given pH (or target pH) or to a selected base saturation for optimum crop yield attainment. Soil pH was the main criteria used for long time to define whether a soil should be limed or not. Kamprath (1984) proposed Al saturation as the criterion for determining whether mineral soils needed to be limed.

2.5.1 Methods for determining lime requirement

The lime requirement of an acid soil can be measured by many methods. Previously, the determination of LR for an acid soil condition and crop or a cropping sequence was based on field experiments. But these methods are time consuming and are not routinely used. However, there are still important for correlating laboratory test data with field response (Mc Lean, 1982). The laboratory methods include: soil lime incubation, soil-base titration, soil buffer equilibrium, SMP (Shoemaker-McLean-Pratt) single buffer method, double buffer SMP method, Adams and Evans method, Yuan double buffer method, Woodruff method, Mehlich method, and exchangeable Al as lime requirement index etc. These methods were developed for distinctly different soils. The SMP method was designed for soils with large lime requirements, pH below 5.8, contain <10 % OM and significant reserves of exchangeable Al (Shoemaker *et al.*, 1961). The Adams-Evans buffer, however, was designed for soils that are coarse-textured, with low cation exchange capacities and OM contents (10 %), small amount of 2:1 clay and thus low lime requirements (Adams and Evans, 1962). The Mehlich lime buffer method was developed primary for use on Ultisols, though it was calibrated for many other soil orders, including Histosols, Alfisols, and Inceptisols (Mehlich, 1976). Exchangeable Al method was designed for highly weathered soil with low pH, low CEC, Low OM, high amount of exchangeable Al (exchangeable Al equal or higher than total base saturation) (Kamprath, 1970). The principle of this method is based on the assumption that (i) Al is the most toxic element in acid soils and the elimination of toxic Al will eliminate other toxic elements (ii) it is no beneficial to increase the soil pH above that required to eliminate toxic elements (Mc Lean, 1982). This method has

certainly an economic advantage because of the predicted low LR, but it presents some insufficiencies. Firstly the Al toxicity is determined by its chemical activity not the level of exchangeable Al or its percentage base saturation, secondly others factors (Mn) may be more detrimental than Al toxicity.

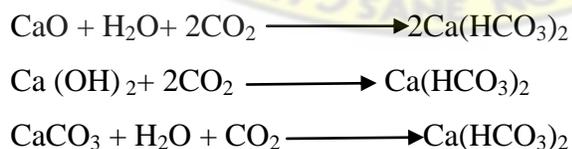
If liming acid soil is generally considered as a good cultural practice in farming, the choice of lime requirement method is also very important. The use of adequate LR method provides: appropriate pH, inactivation of toxic elements and adequate base saturation leading to physical, chemical and biological favourable condition to optimum crop growth. However, too much lime (use of inappropriate LR method) may decrease the availability of some nutrients such Fe, Mn and create the deficiencies of the plants essential elements.

Several factors affect significantly the LR of acid soil. These factors are essentially those affecting their total acidity plus a few relating to methods chosen for the determination: degree of weathering, type of parent material, clay content, organic matter content, forms of acidity, initial and targeted pH, LR method and time of its determination. The removal of high quantity of basic cations by leaching, erosion and crop uptake and their replacement by acidic cations increase significantly LR. The weathering of parent materials (basic rock and minerals) released basic cations which are gradually replaced by acidic cations (H^+ and Al^{3+}) and more parent material contains acidic cations more increased LR. The CEC is composed of clay and organic matter, the greater the concentration of clay and OM in the soil, the greater the CEC and the buffering capacity, and the amounts of acidic cations absorbed that increase LR correspondingly. The forms of acidity account for the total acidity and LR of a soil. The

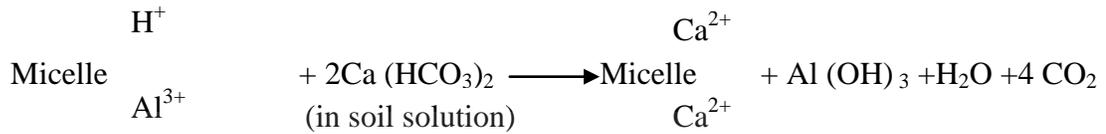
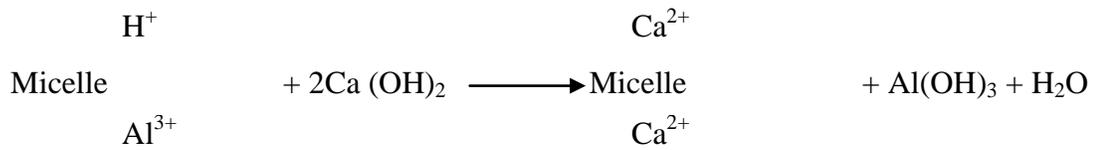
predominance of hydroxyl forms of Al and Fe increase the LR because their polynuclear complexes are partially neutralized and thus are still acidic cations; they markedly increase the total LR of the soil. The soil pH determines generally the predominance of acidic cations present and consequently the LR and the sequence of neutralization (H^+ , Al^{3+} , $Al(OH)^{2+}$, and $Al(OH)_2^+$). The LR is greater to bring a soil pH from 4 to 7 than that from 4 to 6. The LR with Exchangeable Al methods are generally lower than those predicted by SMP buffer method. The degrees of exchangeable and the accessibility to the buffer solution of diverse forms of soil acidity in quick-test methods affect significantly the amount of the LR in a given time (Mc lean, 1982).

2.6 Effect of lime application on soil properties

Liming is an ancient agricultural practice for rehabilitating acid soils. Soil liming is the most effective approach for improving acidic soil properties, preventing associated environmental degradation, and maintaining crop production (Hajkovicz and Young, 2005). Liming materials are in oxide, hydroxide and carbonate forms (Brady and Weil, 1999). The calcium and magnesium compound react in acid soil with carbon dioxide and acid colloidal complex. These reactions will be considered in order. The reaction with carbon dioxide and water leads to the formation of bicarbonate.



According to Brady and Weil (1999), these materials react directly with acid soils, the calcium and magnesium replacing hydrogen and aluminium on the colloidal complex. The adsorption with respect to calcium may be indicated as follows:



The insolubility of $\text{Al}(\text{OH})_3$ and the release of CO_2 to the atmosphere pulls these reactions to the right. The interaction of lime with soil and also the required amount are greatly influenced by some factors such as the lime quality (finesse, purity), the depth of ploughing and the degree of mixing. Walker (1952) reported that 2 to 3 times more limestone was required to raise the pH of the soil in the field compared to the amount calculated from the results of uniform mixing in the laboratory. Ploughing the soil to a depth of 22.5 cm would increase the LR by a factor of 0.5 as compared with ploughing to 15 cm (Shoemaker, 1964).

Liming of acid soil usually increase the pH, the concentration of exchangeable Ca and the effective cation exchange capacity (ECEC). Adetunji and Bamiro (1994) reported that liming some south western Nigerian Ultisol (pH from 4.2 to 4.9) to successive pH's of 5.5, 6.0, 6.5 and 7.0 resulted in a sharp increase of Ca saturation by 20 % within the first three (3) weeks of incubation and thereafter remained relatively constant. Liming to

raise the soil pH to one unite resulted in the increase of ECEC at least 50 % (Kamprath, 1970).

The influence of lime on the availability of exchangeable Mg and K for most soils can be insignificant or decreasing. Adetunji and Bamiro (1994) found an insignificant effect of lime on Mg and K in some Nigerian Ultisol. Reduction in Mg availability as a result of liming acid soils may be due to decreased solution Mg (Adams, 1984) or to an undefined Mg fixation mechanism (Sumner *et al.*, 1978). Grove *et al.* (1981) found significant reductions in both exchangeable Mg and K following lime applications to various acid soils. Magdoff and Bartlett (1980) reported that as liming increased the pH and the CEC, solution K decreased. However, the application of dolomitic limestone resulted in increased concentration of Mg in acid soil. Venter (2004) found that the greater increases in soil Mg concentration were achieved by lime sources with higher Mg contents and smaller Ca/Mg ratios. The author showed a high correlation ($R^2=99.1$) between the dolomitic lime (mooiplaas) and the soil Mg concentration. Increased K retention by soil colloids after liming was thought to be the reason. Liming may, however, increase or have no effect on K concentration in the soil solution, depending on the initial base saturation and pH (Kamprath and Foy, 1985).

The overall effects of lime on soils include among others, the neutralization of toxic concentrations of Al, Mn and Fe; increasing of soil P, Mo availability and uptake. In an earlier study, Juo and Uzu (1977) observed a sharp decrease in soluble levels and corn uptake of Mn, as well as those of Mg and Zn, as pH was increased from 5.4 to 7.1. Similar effects of lime on Fe and Mn, as well as Zn and Cu, were noted by Kamprath (1971). Brallier *et al.* (1994) reported that liming soils from pH 4.6 to 6.9 decreased the

exchangeable fraction of Cd (from 10.9 to 5), Cu (from 11.7 to 4.6), Ni (from 20 to 0.8), and Zn (from 408 to 2.8). The positive effect of lime on soil nutrient status and crop uptake is confirmed by recent findings (Oluwatoyinbo *et al.*, 2005; Opala, 2011; Kisinyo *et al.*, 2014).

Furthermore, lime has an important environmental role by counteracting the acidifying inputs of sulphur (S) and N compounds from fertilizers and the atmosphere (Lundell *et al.*, 2001). Liming can also enhance nutrient leaching and influence the mobility of plant nutrients for decades after application (Curtin and Smillie, 1986). Moreover, liming can help prevent the uptake of radio-nuclides and heavy metals by plants and decrease pollution risk to soils and groundwater (Goulding and Blake, 1998). There are known linkages between pH and calcium carbonate (CaCO_3) supply and soil solution concentrations of arsenic, bromine, molybdenum, sulphur, antimony, selenium, uranium, and tungsten and, to a lesser extent, cobalt, chromium, mercury, magnesium, and strontium (Tyler and Olsson, 2001).

Natural soil acidity strongly influences the decomposition and mineralization of organic matter in limed soils (Hu *et al.*, 2006). Liming of acid soils also increases the activity of microbial populations that are important in nutrient availability or absorption. Especially affected are organic matter mineralization, nitrification, and rhizobial and mycorrhizal functions, SOC and aggregate stability (Chan and Heenan, 1999; Fornara *et al.*, 2011).

2.7 Organic amendments

An organic amendment is any material of plant or animal origin which is more or less decomposed and can be added to the soil to improve its physical, chemical and

biological properties (Naramabuye, 2004; Bouajila and Sanaa, 2011). Typical examples include animal and plant manures, green manure, plant residues, and compost, industrial and municipal wastes. Manure is the most common source that has been used as amendment in agriculture for improving soil fertility and crop yield. The three (3) main types of manure are: animal, compost and plant manure. The effectiveness of manure depends mainly on its quality and the quantity applied. The applied amount of manure is greatly linked to the availability and the cost of transportation. The quality (Nutrient composition) of manure varies greatly with manure type, method of preparation, dry matter content, stage of decomposition, etc (Hue and Silva, 2000).

2.7.1 Effect of manure on soil properties

Organic manure has been used for a long time, by farmers for ameliorating soil quality in general because of its relative availability and low price. Organic materials are simultaneously a source of nutrients and play a vital role in soil fertility maintenance (Bationo *et al.*, 2005). The positive effects of manure on soil fertility are well documented (Hue and Amien, 1989; Qin and Chen, 1997; Shen and Shen, 2001; Opala, 2011). In addition to macro nutrients (N, P, K etc.) and micronutrients (Cu, Mn, Fe, Zn, Mo, B, etc.), manure provides also carbon and other constituents that affect greatly soil humus content, biological activity, soil physical property (structure and moisture retention) (Hue *et al.*, 1998). Manure increases the low ECEC (Kaolinite dominant soil) and organic matter content of soils and decrease P fixation in acid soil (Bationo *et al.*, 2005; Opala, 2011). Powell (1986) showed that the application of cattle manure to a Savanna soil of Nigeria resulted in increased soil pH (5.1 to 5.8), organic carbon (1.50 to 1.91 %), Bray-1 extractable P (4.6 to 9.6 mg kg⁻¹), and CEC (4.34 to 6.15 cmol_c kg⁻¹).

Moreover, the leaving and incorporation of crop residues during land preparation have been reported to increase infiltration of water into soils (Nicou and Charreau, 1985), soil organic matter content (Klaij and Hoogmoed, 1993) nutrient recycling (Geiger *et al.*, 1992), soil pH and nutrient levels and improves crop yield (Coulibaly *et al.*, 2000). It has been reported that farmers applied more than 20 Mg ha⁻¹ of manure preferentially to degraded area of soil in cotton zone of Mali (Bouba, personal communication, 2013).

2.7.2 Liming effect of manure

Some manure types have the liming effects and can reduce soil acidity. Therefore, the application of manures to reduce Al toxicity is a cheapest alternative approach to traditional liming. The release of cations and anions after the mineralisation of manure affect nutrients balance of the soil solution and consequently its reaction. The cations can increase the potential cations and the base saturation of soil thus increasing soil pH and reducing Al toxicity (Cocker *et al.*, 1998, Shen and Shen, 2001). However, the effect of manure on soil pH is a conflicting issue. Manure has been reported to increase (Haynes and Mokolobate, 2001; Noble *et al.*, 1996; Shen and Shen 2001, Hue *et al.*, 1998; Naramabuye and Haynes, 2007; Busari *et al.*, 2008) or decrease (Wong *et al.*, 1999; Pocknee and Sumner, 1997; Kirchmann *et al.*, 2007; Shen *et al.*, 2007) of soil pH. Mattson and Hester (1933) reported that the addition of organic matter could prevent Al toxicity and increase soil pH. The beneficial effects of organic matter application on soil pH and Al detoxification have been further confirmed by many investigations (Noble *et al.*, 1996; Whalen *et al.*, 2002; Ano and Ubochi, 2007; Awodun, 2007; Opala, 2011). Wong *et al.* (1995) reported that the addition of green and animal manures reduced the

total concentration of Al (Al_t) in soil solution and/or the concentration of monomeric Al in solution (Al_{mono}) leading to reduction Al phytotoxicity and increased crop growth.

In greenhouse experiments in a sand culture, Tan and Binger (1986) showed that in the absence of humic acid, growth of maize plants decreased linearly with increasing Al additions. However, addition of humic acid at 100 to 300 mg kg⁻¹ greatly improved plant growth and ameliorated the negative effect of increasing Al concentrations. In solution culture experiments, Suthipradit *et al.* (1990) found that addition of fulvic acid reduced the amount of monomeric Al present in solution and alleviated the toxic effect of Al on growth of soybean, cowpea, and green gram. Hue (1992) reported that soil acidity can be corrected by either Ca (OH)₂ or organic manure additions. Both lime and manures raised soil pH and decrease Al resulting in increased dry matter yield. In terms of pH increases, 5 and 10 g chicken manure kg⁻¹ were equivalent to 3.4 and 6.7 cmol_c kg⁻¹; and 20 g sludge kg⁻¹, equivalent to 6.5 cmol_c kg⁻¹ as Ca (OH)₂. Total dry matter weight (shoots plus roots) of *Desmodium intortum* increased exponentially from 0.25 g in the unamended soil to 1.72 g at 2 cmol_c kg⁻¹ and 3.90 g at 6 cmol_c kg⁻¹ and 4.2 g at 5 g kg⁻¹ and 8.88 g at 10 g kg⁻¹ of chicken manure. Meanwhile Al concentration in shoots decreased accordingly from 198 to 69 and 26 mg kg⁻¹ and Ca concentration increased from 0.40 to 0.74 and 1.32 %, respectively.

The application of animals' manures to a Nigerian weathered Ultisol increased significantly the soil pH from 4.6 to 6.7 and also reduced exchangeable acidity from 3.00 cmol_c kg⁻¹ to 0.1 cmol_c kg⁻¹ while increased soil Ca from 1.6 cmol_c kg⁻¹ to 6.6 cmol_c kg⁻¹ (Ano and Ubochi, 2007). Similarly, Kretzschmar *et al.* (1991) observed more than 44 % decreases in total and labile Al concentrations in the soil solution of an acid

Psammentic Paleustalf in Niger after incorporating millet residue. Furthermore, some other works showed that the liming effect may be short-lived (Haynes and Mokolobate, 2001). However, the longer-term effects are less well-known.

Other authors reported a decrease in soil pH after applying the manure due to oxidation of N and S to SO_4^{2-} , which generated acidity (Summer *et al.*, 1991; Qin and Chen, 2005). The general viewpoint of this issue is well illustrated by Haynes and Mokolobate (2001) as follows: by decomposition of Organic N \longrightarrow $\text{NH}_4^+ + \text{OH}^-$ (hydroxyl increases pH) and the nitrification of NH_4^+ to NO_3^- releases protons: $\text{NH}_4^+ + 2\text{O}_2 \longrightarrow \text{NO}_3^- + \text{H}_2\text{O} + 2\text{H}^+$ (protons decrease pH). The overall transformation of organic N to NO_3^- is, therefore, acidifying with one H^+ being produced per mole of N transformed to NO_3^- . If soil conditions do not favour the nitrification the pH will rise, whilst if nitrification proceeds rapidly the pH will decrease (Haynes and Swift, 1993).

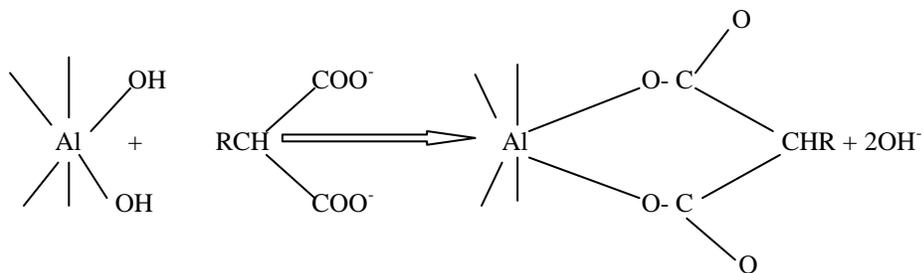
These results were confirmed in more recent works reported by Naramabuye and Haynes (2007) who found a substantial increase in pH and Al decrease after one week incubation with animal manure application due to their high CaCO_3 content released after decomposition. The pH then declined progressively while Al increased after 25 weeks incubation with substantial accumulation of NO_3^- . This pH decline was attributed to the H^+ produced during the conversion of organic N and S to NO_3^- and SO_4^{2-} , respectively. However, this acidification is an artefact of incubation in closed area favouring NO_3^- accumulation. But under field conditions much nitrate produced would be absorbed by growing plants leading to OH^- releasing that can neutralize soil acidity (Heyar and Porter, 1989). This acidification would be permanent only with the leaching of cations by nitrate (Heyar and Porter, 1989).

2.7.3 Mechanism of Al detoxification

Manure can play the dual role of providing nutrients and mitigating the deleterious effects of soil acidity, but the precise mechanism of Al detoxification by manure has not yet well been understood like lime. The decomposition of animal and plant debris released a wide range of organic compounds which can bind strongly Aluminium and render it non toxic. The organic compound involved in Al detoxifying can be grouped in to (i) organic acids: with Low-Molecular-Weight Organic Acids which include formic, acetic, propionic, butyric, crotonic, lactic, oxalic, succinic, fumaric, tartaric and citric (ii) humic materials: with High-Molecular-Weight-Organic-Molecules made up of a core phenolic polymers (Haynes and Mokolobate, 2001). The Al neutralization potential of manure has been attributed to several chemical pathways. The mechanisms involved in the reactions of Al with organic matter are complex and probably include simultaneous chelation, complex formation, adsorption and co-precipitation (Haynes, 1984). The proposed mechanisms include:

- Complexation of Al in soil solution

The products of organic decomposition particularly low-molecular-weight-organic-acids form stable complexes with aluminium (Al) in soil solution as suggested by Bartlett and Riego (1972); Hue *et al.* (1986); Wong *et al.* (1995).

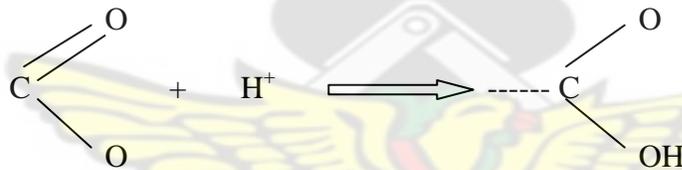


- Adsorption of soluble Al on the surface of organic compounds

Another pathway of Al detoxifying of Al by organic material is the adsorption of soluble Al on the surface of some organic compound (Asghar and Kanehiro, 1980, Haynes and Mokolobate, 2000). Some organic compound form very strong ligand with Al and make it non toxic for plant (Bartlett and Riego, 1972; Hue *et al.*, 1986).

- Protonation of organic anions

Bensho and Bell (1992) attributed the phenomenon of Al detoxifying by manure to the protonation (proton consumption capacity) of organic anions and soluble humic compound as indicated below:

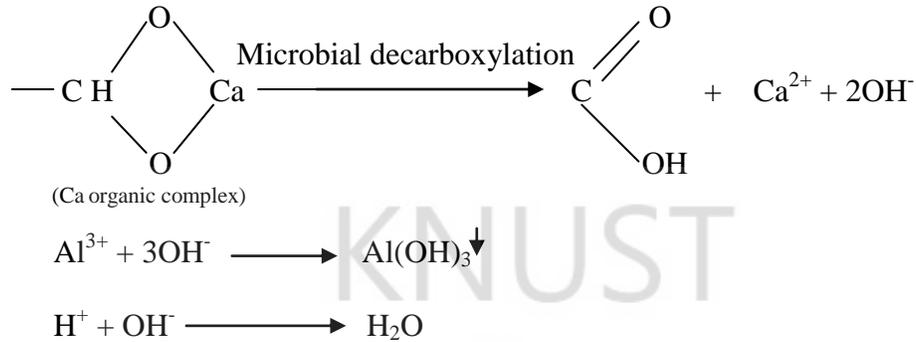


Similar results were reported by Helyar and Porter (1989) who found that the major mechanisms responsible for the elevations in pH were suggested to be the proton consumption capacity of humic material present in household compost and manures.

- Decarboxylation of Ca-organic matter complex

Decarboxylation is a chemical reaction that removes a carboxyl group (COOH) and its replacement with a proton, and releases carbon dioxide (CO₂). The decarboxylation of Calcium organic matter leads to the release of and subsequent hydrolysis of calcium ions. The hydroxyl ions released in the hydrolytic reaction then reacts with both the exchangeable hydrogen and aluminium ions to form water and insoluble aluminium

hydroxide Al (OH)₃ respectively (Ano and Ubochi, 2007). They proposed the following mechanism of reaction:



Similar results were reported by Barekzai and Mengel (1993), Yan *et al.* (1996), Naramabuye and Haynes (2006).

- Increasing the base saturation of the soil by cations

The organic matter contains basic cations such as Ca, Mg, K and Na. These cations released after mineralization may increase the base saturation of the soil solution and result in increasing soil pH. Shen and Shen (2001) reported that addition of pig manure and wheat straw resulted to increased soil pH and soil basic cations and significant decrease in soil Al content compared to the control. More increase in pH and cations content and decreases in Al were more noticed with pig manure than wheat straw because of the higher level of basic cations in first than the second organic material. Similar results were observed by Wong *et al.* (1998), who found that the increased soil pH was directly proportional to the base cation (Ca, Mg and K) concentrations of the added organic material.

The liming effect of ash from plant materials have been reported by many workers (Wong *et al.*, 1998). The decaying of crop residue releases ash compounds which contains a high amount of cations (Ca, Mg, K and Na) and the anions (P, S, and Si). The cations increase the potential cation exchange and base saturation, therefore counteracting the Al in soil indirectly while anions chelate active Al and converted in to a nontoxic form (Wong *et al.*, 1998; Qin and Chen, 2005).

2.7.4 Effect of manure on crop growth and grain yield

Manure has been applied for many centuries as fertilizer and its beneficial effects on soil fertility and crop yields are well documented. In addition to nutrients (N, P, K and micronutrients etc.), manure provides carbon and other constituents that affect greatly soil humus content, biological activity, soil physical property and consequently improve crop yield. The positive effect of manure application on crop growth and yield has been reported by many workers (Hue *et al.*, 1995; Coulibaly *et al.*, 2000, Busari *et al.*, 2008). Baquerol and Rojas (2001) reported that addition of 5 tons of cowpea residue and chicken manure improved maize grain yield by 48 % and 71 % respectively. Opalla (2011) found an increase of maize dry matter up to 100 % compared to the control by the application of both farmyard manure and Tithonia in sole application and the increase was more pronounced by combination with TSP. The effect of manure on crop yield is more enhanced when fertilizer is applied due to their synergetic interaction. Opoku (2011) found an added benefit of 684 kg ha⁻¹ with the combined application of manure and NPK fertilizer on a regosol of Sarauniya (Nigeria)

It is evident that organic matter plays a key role in soil properties improvement particularly for acidic soil but the amount required is very important. However, most of West African farmers cannot use organic amendment at recommended rate. For example, in Mali, the recommended rate of organic matter for cereal is 5 Mg ha⁻¹ but the global mean applied by farmer range from 1000 to 1300 kg ha⁻¹. The high rates required and the cost of transportation may be the main constraints for large application of manure to maintain soil productivity.

2.8 Phosphate Rock (PR)

PR is generally rich in Ca and Mg and phosphate and constitutes the main source for soluble mineral fertilizer production. According to (Henny *et al.*, 1995), the chemical composition of Tilemsi phosphate rock (TPR) of Mali is: pH (9), P₂O₅ (29- 31 %), Ca (30 %-42 %), Mg (0.4 %). Because of the high initial pH, the high content in Ca and P₂O₅ rock phosphate has been used to overcome the main constraints of infertile acid soil. However, there are conflicting reports on the effectiveness of TPR liming effect. Some studies have shown that certain PR have both a substantial liming effect and serve as an important source of Ca (Hellums *et al.*, 1989; Doumbia *et al.*, 1993; Sikora , 2002). The application of PR resulted to an increase in soil Ca content and soil pH, the decrease of soil exchangeable Al in a strongly acid sandy loam after application of Tilemsi phosphate rock (Hellums *et al.*, 1989; Kanabo and Gilkes, 1987). They attributed to the consumption of protons during acidulation of PR and subsequent neutralization due to bases released. Similar results were observed by Sikora (2002) who explained the liming effect of PR by the fact that the dissolution of apatite in PR releases anions (CO₃⁻² and PO₄⁻³) that can consume H⁺ ions and, thus, it can increase soil pH,

depending on its reactivity. The anion PO_4^{3-} exerts a greater effect on the liming potential of PR (due to its greater molar quantity). If a PR is rich in free carbonates, it can further increase soil pH. However, although an increase in soil pH may reduce the Al saturation level. The PR treatment increased soil pH, exchangeable Ca and soil solution Ca while lowering exchangeable Al and Al of soil solution. However, the PR dissolution did not reduce total Al in soil solution, but did release Al complexing anions into soil solution, which along with increased pH, shifted Al speciation from toxic to non toxic forms. The general viewpoint on this conflicting issue was well illustrated by the following results reported by Doumbia *et al.* (1993) who observed an increase in soil pH in green house experiment and contrary a decreased soil pH in field trials on a sandy acidic soil in Mali. Besides, Shanadeh *et al.*(2004) found that TPR had no significant effect on soil pH despite the huge amount applied but reduced Al toxicity and increased Ca content (from 0.22 to 2.87 $\text{cmol}_c \text{ kg}^{-1}$) and soil available P. The precipitation of soluble Al to Al-P compounds by the release P are partly responsible for reduction in soil aluminium content after addition of PR (Sanchez and Uehara, 1980; Shahandeh *et al.*, 2004).

2.8.1 Effect of rock phosphate on crop growth and yield

The positive effect of phosphate rock on soil properties and consequently various crop growth and grain yield has been reported by several authors (Doumbia *et al.*, 1993; Shahandeh *et al.*, 2004). Wright *et al.* (1991) observed in a green house experiment that root length was significantly increased both by PR treatment and CaCO_3 , indicating that dissolution was ameliorating soil acidity. Shahandeh *et al.* (2004) found that application of TPR increased millet yield by up to 89 % compared to the control. The augmentation

in millet yield was attributed to the increase of the plant available P and Ca. Similar effect were found by (Jibrin *et al.*, 2002), who observed very significant improvement in the yields of succeeding maize and reduction of leaves Al content in acidic soil of Northern Guinea Savanna of Nigeria after application of phosphate rock.

2.8.2 Constraints to the use of rock phosphate

Despite some encouraging results, the PR is not widely used in West Africa particularly in Mali due to some constraints such as (i) low reactivity or solubility; and (ii) form (powder or granules). The PRs are certainly cheaper, but are less agronomically effective sources of P and Ca than chemically manufactured fertilizers. Many studies have been conducted to alleviate the major constraints to their direct use in agriculture. In addition, several alternatives have been developed for use of indigenous phosphate rock (PR) sources: (i) grinding to a fine powder for direct application to soil; (ii) development of granulation techniques to improve the physical properties; (iii) mixing of finely ground PR with organic materials, sulphur, soluble P fertilizers or other products capable of increasing the availability of P; and (iv) partial acidulation of PR to increase the water and citrate solubility of P (Hammond *et al.*, 1986).

Besides, the use of PR requires some precautions because of the presence of hazardous elements including heavy metals (cadmium, chromium, mercury, and lead), and radioactive elements (uranium). These elements are recognized to be toxic to human and animal health (Mortvedt and Sikora, 1992).

2.9 Method and rate of application of amendment and fertilizer

Nowadays, because of the scarcity of resources, and the unfavourable socio-economic conditions of farmers, it is imperative to use efficiently the available resources while decreasing the cost of production by reducing the amount of inputs. For this reason, scientists, extensionists and farmers have developed the localized application of water, organic matter and chemical fertilizers. Positive results have been found for water (drip irrigation) and fertilizer (micro-dosing), but only few have been done for liming.

Method of placement has an important effect on the efficiency of fertilizer. Precision application has been widely promoted due to the low fertilizer application rate, high probability of yield response (Palé *et al.*, 2009) and due to a favourable fertilizer/grain price ratio (Abdoulaye and Sanders, 2005; Vitale and Sanders, 2005). Previous research findings have shown the superiority of precision placement methods of fertilizer compared to traditional broadcasting on weed control, nutrient uptake and early growth and crop yield (Poss *et al.*, 1995; Tang *et al.*, 1999; Weligama *et al.*, 2008). The banding or spot applications of fertilizer reduce significantly the losses of nutrients and increase the contact with root and consequently nutrient uptake by plant. Bagayoko *et al.* (2000) reported that point application can reduce P fixation, promote early season shoot and root growth, enhance infection with vesicular arbuscular mycorrhizae, increase nutrients and water uptake leading to increased grain and dry matter yields.

The precision application of fertilizer decreases the weed density and biomass in fields and consequently reduces the time and labour cost for weed control (Mashingaidze *et al.*, 2012). Furthermore, the spot and band placement increases radiation interception and early growth of maize and reduces significantly the emergence, growth and seed

production of weeds, compared to broadcasting. The precision application of some type of fertilizer particularly nitrate can also improve soil chemical properties of acid soil by alkalization. Weligama *et al.* (2008) found an increase in soil pH by 0.4 (top layers) and 0.5 (sub layers) units pH in rhizosphere compared to bulk soil after the localized supply of N and P at crop root zone. The increase in pH was attributed to the greater root growth and greater biomass production leading to greater nitrate uptake by plant from that rhizosphere (Poss *et al.*, 1995; Tang *et al.*, 1999; Weligama *et al.*, 2008).

The positive effect of precision application of fertilizer on nutrients and water uptake results in an increased crop growth and grain yield. Bagayoko *et al.* (2011) reported that the spot fertilizer application increased pearl millet grain yields from 240 to 300 kg ha⁻¹ and stover yield from 250 to 400 kg ha⁻¹ on sandy soils, while in silty soil the increase was by 400 kg ha⁻¹ for pearl millet grain yields and 500 to 2500 kg ha⁻¹ for stover yields. Similar results were reported by Mashingaidze *et al.* (2012) who found a higher maize grain yield by spot or banding placement of fertilizer compared to broadcasting at all rates of application. On the other hand, few studies have compared the efficiency of spot versus banding application of fertilizer and the existing reports are conflicting. Certain findings reported the superiority of banding (Mashingaidze *et al.*, 2012), others the performance of spot over banding (Fox and Kang, 1978; Buresh *et al.*, 1997).

Lime is traditionally applied by broadcasting but the quantity required and the high cost of lime has discouraged farmers to use this amendment. Most studies have been carried out on the agronomic efficiency and financial returns of lime by broadcasting at conventional rate. Whilst several authors found a substantial agronomic and financial benefit effect of liming at conventional rate in some parts of Africa (Mitchell *et al.*,

2005; Ragnar, 1987), in Mali the few studies done, showed certainly an increase of yield, but also a net negative financial benefit due to the high cost of lime and the low grain price (Gigou, 1998). However, the application of lime at reduced rate can increase the agronomic and financial efficiencies of lime. Brady and Weil (1999) found that lime application at reduced rate may improve significantly crop growth and yield by increasing Ca and Mg nutrition and reducing Al toxicity. Mulungu *et al.* (2013) reported that the precision application of lime (on the crop or in basin or in the furrow) at reduced rate of 350 kg ha⁻¹ resulted in a substantial increase in grain yield and financial returns compared to broadcasting. Because of limited quantity and quality of organic materials the combined application of lime and manure at reduced rate can be an alternative to overcome acid soil infertility at affordable cost. The combined application of lime and manure have been reported to increase soil pH, infiltration of water into soils, soil organic matter content, nutrient recycling, and nutrient levels, to improve soil biological activities and soil physical properties leading to increased crop growth and yield (Alloush, 2003; Tabu *et al.*, 2007). The combined application of 5 Mg ha⁻¹ of manure and 2.2 Mg ha⁻¹ of lime resulted in an increased of wheat (*Triticum aestivum*) grain and straw yield by 2.79 % and 1.87 %, respectively over the control, and a net benefit of 28 \$ ha⁻¹ due to additional yield (Asrat *et al.*, 2014). Similar results were reported by Bareeleng, (2011) who found that the application of 10 Mg ha⁻¹ of manure and 3 Mg ha⁻¹ of lime improved acid soil properties leading to increased maize yields.

2.10 Economic indicators

The technology of soil characteristic improvement cannot attract the farmer's attention if it does not results in observable benefit such as increased yields, and increased

profitability (Mulungu *et al.*, 2013). Indeed there is the need to link the agronomic efficacy to the financial profitability for the evaluation of any soil technology. The economic sustainability of a farm enterprise is measured with indicators. The most frequent indicators used to evaluate the economic profitability of a farm enterprise are: the Net Present Value (NPV), the Net Farm Income (NFI), and the Value Cost Ratio (VCR), etc. The NPV is estimated as the value of outputs divided by the value of inputs and a farming enterprise is productive if NPV is greater than or equal to one (Lynam and Herdt, 1989). According to Zhen and Routray (2003), the NFI represents the difference between gross benefit of production and the total variable costs per unit of land area while the VCR is the agronomic efficiency of the prices of inputs and outputs. A farming enterprise is considered as economically viable when the NFI is greater than zero and the VCR is greater than one.

2.11 Knowledge gaps

To use the locally available organic amendments as liming materials, it is necessary to predict their liming effects prior to application. Most studies have evaluated the liming effect of organic amendments but the prediction of liming effect was undertaken particularly for rock phosphate and Ash from cereals.

Most research was focused on the combined effect of lime and manure at higher rates which are unaffordable to many farmers. There is a lack of information on the agronomic efficiency and the financial return from the combined application of lime and manure at reduced rate. There also is a need to develop optimal combination that fits farmers' needs and practices to enhance adoption.

Most studies confirmed the positive effect of combined application of lime and fertilizer on soil properties and crop yields. However, there is a dearth of information on the agronomic efficiency and financial returns of the combined application of lime at reduced rate with the precision application (banding and spot) of fertilizer.

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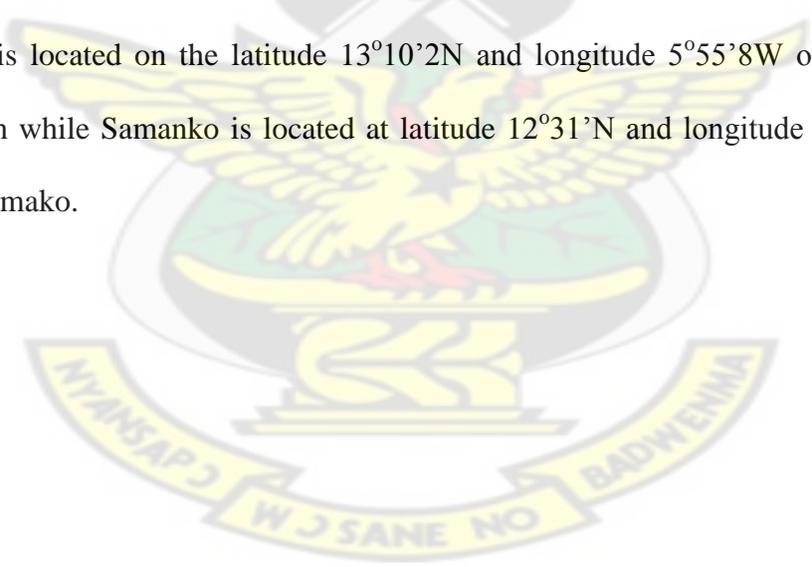
CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study location

This was a multidimensional study to manage soil acidity through the use of locally available materials. Three research studies comprising one laboratory and two field studies were conducted. The laboratory experiment was conducted at the Research Station of the Institut d'Economie Rural (IER) in Sotuba-Bamako during 2012 growing season. The field experiments were carried out at the Research Sub-Station of IER in Samanko during the 2012 and 2013 growing seasons. The selected sites for the various studies are shown in Figure 3.1.

Sotuba is located on the latitude $13^{\circ}10'2''N$ and longitude $5^{\circ}55'8''W$ of the Greenwich meridian while Samanko is located at latitude $12^{\circ}31'N$ and longitude $8^{\circ}4'W$ at 35 km from Bamako.



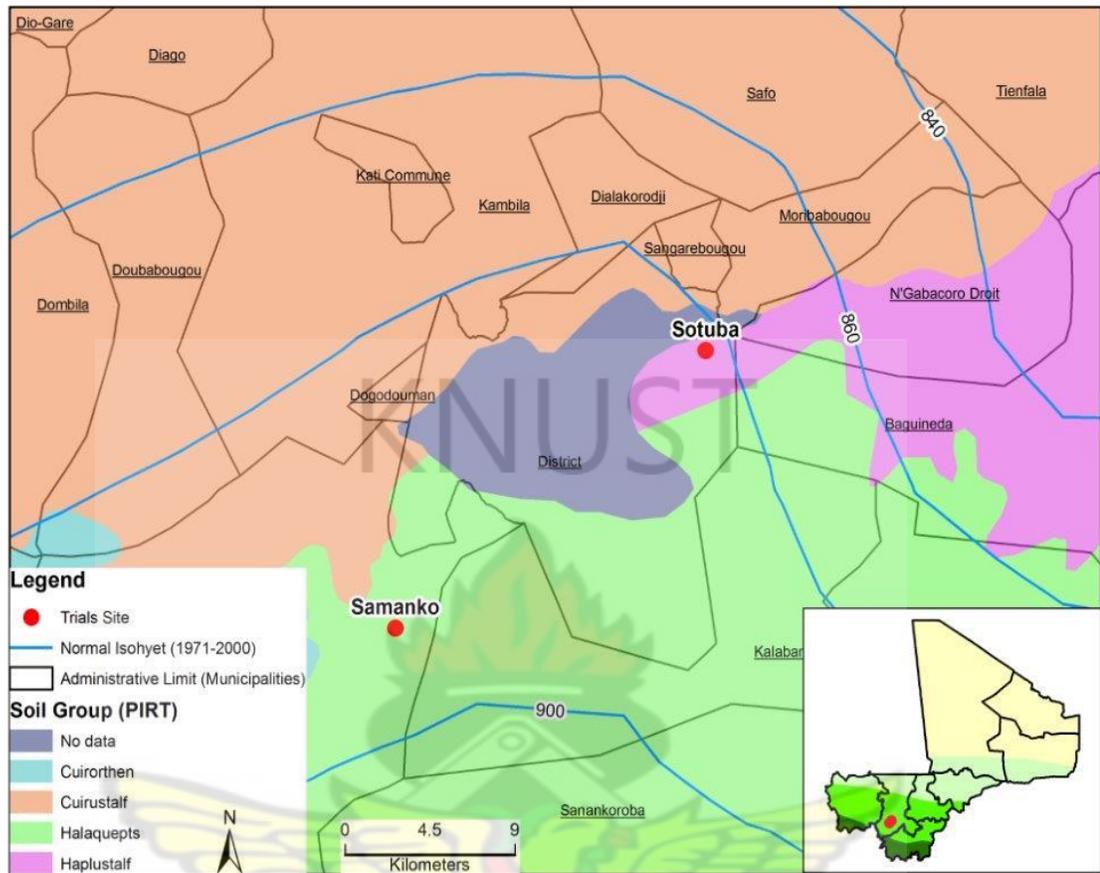


Figure 3-1: Location of study sites (Source GIS unit of the Labo-SEP/IER, Mali)

3.1.1 Climate and vegetation

Sotuba and Samanko are situated in the soudano-sahelian agro-ecological zone typically characterized by the semi-arid tropical precipitation. There are two seasons: the rainy season (from April to October) and the dry season (from November to March). The wet period of the rainy season is between August and September. The annual average rainfall is estimated at 800-1100 mm. About 80 % of that rain usually falls in June - September, and rainfall intensity of 40-90 mm per hour is common in this ecological zone. The Figure 3.2 (Appendix 1) shows the monthly rainfall recorded at Samanko research station during the years of experimentation. The location is characterised by an average temperature of 26.6-38 °C, with a daily maximum of 40 °C and minimum of 14

°C. The monthly air temperature recorded at Samanko research station during the years of experimentation is presented in Fig 3.3 (Appendix 1). The humidity varies between 19 and 78 %, it is higher during the rainy season. The sunlight hours vary between 5 AM and 7 PM a day and are longer during the dry season. The annual average Potential Evapo-Transpiration (PET) is estimated at 1970 mm. This value exceeds the annual precipitation during the year except June to September when PET is lower than rainfall.

The natural vegetation does not exist anymore due to cultivation and land clearance for infrastructure development. There is however a fallow site in south-west of the stations with economic trees including: Kaicedra (*Vitellaria paradoxa*), Nere (*Parkia biblobosa*), ficus (*Guiera senegalensis*) and several species of herbs (Table 3.1). The density of trees and shrubs varies within the station. The density of mature trees is very low in cultivated areas but very important in areas allocated to specific research such forestry, pasture or fallow.

Table 3.1: Most common plant species found at Samanko and Sotuba

Bambara names	French names	English names	Binomial names
None	Andropogon	Gamba grass	<i>Andropogon gayanus</i>
Shi	Karité	Shea tree	<i>Vitellaria paradoxa</i>
Néré	Caroubier Africain	Locust bean	<i>Parkia biglobosa</i>
N'Tomono	Jujubier	Ziziphus	<i>Ziziphus mauritiana</i>
Zira	Fromager	none	<i>Bombax caustatum</i>
N'Tomi	Tamarinier	none	<i>Tamarindus indica L</i>

3.2 Study1: Evaluation of the liming potential of selected locally available materials

Some locally materials such as manure, phosphate rock, ash, crop residue have liming potential and sink of other plant nutrients (Hayes and Mokolobate, 2001). The rationale for the use of these local resources as an ISFM technology is based on the assumption that they have a liming effect on soil acidity by increasing pH and /or complexing with Al, Mn and other metal toxic ions (Wong and Swift, 2003; Tang *et al.*, 2007, Naramabuye and Haynes, 2007). In addition they provide substantial amount of plant nutrients (Hue *et al.*, 1998; Bationo *et al.*, 2005). The use of some of these materials as lime source can be a cheap alternative to improve acid soils in West Africa. This laboratory trial was conducted to evaluate the effect of addition of nine locally available organic materials on acid soil properties and to predict their liming effect with the view to use them as liming materials.

3.2.1 Soil

The study was conducted in the Soil Science Laboratory of IER, Sotuba, Bamako. The soil for the study was ferruginieux tropicaux lessivés (French classification) or Haplustalf (Soil survey staff, 1999) or an Acrisol (FAO-UNESCO, 1994). Soil samples were collected at the depth of 0-15 cm from the Agronomy Research Station of Sotuba, where maize grew poorly due to low pH and Al toxicity. The samples were air-dried, sieved through a 2 mm sieve and characterised for the parameters as described in section 3.2.8. Some selected physical and chemical properties of Sotuba soil are presented in Table 3.2. The soil was a very acidic sandy loam, and had low OC, available P, exchangeable Ca and Mg contents. However, the soil exchangeable K was adequate as compared to the range established by Manson *et al.* (1993).

Table 3.2: Initial physical and chemical properties of Sotuba soil tested

Soil properties	Value
pH (1:1, H ₂ O)	4.90
pH (1:1, KCl)	3.90
O C (%)	0.25
T.N (%)	0.01
Av. P (mg kg ⁻¹)	13.50
Exch. K (cmol _c kg ⁻¹)	0.20
Exch. Ca (cmol _c kg ⁻¹)	2.00
Exch. Mg (cmol _c kg ⁻¹)	0.90
Exch. Na (cmol _c kg ⁻¹)	0.01
Exch. acidity (cmol _c kg ⁻¹)	0.90
Clay (%)	5
Silt (%)	35
Sand (%)	60

3.2.2 Amendments used

The nine (9) soil amendments used in this study were: Cattle manure (CM), Sheep manure (SM), Goat manure (GM), and Poultry manure (PM), Sabunjuma compost (SC), and maize residue (MS), ash from maize straw (AM), Tilemsi phosphate rock (TPR), and lime of Tokouto (TL) as control. The CM and PM were collected from Sotuba Agriculture Research farm and the sheep and goat manure from commercial sheep and goat producers. The maize residue was obtained from the Agronomy Research Station of Sotuba, and the lime from a local private industry called “Calcaire et Chaux du Mali”.

The phosphate rock was from Toguna an agro-industry which manufactures fertilizer. The compost named “Sabunjuma” was an improved organic amendment made by a private agro-industry called PROFEBBA.

The amendments were air dried, crushed with wooden roller and passed through 2 mm sieve. These materials used in the study were analysed for their key liming properties: initial pH, calcium carbonate equivalent (CCE), total organic carbon, total nitrogen, total base cation, proton consumption capacity (PCC) and their other chemical constituents.

3.2.3 Lime requirement

The lime used was a locally available dolomite lime from local industry. Laboratory soil test was used to determine the amount of agricultural lime required for correcting the soil acidity at a level that favours the optimum crop development. The recommendations for liming of acid tropical soils are to raise the pH up to 5.5. The optimal pH for most tropical soils is in the range of 5.2 to 5.8. The lime requirement based on exchangeable aluminium was used because it is effective for soils of the study area which are acid, highly weathered, weakly buffered, kaolinitic systems and poor in organic matter (Kamprath, 1970). The model ADSS (Acidity Decision Support System) use the modified formula of Cochrane (1980) which calculates the lime required to neutralize soil Al-exchangeable at the critical tolerance level of crop. A targeted Al saturation (TAS) is set below the critical Al Saturation of the crop. The formula of Cochrane is:

$$LR = 1.5 [Al - (TAS (ECEC)/100)] \quad \text{Equation 3.1}$$

Where LR = Lime requirement ($\text{CaCO}_3 \text{ Mg ha}^{-1}$) and TAS=Target Al saturation.

The lime requirement was 1300 kg ha^{-1} .

Table 3.3: Selected physical and chemical liming properties of different fractions

Particle size	Percent passing	Efficiency factor	Efficiency rating †	Calcium Carbonate Equivalent (CCE)	Efficient Carbonate (ECC) ‡
<0.25mm	0.16	60	0.96	57	0.54
<0.15 mm	99.84	100	99.84	59	58.9

† Efficiency rating: efficiency factor x percent passing

‡ ECC: efficiency rating x CCE (calcium carbonate equivalent)

The locally available lime had higher finer particle and 100% passed through a sieve 0.25 mm (60 mesh) (Table 3.3). Liming material finer than 0.25 mm (60 meshes) will react almost completely within 6 to 12 months after application (Garman, 1963). The Calcium carbonate equivalent (CCE) of different size fractions of Toukoto lime ranged from 57 to 59 % (higher than 50%). These values are very close to the range of quality standard ($60\% < \text{CCE} < 80\%$) set by the New York State Department of Agriculture and Markets (NYSDAM) (Carey *et al.*, 2006). Moreover, the total ECC (ECC's of different size fractions) of Toukoto lime was 59.44%, very close to 60%.

3.2.4 Experimental design

The experiment was a factorial arranged in a Completely Randomized Design (CRD) in three replications. Treatments consisted of 9 amendments \times 5 rates. The five rates were: 0, 1.3, 2.6, 5.2 and 10.4 Mg ha⁻¹ for Toukoto lime and 0, 5, 10, 20 and 40 Mg ha⁻¹ for other amendments. The 1.3 Mg ha⁻¹ represented the lime requirement calculated and 5 Mg ha⁻¹ was the recommended rate of organic material for cereal in Mali.

3.2.5 Soils treatments

About two hundred and fifty (250) grams of the sieved soil were weighed into each of one hundred and thirty five (135) plastic pots. The capacity of each pot was 1/2 litre. The lime was applied at 0, 1.3, 2.6, 5.2 and 10.4 Mg ha⁻¹ and other amendments at 0, 5, 10, 20, 40 Mg ha⁻¹ in triplicate. The amendments and soil in each pot were mixed thoroughly and moistened to 70 % of field capacity with distilled water. The hundred and thirty five (135) pots comprising a hundred and eight (108) with amendments and twenty seven (27) without amendment (control) were arranged on the laboratory table in a completely randomized design. The soils were moistened at 70 % of field capacity with distilled water and weighed. The soils were incubated for 4 weeks and placed at room temperature. All pots were periodically weighed and brought back to initial weight to maintain moisture at 70 % of field capacity during the experiment. At the end of incubation the samples were removed and soils were air dried and passed through 2 mm sieve and analyzed for some selected chemical and physical properties.

3.2.6 Prediction of lime equivalence of locally available organic resources

The lime equivalence of organic materials was determined by investigating the changes in soil pH after four (4) weeks incubation of lime Ca(OH)₂ on the same acid soil (Hue and Amien, 1989). Nine rates of pure Ca(OH)₂ were used (L0=control, L1= 0.5 mg g⁻¹, L2=1 mg g⁻¹, L3=1.5 mg g⁻¹, L4=2 mg g⁻¹, L5=2.5 mg g⁻¹ and L6=3.0 mg g⁻¹, L7=3.5 mg g⁻¹, L8=4.0 mg g⁻¹, L9=4.5 mg g⁻¹, L10=5.0 mg g⁻¹). A standard curve was drawn using regression analysis between the amounts of Ca(OH)₂ and the induced pH. The lime equivalence (pure calcium hydroxide) of organic materials was determined by

plotting the pH values (induced by 40 mg of organic materials used for incubation) against the standard curve.

3.2.7 Measured parameters

In order to assess the improving effect of locally available resources on soil acid properties the following parameters were measured:

- (i) for amendments: pH, total nitrogen, total phosphorus, OC, proton consumption capacity, CaCO₃ equivalent.
- (ii) for soil: pH, total nitrogen, available P, exchangeable acidity, Ca, Mg, K, Na.

3.2.8 Laboratory analyse of soil, plant and amendment samples

The methods adopted for soil, plant and amendments analyses were as below:

3.2.8.1 Soil samples

Determination of CaCO₃ equivalent by titrating

The CaCO₃ equivalence was measured by titrating method of Bundy and Bremner (1972). A 0.5 g of the dried product was weighed in to a 250 ml Erlenmeyer flask. Then 50 ml of HCl (0.5 M) was added and thoroughly mixed. The mixture was boiled for 5 minutes and allowed to cool. The solution was titrated after with NaOH (0.25 M) until the apparition of pink colour or the pH attained 8.3. After titration, the equivalent of CaCO₃ was calculated by the following formula:

$$\text{CaCO}_3 (\%) = 2.5 * \left(\text{HClml} - \frac{\text{NaOHml}}{2} \right)$$

Determination of exchangeable acidity

The exchangeable acidity was measured using the potassium chloride method as described by Thomas (1982). A 10g of soil sample was weighed and 25 ml of 1.0 N

KCl solution was added. The mixture was shaken on a reciprocating shaker for 30 minutes and filtered into a 250 ml Erlenmeyer flask followed with an additional volume of 125 ml of 1.0 N KCl in 25-ml increments to a total of 150 ml. A blank was also included in the titration. About 4-5 drops of phenolphthalein indicator solution was added. The solution was titrated with 0.1 N NaOH until the colour just turned permanently pink.

Calculations

$$\text{Exch. acidity (cmol kg}^{-1}\text{)} = \frac{(\text{mlNaOH}_{\text{sample}} - \text{mlNaOH}_{\text{blank}})}{\text{g}_{\text{sample}}} * N * 100$$

Where N = Normality of NaOH

Determination of pH

The soil pH was determined by the potentiometric method (1:1 soil water ratio) proposed by (Mclean *et al.*, 1982). A 50 g of dried soil was weighed into a plastic flask and 50 ml of distilled water was added. The mixture was thoroughly shaken on a reciprocating shaker for 1 hour. Just before measuring pH, the bottles were shaken by hand. The pH meter was standardized with buffer solutions of pH 4.0 and 10. After standardization, the electrode of pH meter was inserted into in the suspension and read.

Determination of available P

The available phosphorus was extracted with Bray I extracting solution (0.03 M NH_4F and 0.025 M HCl) as described by Olsen and Sommers (1982). Phosphorus in the extract was determined by the blue ammonium molybdate method with ascorbic acid as the reducing agent using a spectrophotometer auto analyzer. A 2 g soil sample was weighed into a shaking test tube (20 ml) and 14 ml of extracting solution of Bray-I added. The mixture was shaken for 1 minute on a reciprocating shaker and filtered through a

Whatman No. 42 filter paper. An aliquot of the blank and the extract were pipetted into a test tube and placed in auto analyzer sampler. A standard series of 0, 1.5, 3, 4.5 and 6 mgP/L was prepared from 20 mg/L phosphorus. The concentration of P was measured in the standard series, samples and blanks on Technicon Auto Analyzer, manifold P Bray at sensitivity 1.00 to 50 mv.

Calculation

The peak heights of the standard range, blanks and samples were measured relative to the baseline. The standard series was used to calculate the concentrations of blank phosphorus and samples.

$$\text{Av.P (mg kg}^{-1}\text{)} = 7 * (a - b)$$

a = mg kg⁻¹ P measured for the sample.

b = mg kg⁻¹ P measured for blank

Determination of total nitrogen

A 0.5 g of fine air-dried soil was weighed into a 50 ml volumetric flask. A 0.75g of catalyst (1.55 g of Se + 1.55 g of CuSO₄ + 96.9 g of Na₂SO₄), some carborundum grains and 5 ml of concentrated sulfuric acid were added. The mixture was stirred and the flask was placed on a hot plate and heated to 200 °C, for 1 hour. After continuing to heat with 350 ° C, until the colour clear or pale green was appeared. The flasks were removed from the plate and allowed to cool. Slowly about 25 ml of distilled water were added in small portions. When the mixture was cooled, the volume was made to 50 ml with distilled water and mixed well. Clear aliquot of sample and blank were pipetted and put in tube of auto-analyzer Technicon for determination of total nitrogen at sensitivity 6.00

to 50 mV. A standard series of 0, 1.5, 3, 4.5 and 6 mg P L⁻¹ was prepared from 20 mg L⁻¹ phosphorus

Calculation

The peak heights of the standard series, blanks and samples were measured relative to the baseline. The standard series was used to calculate the concentrations of blank nitrogen and samples.

$$N (\%) = 0.01 * (a - b)$$

Where a = % N for sample

b = % N for blank.

Determination of organic carbon

A modified Schollenberger method as described by Nelson and Sommers (1982) was used to determine the soil organic carbon. A 1 g of soil sample was weighed into a digestion flask (100 ml). A reference sample and a blank were included. A 10 ml of 1.0 N (0.1667 M) potassium dichromate was added to the sample and the blank flasks. Concentrated sulphuric acid (15 ml) was carefully added to the soil from a measuring cylinder. Then the digestion flasks was put in the oven at 120°C for one hour and half, and stirred every 15 minutes. The flasks were cooled in a fume cupboard and made to volume with distilled water. A 25 ml of the clear aliquot were pipetted and transferred into a 200 ml Erlenmeyer flask and 1 ml of concentrated phosphoric was added. A diphenylamine indicator (1 ml) was then added and titrated with 1.0 M ferrous sulphate solution. A 2 ml of potassium dichromate (8%) were titrated as control.

Calculation:

The organic carbon content of soil was calculated as:

$$C(\%) = 0.24 * (a - b) * \left(\frac{13}{V}\right)$$

where a= ml ferrous sulphate solution required for blank

b= ml ferrous sulphate solution required for sample

V= ml ferrous sulphate solution required for the control (II)

Determination of exchangeable basic cations

The exchangeable basic cations were measured using the ammonium acetate method as described by (Rhoades, 1982). A 2.5 g of dried soil was taken into 100 ml centrifuge tube and 50 ml of 1.0 N ammonium acetate solution having pH 7.0 was added to it. The mixture was shaken for 30 minutes. The solution was centrifuged until the supernatant liquid was clear and the extract collected into volumetric flask of 50 ml. Then ammonium acetate was used to dilute the solution to 50 ml and the concentration of Ca, Mg, K and Na was read from Agilent 4100-MP-AES.

Calculation:

Using the standard series, the values of the samples and blanks were calculated as follows:

$$\text{Na (cmol}_c \text{ kg}^{-1}) = 0.087 * (a - b)$$

$$\text{K (cmol}_c \text{ kg}^{-1}) = 0.051 * (a - b)$$

$$\text{Ca (cmol}_c \text{ kg}^{-1}) = 0.100 * (a - b)$$

$$\text{Mg (cmol}_c \text{ kg}^{-1}) = 0.165 * (a - b)$$

Where a = cmol_c kg⁻¹ for sample

$b = \text{cmol}_c \text{ kg}^{-1}$ for blank

The ECEC was estimated by summing the exchangeable basic cations and the exchangeable acidity (Mc Lean, 1982).

Determination of particle size distribution

Mechanical analysis was performed according to the method described by Gee and Bauder (1986). Pre-treatment of soil sample was carried out to destroy and remove calcium carbonates, organic matter, iron oxides and soluble salts from the samples. Fifty grams of air-dried soil sample were milled in a 200 ml beaker and 50 ml of hydrogen peroxide added. The beaker was covered with a watch glass and the mixture left to stand overnight. The following day, the beaker, covered with a watch glass, was placed on a hot plate until boiling for the destruction of organic matter (clear supernatant liquid and without bubbles). Further treatment with deionized water was done as necessary. Excess hydrogen peroxide was eliminated by boiling more vigorously for 1 hour. Five drops of ammonia were added and the suspension was boiled for another 30 minutes. The sample was transferred into a 1000 ml graduated sedimentation cylinder and 25 ml of pyrophosphate (or hexametaphosphate) solution were added by means of a pipette and made up to volume with distilled water.

To determine the clay and silt (C + S) fraction, the contents of each cylinder was mixed using a metallic rod by hand for 2 min. The eyedropper Robinson fraction C + S was taken at 10 cm depth after 3.32 min (corresponding to the temperature 32 °C of the suspension and 10 cm depth). The sampled fraction was put in a numbered box of known weighs. The open boxes containing the pipetted suspensions were placed in an oven at 105-110 °C for 24 hours. The boxes were removed thereafter from the oven and

immediately placed in a desiccator to cool. Then the boxes with the fraction were weighed on an analytical balance precision 0.1 mg.

The clay (C) fraction was determined using the same steps as for fraction C + S, but with a time corresponding to the clay fraction which was 2 hours 57 min. The suspension was put in boxes of known weights, dried at 105-110 °C for 24 hours. The box with dried clay fraction was weighed after cooling in a desiccator.

Calculations:

$$\text{Clay (\%)} = \frac{(TC_2 - TC_1) - B}{V * P} * 1000 * 100$$

Where, TC1 = weight of empty box (g)

TC2 = weight of box + dried clay (g)

B = correction factor due to the presence of sodium hexametaphosphate

V = volume of pipetted fraction (ml)

P = weight of soil sample (g)

$$\text{Clay + Silt (\%)} = \frac{T(C+S)_2 - T(C+S)_1 - B}{V * P} * 1000 * 100 \quad (1)$$

Where, T(C+S)₁ = weight of empty box

T (C+S)₂ = weight of box + dried clay and silt

$$\text{Silt (\%)} = [\text{Clay + Silt (\%)}] - \text{Clay (\%)} \quad (2)$$

3.2.8.2 Plant materials and amendments

Determination of pH and proton consumption capacity of organic materials

The pH and proton consumption capacity of organic materials were determined in the same solution as described by Wong *et al.* (1998). The pH of the organic materials was measured in suspensions of 1.5 g samples in 30 ml of 2 mM CaCl₂. The suspensions

were then slowly titrated from their natural pH values down to pH 4.0 with 0.05M H₂SO₄ to determine their protons consumption capacities in that pH range.

Determination of Organic matter

The organic matter content of plant material and amendment were measured by loss on Ignition (Ben Dor and Banin, 1989). The clean porcelain crucibles were used for the calcinations of samples. The crucibles were heated in a drying oven at 105 °C over night and cooled down in a dessicator. The empty crucibles were weighed before transferring samples (3 to 5 g) into them and weighed with the samples. The crucibles were heated again with sample in the drying oven at 105 °C over night. They were removed from the oven and left to cool in a dessicator. The crucibles and sample were weighed: DW_{105 °C}. The crucibles with samples were heated in a muffle furnace at 350 °C for 16 hours and weighed after cooling.

$$\text{Calculation: Loss Weight, (g kg}^{-1}\text{)} = \frac{(DW_{105^{\circ}\text{C}} - DW_{350^{\circ}\text{C}})}{DW_{105^{\circ}\text{C}}} \times 100$$

Where: DW_{105 °C}: weight at 105 and DW_{350° C} weight at 350 °C.

Wet digestion of plant and amendment

The samples of plant and amendment were wet digested following the procedure described by Nelson and Sommers (1980). A 0.5 g of the dried plant material was taken into 50 ml volumetric flask. A 2.5 ml of concentrated sulphuric acid and one ml of hydrogen peroxide were added to it .The material was swirled and placed on hot plate and heated at 270 °C for 10 minutes. The flasks were removed from the plate and let cool for 10 minutes after which 1 ml H₂O₂ was added and heated for 10 minutes at the same temperature. Heating, cooling and adding of 0.5 ml of H₂O₂ sequences were

repeated until the solution was colourless .The solution was removed from the hot plate. The volume was made with distilled water and all the nutrients were determined from this solution.

Determination of phosphorus and nitrogen

Total phosphorus and nitrogen were measured using the Technicon Auto Analyzer, manifold P Bray at sensitivity 1.00 to 50 mv and 1.5 to 100 mV for N and P, respectively (Technicon Industrial Systems, 1977).

$$N (\%) = 0.015 * (a - b)$$

$$P (\%) = \frac{[(a - b) * 0.005]}{g}$$

Where a = P for sample, b = P for blank and g = weigh of sample

Determination of basic cation and micro-nutrients

The Agilent 4100-MP-AES was used to analyze the basic cation (Ca, Mg, K and Na) and micronutrient (Al, Fe, Zn, Mn and Cu) contents of the plant materials and amendment (Page *et al*, 1982). Using standard series, the values of the samples and blanks were calculated as follows:

$$Ca, Mg, K, Na (\%) = 0.015 * (a - b)$$

$$K_2O (\%) = 0.018 * (a - b)$$

$$Fe, Mn, Cu, Zn (mg kg^{-1}) = 150 * (a - b)$$

Where a= value for sample and b= value for blank

3.2.9 Statistical analysis

Data on parameters/response variables (pH, exch. aci, OC, P, K, Ca, Mg and ECEC etc.) were subjected to analysis of variance (ANOVA) using the GenStat statistical package (GenStat, 2007). Means were separated using the Least Significant Difference (LSD) method at 5 % level of probability. Regression and correlation analyses were carried out to determine the nature and magnitude of relationships between and among amendments key factors and soil parameters.

3.3 Study 2: Assessment of the effect of lime and manure application on maize growth and yield, and soil properties

Farmers use organic matter for improving soil quality and crop yield. However, this source is not always available at sufficient amount. The recommended rate by research in Mali is about 5 Mg ha⁻¹ while the mean applied at national level is around 1000-1300 kg ha⁻¹. Even though lime is recognized as the most efficient to correct soil acidity; it is not applied as ISFM practice by poor farmers because of the high quantity required associated to the high price. This field experiment was carried out to evaluate the interaction effect of combined application of reduced amount (that fits with farmer practice) of lime and manure on some selected soil properties, maize growth and yield and the financial benefit.

3.3.1 Soil of the selected site

The study was conducted at the sub-station of Samanko on a plot of land in fallow since 2008 due to severe failure of experiments caused by the soil problem under study. The soil of the field experiment was an indurated tropical ferruginous Regosol according to

the soil classification FAO-UNESCO (1994) or a Halaguepts (Soil Survey Staff, 1999). Some physical and chemical properties of the soil of field experiment are presented in Table 3.4. The soil was sandy loam very acidic, and had low available P, OC, exchangeable Ca and Mg contents. However, the soil exchangeable K was adequate as compared to the range established by Manson *et al.* (1993).

Table 3.4: Some selected properties of the field experiment soil

Soil properties	Value
pH (1:1, H ₂ O)	4.80
pH (1:1, KCl)	4.10
OC (%)	0.35
T.N (%)	0.01
Av. P (mg kg ⁻¹)	12.30
Exch. K (cmol _c kg ⁻¹)	0.29
Exch. Ca (cmol _c kg ⁻¹)	2.00
Exch. Mg (cmol _c kg ⁻¹)	0.80
Exch. Na (cmol _c kg ⁻¹)	0.01
Exch. acidity (cmol _c kg ⁻¹)	0.89
Clay (%)	3
Silt (%)	35
Sand (%)	62

3.3.2. Manure

The manure used in this study was obtained from the main kraal of Bamako for animal trading. A sample of manure was air dried and passed through a sieve of 2 mm and analysed for some chemical and physical properties as described in section 3.2.8. Table

3.5 shows some selected chemical properties of the kraal manure used in this experiment. Using the guidelines established by Doumbia *et al.* (2008), the content of kraal manure in macro nutrients was lower for N, P, K Ca and Mg. Conversely, the total content P and micronutrients such as Cu and Mn and Al was higher. The C/N ratio was higher than the range of 19-25 required for quick release of mineral N.

Table 3.5: Some selected chemical properties of manure used in field experiment

Manure properties	Value
pH (1:10, H ₂ O)	7.00
OC (%)	37.00
Total N (%)	1.23
Total P (%)	0.01
C/N ratio	30.01
Total K (mg kg ⁻¹)	12.30
Total Ca (mg kg ⁻¹)	0.29
Total Mg (mg kg ⁻¹)	2.00
Total Mn (mg kg ⁻¹)	0.80
Total Cu (mg kg ⁻¹)	0.01
Total Al (mg kg ⁻¹)	412.00

3.3.3 Lime requirement

The lime requirement was calculated using the Al saturation method as described in section 3.2.3.

3.3.4 Experimental design

Experimental design used was the Randomized Complete Block Design in 3 replications. The experimental unit consisted of a plot of 6 rows (4.8 m) x 5 m long. The spacing between rows was 80 cm and maize was planted in hill 50 cm apart. The test was factorial with $4 \times 4 = 16$ treatments. The following treatments were compared:

- Lime rate: 0, 25 %, 50 % and 100 % of lime requirement (LR)
- Manure rate: 0, 1250, 2500, and 5000 kg ha⁻¹.

Each block represented a repetition and the blocks were separated by 1 m wide access and 2 m separated the block to the field border. The LR was 1300 kg ha⁻¹ and the 5000 kg ha⁻¹ represented the recommended rate of organic matter for cereal production in Mali. The range of manure applied effectively by farmers is 1000-1300 kg ha⁻¹.

3.3.5 Soil sampling

The soil was sampled (0-20 to 20-40 cm) depth and geo-referenced prior to planting. A composite soil sample was collected from each experimental unit prior to applications of lime, manure and fertilizer. The soil samples were air dried, sieved through 2 mm and 0.5 mm screens for analyses. Soil tests were performed on these samples for estimating the amount of lime required. At harvesting a composite soil sample was collected (0-20 to 20-40 cm) from each unit plot.

3.3.6 Amendment incorporation

Lime and manure was applied after ploughing 30 days prior sowing. Manure and limestone were weighed into the appropriate proportions, spread evenly on the designated plots, and incorporated into the soil during the ridging by animal traction.

3.3.7 Land preparation and sowing

The farm tractor was used for crossed harrowing to prepare the plots for maize sowing. It was then lined and pegged. The maize genotype “Sotuba” was planted at a spacing of 0.80 x 0.50 m at 3-4 seeds hill⁻¹ and plants were thinned to two per hill one week after germination.

3.3.8 Crop management

Mineral fertilizers were applied at 100 kg ha⁻¹ (DAP) (homestead fertilizer) and 150 kg ha⁻¹ (urea) (additional fertilizer). This represents the blanket fertilizer recommendation on maize in Mali. Nitrogen was obtained from Urea and Diammonium Phosphate (DAP), phosphorus from DAP; potassium was not applied because of the initial sufficiency of soil in potassium. DAP was incorporated into ridges before planting followed by split application (50-50-50 kg ha⁻¹) of N as Urea at 2, 4 and 6 WAP. Because of the high infestation of the study area, weeds were controlled by application of herbicide one day AP and manually by hoeing 7 WAP.

3.3.9 Harvesting and plant sample preparation

At maturity, crops of the two middle rows were harvested from net plots. Then, samples of grain and stover were collected, air dried and crushed with wooden roller and passed through 1 mm sieve.

3.3.10 Soil and plant parameters measured

In order to assess the effects of lime and manure on acid soil properties and maize growth and yield, the following biometric parameters were recorded at the end of each season:

- (i) Soil (pH, OC, exchangeable acidity, exchangeable basic cations, available P, total N);
- (ii) Plant: height (from the base to the tip of the ear), stem girth, biomass yield and grain yields. The mean from five plants measured was converted to kg ha⁻¹.

3.3.11 Soil and plant sample analysis

Air-dried soil and plant samples were passed through a 2 mm and 1mm sieve respectively and analysed for physical and chemical properties as described in section 3.2.8.

3.3.12 Economic analysis

The economic analysis of the application of reduced rate of lime and manure was based on the Net Farm Benefit (NFB) and the Value Cost Ratio (VCR). The VCR associated with each treatment were compared using the partial budgeting (CIMMYT, 1988) which included only costs and benefits that varied from treatment, i.e. costs of inputs and increased maize yield. The gross benefit was calculated from each treatment as the product of grain yields obtained and the unit price of grain. The NFB for each treatment was determined as the difference between gross benefit and the variable input cost. The variable costs of input were the price of labour for spreading lime and manure because the rate and the mode of application were different between treatments. On the other hand, other costs such as: amendment incorporation, land preparation planting, fertilizer addition, weeding, mounding did not differ among treatments and were therefore ignored. Maize grain prices and the operational cost came from Economic Program of IER (ECOFIL) and were the average prices prevailing at Samanko market during the

trial. The VCR was calculated using the formula:
$$\text{VCR} = \frac{(Y_{LM} - Y_C) P_G}{Q_{LM} * P_{LM}}$$
 where Y_{LM} is

the grain yield from plots with lime and/or manure application, Y_C is the grain yield from control plots, P_G is the unit price of maize grains yield and P_{LM} is unit price for lime and/or manure incorporation, and Q_{LM} , the quantity of lime and/or manure applied.

3.3.13 Statistical analysis

Data on parameters/response variables (pH, exch acidity, OC, P, K, Ca, Mg and ECEC etc.) were subjected to analysis of variance (ANOVA) using the GenStat statistical package (GenStat, 2007). Means were separated using the Least Significant Difference (LSD) method at 5 % level of probability. Correlation analysis was used to determine the degree of association between the grain yield, crop growth parameters and biomass yields to the soil parameters following amendments addition.

3.4 Study 3: Assessment of the effect of the combined application of lime and fertilizer on crop and acid soil properties

Liming is one of the most efficient and prevailing practice to correct soil acidity and improve crop yield. However, it is not a common practice in Mali due mainly to the high lime requirement. However, precision application of lime at reduced rate would reduce the lime requirement and increase lime use efficiency. The application of fertilizer at root zone would reduce the losses of nutrients and increase their use efficiencies. This field experiment was conducted to determine in precision application: (i) the appropriate rate of lime and (ii) the effect of fertilizer and lime on maize yield and soil properties and the return benefit.

3.4.1 Soil of selected site

The study was conducted at the sub-station of Samanko and the soil was described in section 3.3.1.

3.4.2 Lime requirement

The lime requirement was calculated using the AI saturation method as described in section 3.2.3.

3.4.3 Experimental design

The experiment was a 4×2×2 factorial split-split-plot design with 3 replications. The experimental unit consisted of a plot of 6 rows (4.8 m) x 5 m long. The following treatments were compared:

- Lime application method (main factor): Broadcasting, Banding
- Fertilizer application method (sub-factor): Banding, Spot
- Lime rate (sub-sub-factor): 0, 25 %, 50 % and 100 % of the lime requirement

The lime requirement was 1300 kg ha⁻¹. Blocks were separated by 1 m wide alley and 2 m from edge of the field.

3.4.4 Soil sampling

Soil samples were randomly collected before planting as described in section 3.2.3. But after harvest samples were randomly collected on the ridge and between the ridges.

3.4.5 Amendment incorporation

The dolomite limestone was applied into soil after ploughing 30 days prior to sowing. The required amount of limestone was spread evenly and incorporated into the soil during ridging by animal traction.

3.4.6 Land preparation and sowing

The seed bed preparation consisted of ploughing and harrowing. The maize genotype “Sotuba” was planted at a spacing of 0.80 x 0.50 m at 3-4seeds hill⁻¹ and plants were thinned to two per hill one week after germination.

3.3.7 Crop management

The mineral fertilizer was applied at blanket fertilizer recommendation of 100 kg ha⁻¹ of DAP (homestead fertilizer) and 150 kg ha⁻¹ of urea (additional fertilizer). Potassium was not applied because of the initial sufficiency of soil in potassium (Table 3.4). The DAP was incorporated into ridge during planting, followed by three split applications of 50 kg ha⁻¹ each of N as urea at 2, 4 and 6 WAP. The DAP was applied in the same hill with seeds for spot application and along the ridge for banding. From the recommended rate of 100 kg ha⁻¹ the amount of homestead fertilizer per hill was 4g. The urea was applied near the shoots for spot application and along the ridge for banding. Weeds were controlled by application of herbicide (Roundup) one day after planting (AP) and manually by hoeing 7 WAP.

3.4.8 Harvesting and plant sample preparation

At maturity, crops of the two middle rows per plot were harvested. Then, samples of grain and stover were collected, air dried and crushed with a wooden roller and passed through 1 mm sieve.

3.4.9 Soil and plant parameters measured

In order to assess the effects of lime (method and rate of application) and fertilizer (method of application) on acid soil properties and maize growth and yield, the following parameters were recorded at the end of each season:

(i) Soil (pH, OC, exchangeable acidity, exchangeable basic cations, available P, total N); (ii) Plant: height (from the base to the tip of the ear), stem girth, biomass yield and grain yields. The mean from five plants measured was converted to kg ha^{-1} .

3.4.10 Laboratory analysis of soil and plant samples

Air-dried soil and plant samples were passed through a 2 and 1 mm sieve respectively and analysed for physical and chemical properties as described in section 3.2.8.

3.4.11 Economic analysis

The methodology described in section 3.3.12 was used to estimate the NFB of lime (method and rate of application) and fertilizer method of application.

3.4.12 Statistical analysis

The data were subjected to analysis of variance (ANOVA) using the GenStat statistical package (GenStat, 2007). Means were separated using the Least Significant Difference (LSD) method at 5 % level of probability. Correlation analysis was used to determine the degree of association between measured parameters.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Evaluation of the liming potential of selected locally available amendments

4.1.1 Results

4.1.1.1 Chemical properties of locally available amendments

The nutrients content of the amendments used is shown in Table 4.1. The amendments and their acronyms are: Tilemsi phosphate rock (TPR), Sabunjuma compost (SC), poultry manure (PM), ash from maize straw (AM), sheep manure (SM), goat manure (GM), cattle manure (CM) and lime (TL). The total phosphorus content of these amendments ranged from 0.38 to 28.7 % TPR provided the highest total phosphorus content followed by SC, PM, AM, SM, GM, CM and TL. Also, TL and TPR had the highest amount of total basic cations followed by AM, GM, SM, SC, CM and MS. The Ca content ranged from 0.5 to 36.7 % and TL had the highest Ca. The Mg varied from 0.03 to 24.5 % with TPR recording the highest value. The potassium content varied from 0.17 to 8.3 % with AM producing the highest potassium followed by GM, SM, CM, MS, SC, PM, TPR and TL (0.17 %). The C/N ratio ranged from 1.7 to 166, MS and CM had the highest C/N ratios while TPR and TL had the lowest. The SC had the highest content of nitrogen.

The micronutrient content of amendments was generally higher than the optimal level established for organic materials. The Cu content ranged from 17.2 mg kg⁻¹ (PM) to 117 mg kg⁻¹ (TPR) while Mn varied from 124 mg kg⁻¹(MS) to 555 mg kg⁻¹ (AS). The micronutrients content was generally higher in animal manure.

The pH of the amendments varied from 5.7 to 10.7. The AM had the highest pH followed by TL, CM, SC, GM, SM, PM, TPR and MS. The initial pH of all amendments was higher than that of the soil used ($\text{pH}_{\text{water}}=4.9$). The organic carbon content of amendments varied from 1.44 to 49.4 %. Maize straw had the highest OC content followed by CM, SM, GM, PM, SC, AM, TPR and TL. The organic carbon content of MS and animal manures was greatly higher than that of TL and TPR. The total nitrogen content of amendment ranged from 0.05 to 14 % .The SC had the highest content followed GM, SM, CM, PM, MS, AM, TPR and TL. The calcium carbonate equivalent (CCE) varied from 0.12 to 50.89 %. TL had the highest content of Calcium Carbonate Equivalent (CCE) followed by TPR, AM, SC, PM, CM, GM, SM and MS. The sum of basic cations content ranged from 2.26 to 61 %. TL had the highest sum of base cations content while maize straw had the lowest. The proton consumption capacity (PCC) varied from 9.53 to 862 $\text{cmol}_c \text{kg}^{-1}$. However, TL had the highest PCC value followed by AM, GM, PM, CM, SC, SM, TPR and MS.

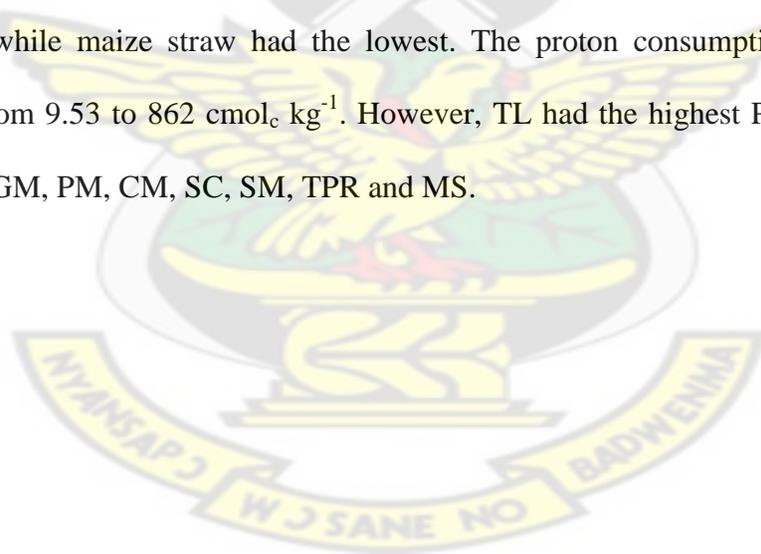


Table 4.1: Some selected chemical properties of amendments

Amend	pH (1:1)	C	T. N	T. P	C/N	Ca	Mg	K	Sum	CCE	Cu	Mn	PCC
	CaCl ₂	-----%-----				-----%-----				----mg kg ⁻¹ ----		cmol Kg ⁻¹	
TPR	6.86	1.49	0.10	28.74	15.43	20.44	0.03	0.31	21.20	9.99	30.50	555.50	9.53
TL	8.00	1.43	0.05	0.38	30.57	36.71	11.22	0.17	48.34	50.86	17.15	354.02	862.20
SM	8.23	37.68	2.00	2.66	18.83	0.53	0.21	2.45	4.02	2.54	27.50	398.10	41.46
CM	8.33	44.79	1.94	1.60	23.10	0.49	0.39	2.42	3.65	2.58	23	567.60	49.52
GM	7.86	31.51	3.40	2.15	9.27	1.45	0.33	2.50	5.24	2.58	20.95	397.60	55.27
PM	6.83	24.17	1.60	3.38	15.13	1.65	0.15	0.85	3.21	3.63	19.23	166.10	49.74
MS	5.73	49.27	0.31	0.68	166.1	0.39	0.09	1.48	2.26	0.12	7.25	257.60	9.23
SC	6.86	23.83	14.00	4.81	1.70	0.78	0.10	1.13	2.70	5.50	19.30	521.90	49.09
AM	10.00	3.96	0.29	3.37	13.53	0.47	0.42	8.31	9.73	6.42	117.5	491.20	126.21
F.pr	<001	<001	<001	<001	<001	<001	<001	<001	<001	<001	<001	0.06	<001
Lsd (0.05)	0.12	1.95	0.57	0.45	3.31	0.53	0.14	0.24	0.8	1.43	9.22	268.2	6.06
CV (%)	0.9	4.7	12.7	4.9	5.9	4.5	24.8	6.5	3.7	8.9	17	37.6	2.5

TPR: Tilemsi phosphate rock, TL: Toukoto lime, SM: Sheep manure, CM: Cattle manure, GM: Goat manure, PM: poultry manure, MS: maize straw, SC: Sabunjuma compost, AM: Ash from maize straw.

4.1.1.2 Effect of amendments on some selected soil properties

4.1.1.2.1 Soil pH as affected by amendments application

The effect of amendment and rate of application on soil pH is shown in Table 4.2. The soil pH increased significantly ($P < 0.001$) by application of all amendments and the effects were greater at higher rate of application. The general trend of soil pH increase following the application of amendments was: AM > TL > CM > GM > PM > SC > MS > SM > TPR. Regardless of source of amendment the soil pH ranged from 4.65 (control) to 6.3 (40 Mg ha⁻¹). Ash and lime had the highest effect on soil pH while maize straw and phosphate rock the lowest. Increasing the rate of application led to increased soil pH with the highest recorded at (40 or 10.4 Mg ha⁻¹). As illustrated in Figure 4.1, there was a positive interaction between source of amendment and application rate. The higher soil pH was observed with the ash amended soil followed by cattle manure at 40 Mg ha⁻¹. SM at 5 Mg ha⁻¹ provided the lowest soil pH. There was a decrease in the pH of unamended soil relative to the initial value of the soil (4.9) for AM, GM, PM and SM.

Table 4.2: Effect of amendment on selected soil properties

Soil amendments	pH (1:1,H ₂ O)	O C (%)	Exch. Ca cmol _c kg ⁻¹	Exch.Mg cmol _c kg ⁻¹	Exch. K cmol _c kg ⁻¹	Exch.Ac cmol _c kg ⁻¹
AM	6.19	0.19	2.41	0.89	1.64	0.24
C.M	5.73	0.25	2.25	1.13	0.83	0.29
SC	5.16	0.18	2.28	0.83	0.86	0.30
GM	5.49	0.22	2.58	0.86	0.80	0.30
TL	5.83	0.18	2.99	1.05	0.18	0.22
MS	5.10	0.25	2.01	0.67	0.41	0.33
PM	5.17	0.26	2.20	0.70	0.29	0.29
SM	5.02	0.18	1.80	0.77	0.78	0.30
TPR	4.98	0.21	2.28	0.63	0.18	0.27
F.pr	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lsd (0.05)	0.10	0.04	0.36	0.16	0.09	0.001
Application rate (Mg ha ⁻¹)						
0	4.65	0.16	1.88	0.58	0.15	0.83
5	4.97	0.18	1.94	0.72	0.44	0.22
10	5.29	0.21	2.26	0.79	0.55	0.15
20	5.81	0.23	2.62	0.94	0.80	0.12
40	6.31	0.27	2.96	1.16	1.22	0.09
F.pr	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lsd (0.05)	0.08	0.03	0.27	0.11	0.07	0.009
Interaction						
F.pr (Amend * application Rate)	<0.001	0.44	0.20	0.19	<0.001	<0.001
Lsd (0.05)	0.24	0.09	0.80	0.35	0.21	0.02
CV (%)	2.7	27.1	21.7	26.4	20.8	6.1

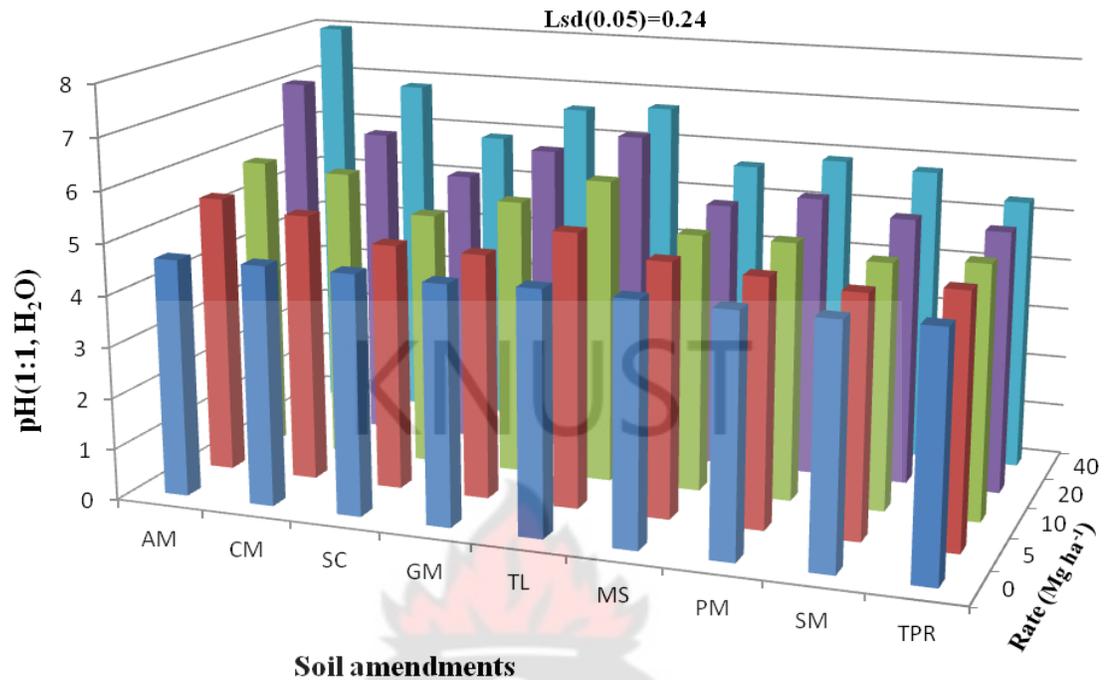


Figure 4.1: Interactive effect of amendment and application rate on soil pH.

4.1.1.2.2 Soil organic carbon as affected by amendments application

Table 4.2 shows the effect of amendment and application rate on soil carbon changes. The SOC ranged from 0.16 to 0.36 % for all amendments. The application of amendment led to increase in SOC content ($P < 0.05$). The improvement in SOC content following the application of amendment was: 14, 43, 4, 26, 9, 41, 36, 6 and 24 % respectively for AM, CM, SC, GM, TL, MS, PM, SM and TPR. Furthermore, CM and PM had the highest effect on SOC while SC and SM recorded the lowest. Regardless of the source of amendment the increasing application rate increased SOC and the improvements were: 9, 23, 33 and 41 % respectively by the application of 5, 10, 20 and 40 Mg ha^{-1} . For the lower rate of application (5 or 1.3 Mg ha^{-1}) the SOC content was less than that of the initial level (0.24 %) for all amendments except PM. The interaction between amendment and rate of application was not significant ($P > 0.05$).

4.1.1.2.3 Soil exchangeable calcium as affected by amendments application

The effect of soil amendment and rate of application on soil exchangeable calcium is shown in Table 4.2. The application of all amendments led to significant ($P < 0.05$) increase of soil exchangeable Ca compared to control. The addition of AM, CM, SC, GM, TL, MS, PM, SM and TPR increased soil exchangeable Ca by 36, 19, 22, 35, 46, 8, 21, 1 and 28 % respectively. TL had the highest effect on soil exchangeable Ca changes while SM the lowest. The increasing application rate of amendment significantly increased the soil Ca. The improvement of soil exchangeable Ca following the application of 0, 5, 10, 20 and 40 Mg ha⁻¹ was 9, 24, 37 and 45 % respectively. There was no significant ($P > 0.05$) interaction between source of amendment and rate of application on soil exchangeable Ca content.

4.1.1.2.4 Soil exchangeable magnesium as affected by amendments application

The application of soil amendment increased soil exchangeable Mg significantly ($P < 0.001$) as compared to the control (Table 4.2). The addition of amendments led to significant increase in soil exchangeable Mg. The increase of soil exchangeable Mg following the addition amendment was: 52, 62, 22, 33, 55, 8, 17, 26, 6 % for AM, CM, SC, GM, TL, MS, PM, SM and TPR respectively. Furthermore CM and TL had the highest effect on soil exchangeable Mg while TPR had the lowest. Increasing the application rates of soil amendment led to increases in soil exchangeable Mg. Regardless of the source of amendment, exchangeable Mg was increased by 23, 27, 46, and 62 % by the application of 0, 5, 10, 20 and 40 Mg ha⁻¹ respectively. The interaction between source of amendment and rate of application was not significant ($P > 0.05$).

4.1.1.2.5 Soil exchangeable potassium as affected by amendments application

The effect of soil amendment and rate of application on soil exchangeable K is shown in Table 4.2. Exchangeable K varied from 0.15 to 3.62 $\text{cmol}_c \text{kg}^{-1}$. The application of amendments significantly increased ($P < 0.05$) exchangeable K. The soil exchangeable K was increased by 984, 41, 50, 115, 3, 149, 34, 218 and 5 % with the application of AM, CM, SC, GM, TL, MS, PM, SM and TPR respectively. AM and SM had the greatest effect on soil exchangeable K changes while TL had the least effect. Moreover, increasing of application rates increased the amount of exchangeable K in the soil. The improvement of soil exchangeable K was 195, 88, 119 and 134 % respectively by the addition of 0, 5, 10, 20 and 40 Mg ha^{-1} . The ash and cattle manure had the most impact on soil exchangeable potassium while Lime and phosphate rock had the lowest effect. The interaction between source of amendment and rate of application was also significant (Figure 4.2). The ash amended soil had the highest exchangeable potassium ($3.62 \text{ cmol}_c \text{ kg}^{-1}$) at 40 Mg ha^{-1} while the lowest was obtained with TPR at 40 Mg ha^{-1} ($0.15 \text{ cmol}_c \text{ kg}^{-1}$) and TL at 10.4 Mg ha^{-1} ($0.15 \text{ cmol}_c \text{ kg}^{-1}$).

Lsd(0.05)=0.2

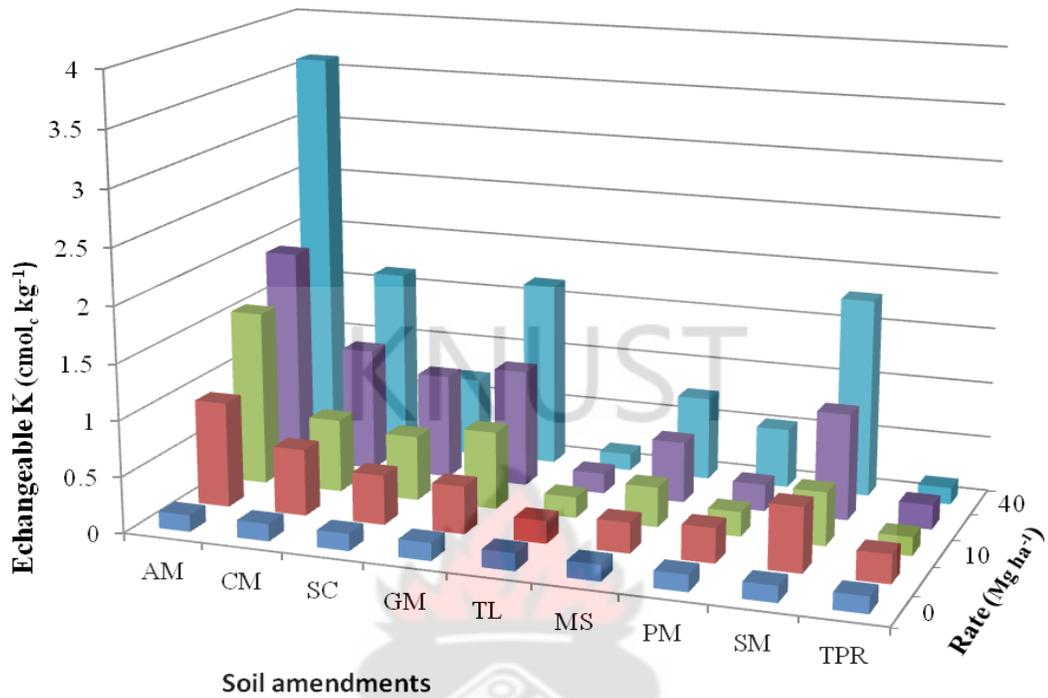


Figure 4.2: Interactive effect of amendment and application rate on soil exchangeable K

4.1.1.2.6 Soil exchangeable acidity as affected by amendments application

Table 4.2 shows the effect of amendment and rate of application on soil exchangeable acidity concentration. The soil exchangeable acidity ranged from 0.05 to 0.84 cmol_c kg⁻¹. The addition of all amendments significantly ($P < 0.05$) decreased the soil exchangeable acidity and the effect was greater at higher rate of application. The improvement of soil exchangeable acidity following the addition of amendment was 71, 65, 64, 73, 60, 54, 64 and 67 % respectively for AM, CM, SC, GM, TL, MS, PM, SM and TPR. Lime and ash from maize straw were the most effective at reducing soil exchangeable acidity while maize straw, compost and sheep manure were the least effective. Increasing rate of application rate decreased significantly ($P < 0.05$) soil exchangeable acidity by 73, 81, 86, and 89 % at 0, 5, 10, 20 and 40 Mg ha⁻¹ respectively.

The interaction between source of amendment and rate of application was significant on reducing soil exchangeable acidity as illustrated in Figure 4.3. The highest soil exchangeable acidity was observed with MS at 5 Mg ha⁻¹(0.33 cmol_c kg⁻¹) while the lowest was recorded under lime at 10.4 Mg ha⁻¹ (0.05 cmol_c kg⁻¹) followed by AM at 40 Mg ha⁻¹(0.07 cmol_c kg⁻¹).

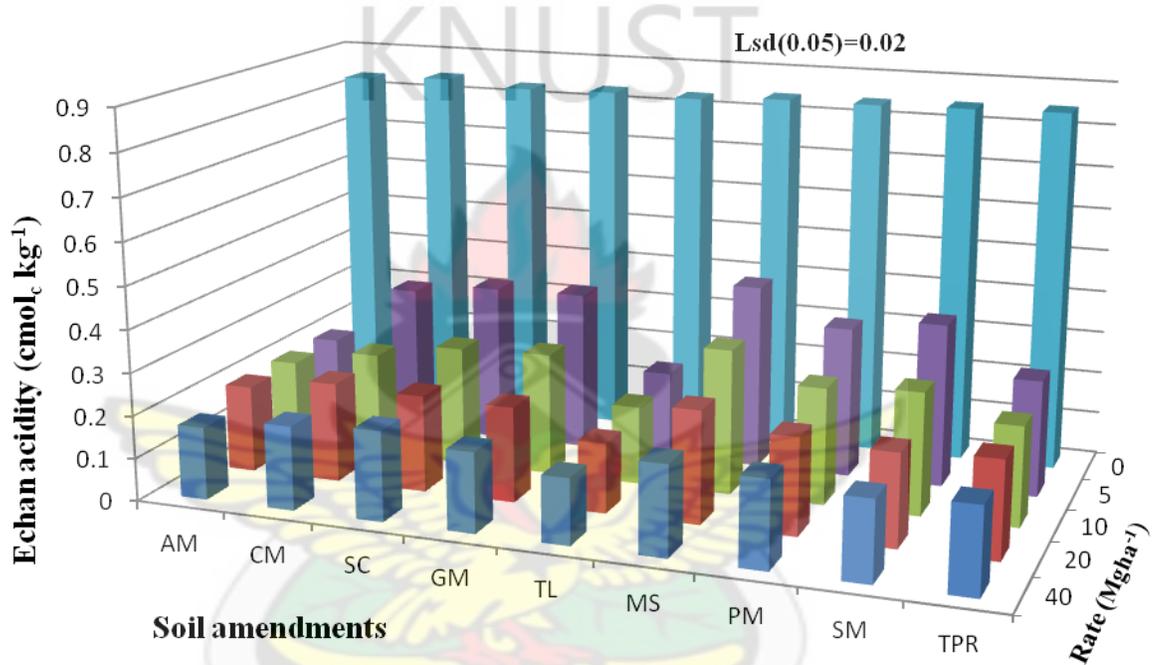


Figure 4.3: Interactive effect of amendment and application rate on soil exch. Acidity

4.1.1.3 Relationship between some soil factors and soil pH after incubation

Correlation analysis was used between soil parameters and pH to indicate the magnitude and direction (\pm) of the correlation whilst a multiple regression was used to provide expression for soil pH as a function of parameters which were significant. The soil pH was positively and strongly correlated with soil exchangeable calcium, magnesium, and potassium (Table 4.3). The same trend was observed with soil total basic cation content. The soil pH was negatively and highly correlated with soil exchangeable acidity. On the other hand, positive correlation between soil pH, organic carbon, C/N ratio was not significant. The correlation between pH, total N and available P was positive but not significant. Soil pH as function of various parameters is indicated by Equation 4.1. The SOC, available P, total N, C/N ratios did not significantly affect soil pH. Conversely, the exchangeable Ca, Mg and K increased soil pH (Table 4.4 and Equation 4.1).

Table 4.3: Relationship between soil factors and soil pH after amendment application

Soil parameters	Soil pH (1:1,H ₂ O)
Exch. Ca	0.51 ^{**}
Exch. Mg	0.53 ^{**}
Exch. K	0.71 ^{**}
Exch. acidity	-0.63 ^{**}
O C	0.20 ^{NS}
T. N	-0.002 ^{NS}
Av. P	-0.16 ^{NS}
C/N ratio	0.16 ^{NS}

NS: not significant, *Significant at $P < 0.05$; ** significant at $P < 0.01$

Table 4.4: Multiple regression of soil pH with soils factors

Soil parameters	Coefficients	Standard Error	Significance
Constant	3.63	0.17	<0.001
SOC	1.55	1.26	0.21
Av. P	3.39.10 ⁻⁵	0.0002	0.87
T. N	3.75	11.09	0.73
C/N ratios	0.001	0.012	0.88
Exch. Ca	0.50	0.05	<0.001
Exch. Mg	0.80	0.13	<0.001
Exch. K	1.01	0.06	<0.001

Soil pH= 3.63(±0.17) +1.01(±0.06) K+0.05(±0.05) Ca+0.8(±0.13) Mg Equation 4.1
(R²=0.82, P<0.001)

4.1.1.4 Relationship between selected factors of amendment and soil pH

Table 4.5: Correlation between selected factors of amendment and soil pH

Factors of soil amendments	Soil pH (1:1, H ₂ O)
Initial pH	0.80 ^{***}
Total CaCO ₃ content	0.43 [*]
Total basic cations content	0.41 [*]
Proton consumption Capacity	0.52 ^{**}
Total Carbon content	-0.28 ^{NS}
Total Nitrogen content	-0.38 [*]

NS: not significant, * significant at P<0.05, ** significant at P<0.01 and ***significant at P<0.001

Table 4.6: Multiple regression of soil pH with amendments factors

Amendments factors	Coefficients	Standard Error	Significance
Constant	6.68	1.90	0.002
pH (CaCl ₂)	0.11	0.12	0.36
OC	0.03	0.02	0.11
T. N	-2.30	1.12	0.05
C/N	-0.04	0.03	0.16
Total Basic cation	-0.10	0.06	0.11
CaCO ₃	0.007	0.003	0.02
PCC	-0.03	0.03	0.32

Soil pH= 6.68 (± 1.90) +0.007(± 0.003) CaCO₃-2.3(± 1.12) Total N. Equation 4.2
(R²=0.85, P<0.001)

Table 4.5 shows the relationship between soil pH and some selected amendments factors susceptible to affect soil pH. The soil pH was positively and very strongly correlated with the initial pH of amendments. It was also positively correlated with PCC, total base cation content and total CaCO₃ content. On the other hand, the correlation between total carbon and nitrogen content of amendment was not significant. A multiple regression function describing the relationship between amendment factors and soil pH is indicated by Equation 4.2. The soil pH was not significantly correlated with pH, OC, total N, C/N ratios, total basic cation and PCC of amendments. However, total CaCO₃ increased soil pH while total N decreased soil pH as illustrated in Table 4.6 and Equation 4.2. For animal manure, only the PCC increased the soil (Equation 4.3 in Appendix 2). Without TPR and TL, the soil pH was increased by the initial pH, OC and total basic cations of amendments as indicated in Equation 4.4 (Appendix 2).

4.1.1.5 Prediction of liming effect of locally available resources

The application of the amendments resulted in an increase in soil pH. To estimate their liming potential, incremental amounts of 0.5 Mg ha⁻¹ of pure calcium hydroxyl (Ca(OH)₂) were added to the same soil resulting in corresponding increase in the soil pH from 4.8 to 9.3 as illustrated in Figure 4.4. The curve obtained was used as standard for the estimation of the lime equivalence (pure hydroxyl calcium) of the organic amendments used in increasing soil pH. The lime equivalence values given corresponded to 20 mg g⁻¹ (or 20 Mg ha⁻¹) of amendments used (Table 4.5). The lime equivalence ranged from 5.88 mg g⁻¹ (Toukoto lime) to trace (Tilemsi phosphate rock). The lime equivalence followed the general order of: Toukoto limestone > ash from maize straw > cattle manure > goat manure > poultry manure > compost > sheep manure > maize straw > Tilemsi phosphate rock. The general trend of lime equivalence was the same as the trend of soil pH increase.

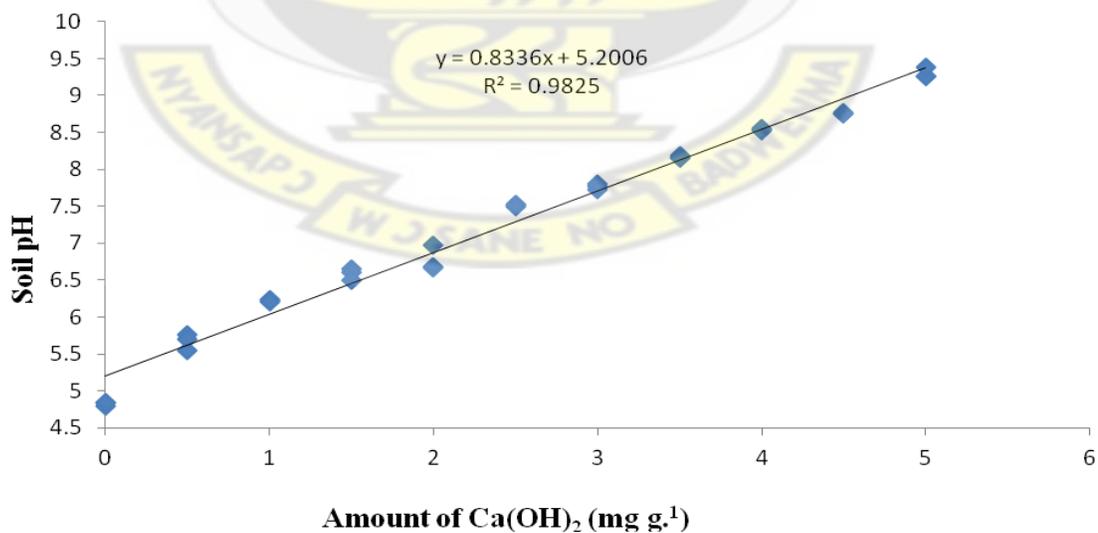


Figure 4.4 : Relationship between Ca(OH)₂ and soil pH after 4 weeks of incubation

In terms of lime equivalence, the addition of 20 mg g⁻¹ (or 20 Mg ha⁻¹) of soil amendment were equivalent to 2.25, 5.88, 0.02, 0.33, 1.15, 1.05, 0.05 mg g⁻¹ (or Mg ha⁻¹) of pure Ca(OH)₂ in increasing soil pH respectively for AM, TL, MS, PM, CM, GM and SM at least in the relatively short period of this experiment (Table 4.7). On the other hand, the lime equivalence in increasing soil pH was negative for the TPR at 20 Mg ha⁻¹.

Table 4.7: Estimation of lime equivalence of organic materials

Soil amendment (20 mg g ⁻¹)	Equivalent Ca(OH) ₂ mg g ⁻¹
Ash from maize residue	2.25
Tilemsi phosphate rock	-
Toukoto lime	5.88
Maize residue	0.02
Sabunjuma Compost	0.27
Poultry manure	0.33
Cattle manure	1.15
Goat manure	1.05
Sheep manure	0.05

4.1.2 Discussion

4.1.2.1 Chemical properties of amendments

Apart from maize straw, the pHs of amendments were neutral to alkaline. This initial pH value is attributable to the high content in basic cation for lime and TPR and to the proton consumption capacity for manure and compost. As expected, the higher CCE value of lime is due to the high content in Ca and Mg. The C/N ratios of animal manure

and compost were less than 25 indicating their advanced decomposition status (Rynk *et al.*, 1992, Wortmann, and Shapiro, 2012). The quality of manure produced by livestock varies according to their diet (Romney *et al.*, 1994). The addition of mineral fertilizer during composting explained the concentration in N of the compost. The high content in Ca for poultry and goat manure can be explained by the diet of animal. For poultry manure because of the higher requirement for eggshell formation, calcium has been added to their feed (Sims and Wolf, 1994). The high concentration in K for ash is provided by maize leaves which are rich in potassium (Cerda *et al.*, 1995; Lin and Yeh, 2008). Plant leaves in animal diet are partly responsible for the concentration of K observed in SM, CM, and GM. The release of organic compound which can consume protons explained the high CCE value measured in animal and compost (Haynes and Makolobate, 2001). The short period of incubation which did not allow the release of organic compounds may explain the low PCC observed with maize straw.

4.1.2.2 Effect of amendments on soil pH

Addition of all amendments increased significantly soil pH and the effect was proportional to the rate of application. The increase in soil pH relative to the control following the application of amendment observed at higher rate (3.1 units for AS and 2.1 units for CM and 1.8 for TL) may be attributable to the low buffering capacity of the soil used due to its sandy nature and the low content of organic matter. Similar results were observed by Noble *et al.* (1996); Naramabuye (2004). Also the increases of 0.2-0.6 unit and 0.8-1.5 units were observed after application of respectively 20 Mg ha⁻¹ and 40-50 Mg ha⁻¹ of organic residues (Berek *et al.*, 1995; Iyamuremye *et al.*, 1996; Noble *et al.*, 1996). On the other hand, soil pH decreased for unamended soil (SM, GM, PM, and

AM) relative to the initial soil pH value (4.9). This observed decrease in pH may result from the acidity generated by the oxidation of N and S to NO_3^- and SO_4^{2-} (Summer *et al.*, 1991; Qin and Chen, 2005). The 5 Mg ha^{-1} represents the recommended rate of organic matter for cereal production in Mali. However, the mechanisms involved in soil pH rise after four weeks of incubation are likely to have differed depending on the nature of amendments used.

The higher increases in pH observed with ash-amended soil at all rates of application could be explained by the higher amount of basic cations particularly potassium and the relative high solubility of these cations. Shen and Shen (2001) and Wong *et al.* (1998) reported that the increase in soil pH was directly proportional to the concentration of basic cations in the added organic material. The initial pH and proton consumption capacity also contributed to raise the pH of ash-amended-soil. All amendments were effective in increasing soil pH as compared to limestone and the ash from maize residue was the most effective in increasing soil pH and the TPR the least.

The four types of animal manures (cattle, goat, poultry, and sheep), compost and maize residue increased the soil pH after incubation (Table 4.2). Similar observations have been reported by other workers (Wong *et al.*, 1998; Mokolobate and Haynes, 2001; Qin and Chen, 2005; Naramabuye and Haynes, 2007; Tang *et al.*, 2007; Opala, 2011). This is mainly attributable to the proton exchange between the soil and amendment (Wong and Swift, 2003) as illustrated in Equation 4.4. As indicated by Stevenson and Vance (1989); Wong and Swift (2003), the microbial decomposition of organic materials produces a large number of humic substances containing functional groups such as carboxylic, phenolic and alcoholic, which can consume protons and then raise soil pH.

The release of OH⁻ from humic molecules during complexation of Al species may also contribute to increase manure and compost amended soil pH (Hue *et al.*, 1986). The basic cations and the total CaCO₃ content may contribute to increase soil pH. The release of basic cation after decomposition especially Ca and Mg increased the base saturation and resulted in elevated soil pH (Wong *et al.*, 1998; Shen and Shen, 2001). Furthermore, the dissociation of CaCO₃ in soil solution releases CO₃²⁻ which combines with protons forming H₂CO₃ to increase the pH (Sims and Wolf, 1994; Mokolobate and Hayes, 2002; Naramabuye, 2004). The relative limited effect of maize residue on soil pH may be explained by the low level of main properties. Furthermore, the time of incubation (four weeks) was not sufficient for complete mineralisation of residue.

Despite the high CCE and total basic cations, TPR was the least effective in increasing soil pH (Table 4.2). The low reactivity of TPR may largely be responsible of the low effect on soil pH changes, as the four (4) weeks incubation period was not sufficient for the material to dissolve. On the other hand, increasing application rate led to increase soil pH from 4.8 (10 Mg ha⁻¹) to 5.1(40 Mg ha⁻¹). However, the increase in soil pH at all rates of application was below 5.5 (critical level of aluminium toxicity). Similar results were reported by Hellums *et al.* (1989) who found an increase of soil pH on a strongly acid sandy loam soil after the application of TPR. Kanabo and Gilkes (1987) observed an increase in soil pH and attributed it to the consumption of protons during acidulation of PR and subsequent neutralization of bases released. Doumbia *et al.* (1993) observed an increase in soil pH in greenhouse experiments and contrary a decreased soil pH in fields following the addition of TPR on a sandy acidic soil in Mali.

The nitrogen mineralization may lead to a decrease in soil pH as illustrated in Table 4.6 and Equation 4.2. The nitrification of NH_4^+ to NO_3^- releases protons: $\text{NH}_4^+ \rightarrow 2\text{O}_2 + \text{NO}_3^- + \text{H}_2\text{O} + 2\text{H}^+$ (protons decrease pH). The overall transformation of organic N to NO_3^- is, therefore, acidifying with one H^+ being produced per mole of N transformed to NO_3^- (Haynes and Swift, 1993). However, considering the high C/N ratios of some amendments (166 for maize straw or 35 for cattle manure) (Haynes and Mokolobate, 2001), N mineralisation probably had little effect on soil pH as illustrated in Table 4.4 and Equation 4.1 due the duration of incubation which did not favour the higher nitrification.

4.1.2.3 Effect of amendments on exchangeable acidity concentration

Application of all amendments to the acid soil led to decreased soil exchangeable acidity (Table 4.2); but the magnitude of the reduction at the same rate of application varied among materials. This general decrease was presumably related mainly to the increase in soil pH as attested by the strong negative correlation (Table 4.3) between soil pH and soil exchangeable acidity ($r=-63$). The increase in soil pH involves the precipitation of soluble aluminium as insoluble hydroxyl-Al species as indicated by Noble *et al.* (1996). The ash was the most effective in reducing exchangeable acidity and this is attributable to its high content of cations Ca, Mg, K and the anions P, S and Si (Cocker *et al.*, 1998). The cations increase the potential cation exchange and base saturation, therefore counteract the Al in soil indirectly while anions chelate active Al and convert it in to a nontoxic form (Cocker *et al.*, 1998; Qin and Chen, 2005). In contrast to its low ability to increase soil pH, TPR significantly reduced soil exchangeable acidity. The TPR was the most effective in reducing soil exchangeable acidity after Ash and lime. The

precipitation of soluble Al to Al-P compounds after adding of P is responsible for reducing soil aluminium concentration (Hellums *et al.*, 1989; Shahandeh *et al.*, 2004). Sanchez and Uehara (1980) reported that 1 cmol_c kg⁻¹ of exchangeable Al can fix up to 102 mg kg⁻¹ of P in soil. Moreover, the high available P value of TPR amended soil confirms this affirmation (from 451 to 821 mg kg⁻¹). Thus, exchangeable acidity was negatively and strongly correlated with soil pH (Table 4.3).

Several other factors such as complexation of Al in the solid phase or in soil solution by organic matter are involved in soil exchangeable acidity decrease. These factors are of lesser importance in this study because the exchangeable acidity was not significantly correlated with soil organic carbon content (Table 4.5). These observed results are consistent with those reported by other workers (Naramabuye, 2004, Ano and Ubochi, 2007). In contrast, other workers reported significant negative correlation between soil organic carbon content and soil aluminium concentration (Qin and Chen, 1998; Xiong and Chen, 1990). They concluded that the complexation of aluminium with organic compounds was the most contributing factor to Al detoxification with organic amendment application in acid soil.

4.1.2.4 Effect of amendments on exchangeable basic cations and ECEC

The different amendments significantly influenced the concentrations of exchangeable bases and hence the effective cation exchange capacity (ECEC) of the incubated soil. The effect of amendments on soil basic cation content was influenced by the type of material and the rate of application. The effect of animal manures on soil Ca, Mg and K is influenced mainly by the feed rations fed the animals. The release of basic cations after mineralisation contributed to raise soil base content. The high basic cation

concentration of ash amended soil was mainly due to high solubility of this material. Indeed, the calcinations burnt organic element and then released cations. TRP and maize straw were least effective in increasing soil exchangeable cation due to their relative low solubility during the incubation period. Increased ECEC as a result of soil amendments was mostly due to increases in basic cations particularly Ca, Mg and K. Other researchers such as Muhrizal *et al.* (2003); Naramabuye and Hayes, (2007); Ano and Ubochi (2007) have reported significant increases in exchangeable Ca, Mg and ECEC following the application of organic materials.

4.1.2.5 Effect of amendments on soil organic carbon content

All amendments increased soil organic carbon content and the effect was more pronounced at the higher rates of application. This could be attributable to the initial OC content of the amendment. In addition, the undigested portion of carbon may contribute to increase SOC content particularly for animal manure and compost (Vanlaume, 2002). At 5 Mg ha⁻¹ the decrease in soil organic content for almost all the amendments compared to the initial value of soil used (4.9) may be attributed to increased microbial activities estimated by the added material resulting in decay of organic matter (Marchner and Noble, 2000). Similar results were observed by other workers such as: Qin and Chen (1998); N'Dayegamiye and Tran (2001); Ano and Ubochi (2007). At 40 Mg ha⁻¹ the accumulation of organic carbon during the short period of incubation may increase the organic carbon content. The higher carbon input is largely greater than its decay in the short term. CM, PM and MS were the most effective in increasing soil organic carbon content due to their initial high carbon contents.

4.1.2.6 Prediction of the liming effects of amendments

The liming effect of organic material is related to its ability to raise the pH of soil. The amendments tested had all the potential to increase soil pH. Several factors can contribute to the increase in soil pH when the organic material is added to soil. The factors include those which correlated with pH during the incubation studies such as: initial pH, the total basic cation, total CaCO₃ content, total carbon content and the proton consumption capacity (Table 4.5). This shows the important role played by these properties in the increasing of soil pH observed after addition of amendments. The magnitude of importance in term of correlation (contribution) was: initial pH, proton consumption, total CaCO₃ and basic cations content.

In terms of pH increase, a practical application was made by estimating lime equivalence of added organic materials. The lime equivalence of amendments was calculated through the regression equation presented in Figure 4.4. The differences observed in lime equivalence of amendments are explained by the various factors involving in pH increase depending on the material. Thus, the proton consumption capacity was the most contributing factor in increasing soil pH for animal manure and compost as illustrated in Equation 4.3 (Appendix 2). The organic molecules (oxalate, citrate etc.) releases after decomposition may consume protons from the soil and /or release OH⁻ leading to increase in soil pH (Wong *et al.*, 1998). The high liming potential of ash may be attributable to the total basic cations. Indeed the decaying of crop residue released ash compound which contains Ca, Mg and K that increased the base saturation and consequently soil pH (Shen and Chen 2001; Qin and Chen, 2005). The estimated lime equivalence can be used to determine the amount of each organic amendment to be

added to the soil based on the lime requirement calculated in terms of amount of $\text{Ca}(\text{OH})_2$. Table 4.5 showed the lime equivalence of the amendments used and their neutralizing power of soil acidity. The lime equivalence was negative for TPR despite its high ability to reduce soil acidity (Table 4.2 and Figure 4.3). The low potential of TPR is due to its low solubility and the short time of incubation which did not allow the dissolution and the release of basic cations. This indicates clearly that the lime equivalence estimation based on soil pH increase is not an appropriate method for this source of TPR.

4.1.3 Conclusions

This study has demonstrated that locally available resources such as animal manures (cattle, sheep, goat, and poultry), compost, maize straw and ash from maize straw reduced soil aluminium toxicity. These locally available materials can substitute for lime in detoxifying Al at least on a short-term basis. The “Liming” effectiveness of these materials varied with source and rate of application. The precipitation of soluble aluminium to insoluble Al-species through increased pH was the major mechanism. The ash from maize straw was the most effective both in increasing soil pH and reducing exchangeable acidity because of the high content in basic cation (K) and the PCC. The Tilemsi rock phosphate was the least effective in increasing soil pH because of its low solubility but the most in reducing exchangeable acidity after ash and lime. Indeed, Al precipitation with P may play significant role in reducing Al in TPR amended soil. In practice, the lime equivalence of organic material and the lime requirement of soil can be used to determine the application rate of organic amendments for soil acidity correction.

4.2 Assessment of the effect of lime and manure application on maize growth and yield, and soil properties

4.2.1 Results

4.2.1.1 Effect of lime and manure on some selected soil properties

The effects of lime, manure and their combinations on some selected acid soil properties during the two growing seasons are presented in Tables 4.8 and 4.9.

4.2.1.1.1 Effect of lime and manure on soil pH

Comparison of treatment means showed that there was significant difference as compared to control (Tables 4.8 and 4.9). Application of lime increased soil pH significantly ($P < 0.05$) from 4.8 to 6.8 in 2012 growing season and from 4.9 to 6.2 in 2013 growing season. The increase in soil pH was 0.74, 1.21, 1.95 units in 2012 by the application of 25, 50 and 100 % of LR respectively. The corresponding increases in soil pH over the control in 2013 were 0.69, 1.3 and 1.21 units. The use of manure did not significantly increase soil pH in 2012 season, but did so in 2013 season with an increment of pH from 5.5 to 6.14. Only the application of 5 Mg ha⁻¹ increased significantly soil pH by 0.62 units. Increases in soil pH were greater at higher rate for both lime (100 % LR) and manure (5 Mg ha⁻¹). The quarter rate of both lime (25 % LR) and manure (1.25 Mg ha⁻¹) increased soil pH above 5.5 (critical level for Al toxicity) in two growing seasons. The interaction effect between lime and manure on soil pH was not significant in both growing seasons.

Table 4.8: Effect of lime and manure on selected soil properties (2012)

Soil factors	pH (1:1, H ₂ O)	O.C %	Av.P mg kg ⁻¹	Exc.K cmol _c kg ⁻¹	Exc.Ca cmol _c kg ⁻¹	Ex.Mg cmol _c kg ⁻¹	Ex.Ac cmol _c kg ⁻¹	ECEC cmol _c kg ⁻¹
Lime (% of LR)								
0	4.80	0.30	22.9	0.14	1.67	0.24	0.22	2.23
25	5.54	0.27	23.29	0.13	2.22	0.36	0.09	2.87
50	6.01	0.30	20.70	0.13	3.45	0.41	0.08	4.24
100	6.75	0.28	21.34	0.15	4.95	0.54	0.06	5.80
F.pr	<0.001	0.80	0.60	0.60	<0.001	<0.001	<0.001	<0.001
Lsd(0.05)	0.38	0.09	4.99	0.05	0.81	0.11	0.02	0.88
Manure (Mg ha ⁻¹)								
0	5.83	0.30	13.98	0.14	2.96	0.40	0.22	3.67
1.25	5.68	0.31	28.66	0.13	3.15	0.42	0.08	3.87
2.5	5.84	0.28	21.61	0.15	3.16	0.38	0.07	3.92
5	5.80	0.28	23.99	0.13	3.06	0.34	0.07	3.69
F.pr	0.82	0.90	<0.001	0.60	0.90	0.90	<0.001	0.90
Lsd(0.05)	0.38	0.09	4.99	0.05	0.80	0.10	0.02	0.88
Interaction								
F.pr (L*M)	0.42	0.90	<0.001	0.04	0.50	0.51	<0.001	0.68
Lsd(0.05)	0.76	0.19	9.99	0.05	1.62	0.22	0.05	1.77
CV(%)	8.0	40.0	27.2	24.2	11.7	7.8	28.5	20.1

Table 4.9: Effect of lime and manure on selected soil properties (2013)

Soil factors	pH (1:1, H ₂ O)	O.C %	Av.P mg kg ⁻¹	Exc.K cmol _c kg ⁻¹	Exc.Ca cmol _c kg ⁻¹	Ex.Mg cmol _c kg ⁻¹	Ex.Ac cmol _c kg ⁻¹	ECEC cmol _c kg ⁻¹
Lime (% of LR)								
0	4.86	0.30	18.25	0.14	2.90	0.24	0.21	3.45
25	5.55	0.32	17.48	0.13	3.20	0.35	0.11	3.81
50	6.17	0.30	24.18	0.14	3.35	0.34	0.07	3.93
100	6.07	0.31	20.28	0.16	4.76	0.48	0.06	5.50
F.pr	<0.001	0.80	0.002	0.01	<0.001	<0.001	<0.001	<0.001
Lsd (0.05)	0.29	0.05	3.37	0.01	0.29	0.05	0.02	0.31
Manure (Mg ha ⁻¹)								
0	5.52	0.25	12.27	0.11	3.26	0.37	0.22	3.92
1.25	5.62	0.3	20.93	0.12	3.64	0.35	0.09	4.23
2.5	5.37	0.35	19.55	0.14	3.54	0.35	0.08	4.15
5	6.14	0.34	27.4	0.18	3.76	0.34	0.07	4.39
F.pr	<0.001	0.007	<0.001	<0.001	<0.001	0.75	<0.001	0.03
Lsd (0.05)	0.29	0.05	3.37	0.01	0.29	0.05	0.02	0.31
Interaction								
F.pr (L*M)	0.60	0.20	0.003	0.01	0.01	0.01	<0.001	0.01
Lsd (0.05)	0.58	0.11	6.74	0.03	0.59	0.10	0.03	0.63
CV(%)	6.1	21.2	20.2	15.4	10.1	17.5	23.7	9.2

4.2.1.1.2 Effect of lime and manure on exchangeable acidity

The effects of lime and manure and their interaction on soil exchangeable acidity are presented in Tables 4.8 and 4.9. The application of lime reduced soil exchangeable acidity significantly ($P < 0.001$) in both growing seasons and the effect was more pronounced at higher rate (100% LR). The percentage reduction in soil exchangeable acidity was 59, 64 and 73 % in 2012 with the application of 25, 50 and 100 % of LR respectively. The corresponding values in 2013 were 47, 67 and 72 %. The use of manure significantly ($P < 0.05$) reduced soil exchangeable acidity in two growing seasons. The reduction on soil exchangeable acidity following the application of lime was 63, 68 and 68 % in 2012 for the application of 1.25, 2.5 and 5 Mg ha⁻¹ respectively. In 2013, the application of 1.25, 2.5 and 5 Mg ha⁻¹ reduced soil exchangeable acidity by 59, 64 and 68 % respectively. On the other hand, soil exchangeable acidity concentration was statistically similar ($P < 0.05$) for each rate of application (1.25, 2.5 and 5 Mg ha⁻¹) in both growing seasons. The general trend of soil exchangeable acidity for both lime and manure was similar in the two seasons. There was significant interaction between lime and manure on soil exchangeable acidity in 2013. The lowest exchangeable acidity was obtained with 100 % LR+5 M (0.05 cmol_c kg⁻¹) and the highest with all combinations including 25 % LR (0.9 cmol_c kg⁻¹) in 2012 (Figure 4.5). The lowest reduction was observed with 25 % LR+2.5 M (0.10 cmol_c kg⁻¹) and the highest with 100 % LR+5M (0.4 cmol_c kg⁻¹) in 2013 (Figure 4.6).

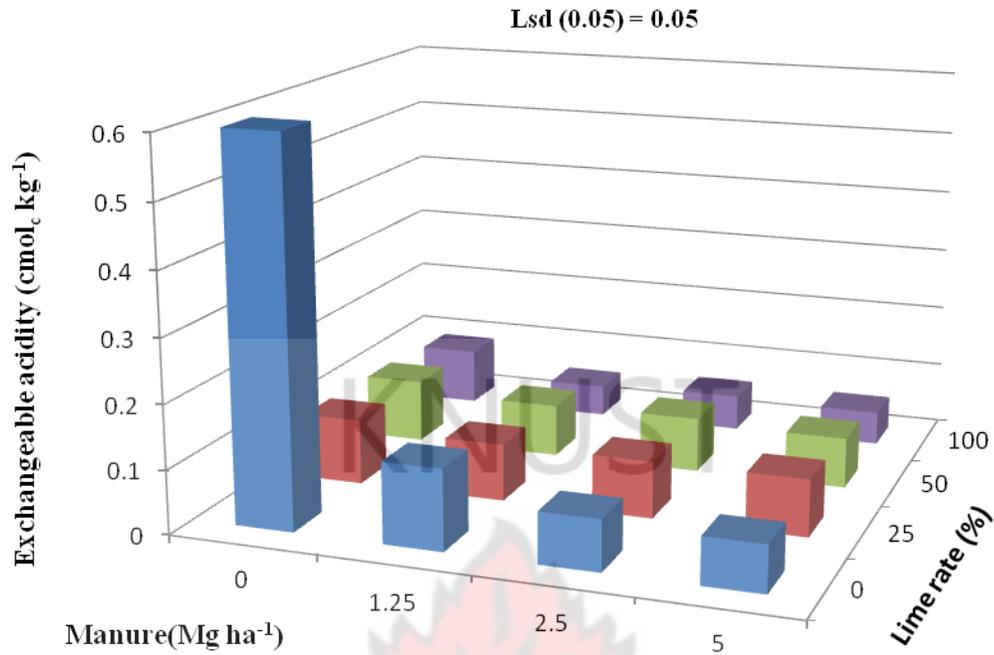


Figure 4.5: Interactive effect of lime and manure on soil exchangeable acidity (2012)

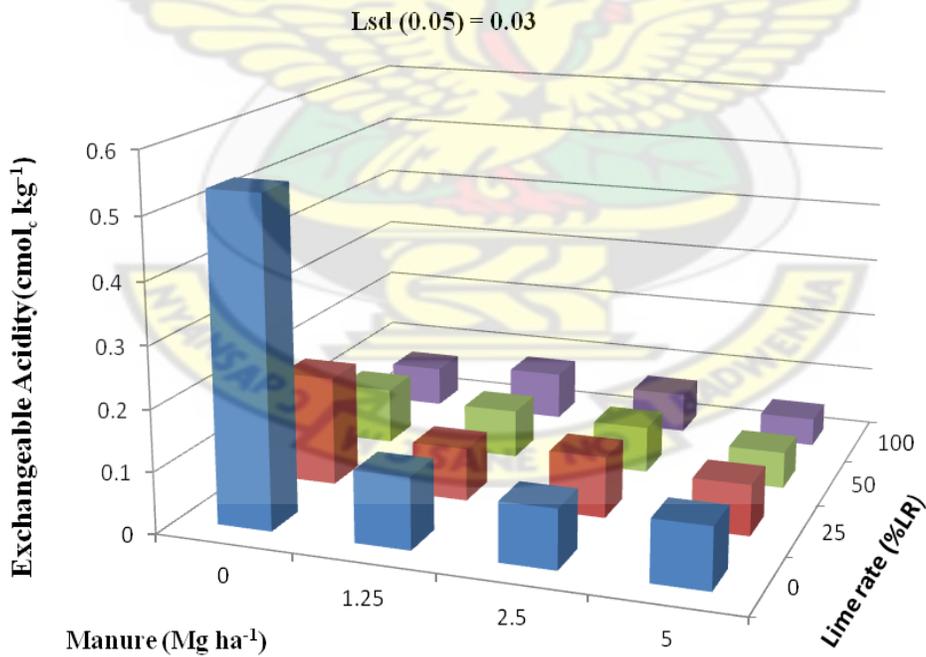


Figure 4.6: Interactive effect of lime and manure on soil exchangeable acidity (2013)

4.2.1.1.3 Effect of lime and manure on exchangeable calcium

Lime application significantly increased soil exchangeable Ca content from 1.67 to 4.95 $\text{cmol}_c \text{ kg}^{-1}$ (2012) and from 2.9 to 4.76 $\text{cmol}_c \text{ kg}^{-1}$ (2013) as shown in Tables 4.8 and 4.9. The improvement in soil exchangeable Ca over the control following the application of lime was 33, 107 and 196 % in 2012 as compared to 10, 15 and 15 % in 2013 at 25, 50 and 100 % of LR respectively. The increase was significantly ($P < 0.05$) higher for all rates of LR as than to control. The use of manure also increased exchangeable Ca content relative to the control in 2013, but not in 2012. The increases in soil exchangeable Ca attributable to manure application were 11, 9 and 15 % by addition respectively of 1.25, 2.5 and 5 t ha^{-1} . The soil exchangeable Ca of all rates of application was significantly ($P < 0.05$) higher than the control but there was no significant difference between the rates of 1.25, 2.5 and 5 Mg ha^{-1} . The interaction effect of lime and manure on soil exchangeable Ca content was significant in 2013. The lowest Ca content was obtained with the combined application of 25 % LR+1.25 M (2.99 $\text{cmol}_c \text{ kg}^{-1}$) while the highest with 100 % LR+1.25 M (4.97 $\text{cmol}_c \text{ kg}^{-1}$) as shown in Figure 4.7.

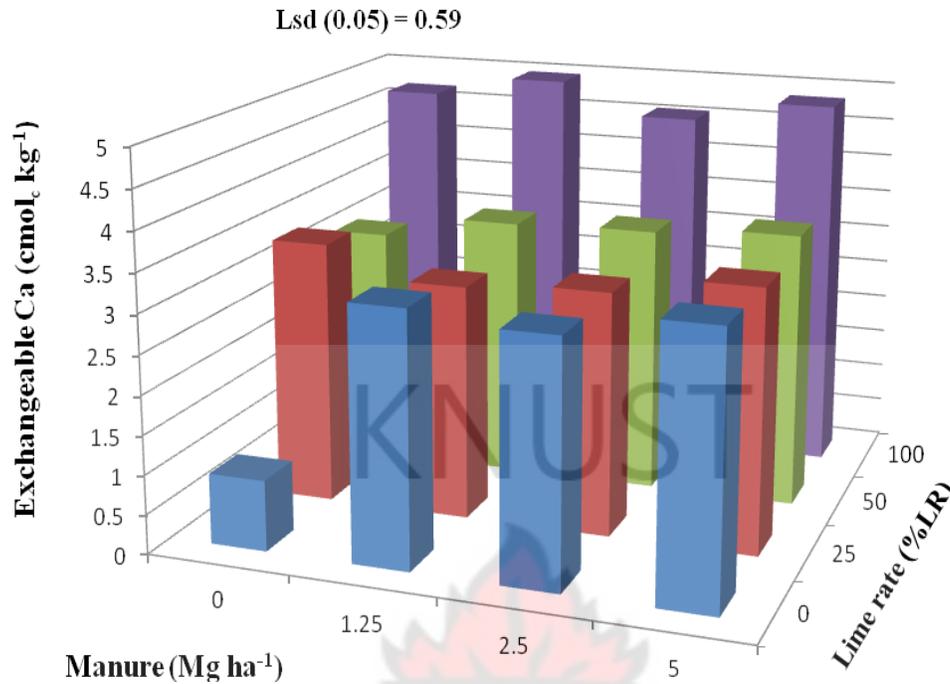


Figure 4.7: Interactive effect of lime and manure on soil exchangeable Ca (2013)

4.2.1.1.4 Effect of lime and manure on exchangeable magnesium

Lime application significantly ($P < 0.05$) increased soil exchangeable Mg in both growing seasons as compared to the control (Tables 4.8 and 4.9). The increase in soil exchangeable Mg ranged from 0.24 to 0.54 ($\text{cmol}_c \text{kg}^{-1}$) in 2012 and from 0.24 to 0.48 ($\text{cmol}_c \text{kg}^{-1}$) in 2013. The highest value was observed with the full rate of lime and there was no significant difference between the 25 % and 50 % of lime requirement in both growing seasons. Manure did not significantly affect soil Mg content as compared to the control in both growing seasons. There was however significant interaction between lime and manure on soil exchangeable Mg in 2013. The combined application of 50 % LR+2.5 M provided the lowest soil Mg content ($0.3 \text{ cmol}_c \text{kg}^{-1}$) while the highest ($0.6 \text{ cmol}_c \text{kg}^{-1}$) was obtained by 100 % LR+5 M as illustrated in Figure 4.8.

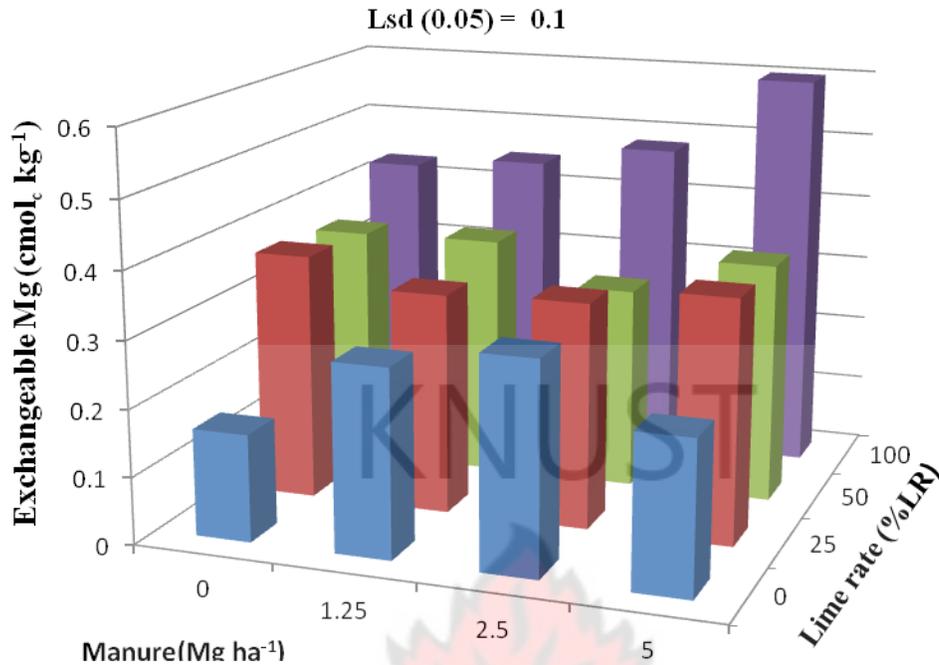


Figure 4.8: Interactive effect of lime and manure on soil exchangeable Mg (2013)

4.2.1.1.5 Effect of lime and manure on exchangeable potassium

Lime application did not significantly affect soil exchangeable K in 2012. On the contrary, lime increased the soil exchangeable K content in 2013 relative to the control and the highest value at the full rate (Tables 4.8 and 4.9). Manure significantly ($P < 0.001$) increased soil exchangeable K in 2013 as compared to control but not in 2012. The increase effect of manure on soil exchangeable K observed in 2013 was 10 % by application of 1.25 Mg ha⁻¹, 27 % by 2.5 Mg ha⁻¹ and 64 % by 5 Mg ha⁻¹. The soil exchangeable K increased with increasing in manure rate. The Figure 4.9 shows the significant interaction between lime and manure in 2013. The lowest (0.12 cmol_c kg⁻¹) soil exchangeable K was obtained by the use of 50 % LR+1.25 M and the highest (0.24 cmol_c kg⁻¹) with 100 % LR+5 M.

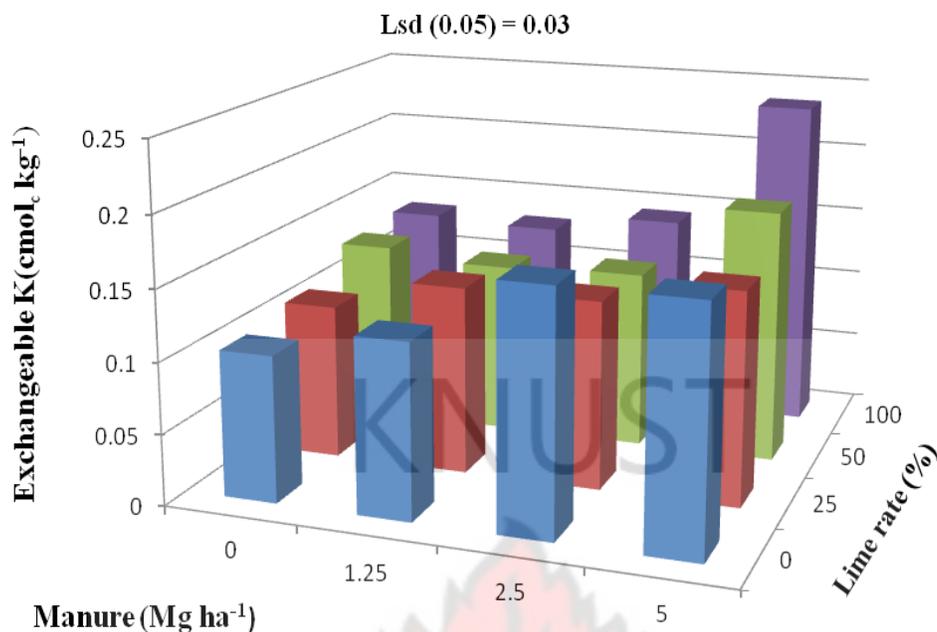


Figure 4.9: Interactive effect of lime and manure on soil exchangeable K (2013)

4.2.1.1.6 Effect of lime and manure on Effective Cation Exchange Capacity

The effect of lime and manure on soil ECEC is presented in Tables 4.8 and 4.9. Lime application increased the ECEC for both growing seasons as compared to control ($P < 0.001$). Increasing rate of lime significantly increased ECEC with the highest value was obtained at the full rate. The application of lime led to increased ECEC by 29, 90, and 100 % in 2012 as compared to 10, 14, and 59 % in 2013 with the addition of 25, 50 and 100 % of lime requirement. The general trend for lime was similar in the two growing seasons. Manure application had no significant effect on soil ECEC in 2012. However, it increased soil ECEC in 2013 with the 5 Mg ha⁻¹ application producing the highest value. The improvement of ECEC following manure addition in 2013 was only 8, 6 and 12 % by application of 1.25, 2.5 and 5 Mg ha⁻¹. The interaction effect of lime and manure on soil ECEC was significant in 2013, but not in 2012. The combined

application of 25 % LR+1.25 M gave the lowest ECEC ($3.56 \text{ cmol}_c \text{ kg}^{-1}$) while the highest ECEC was provided by 100 % LR+5 M ($5.55 \text{ cmol}_c \text{ kg}^{-1}$) as illustrated in Figure 4.10.

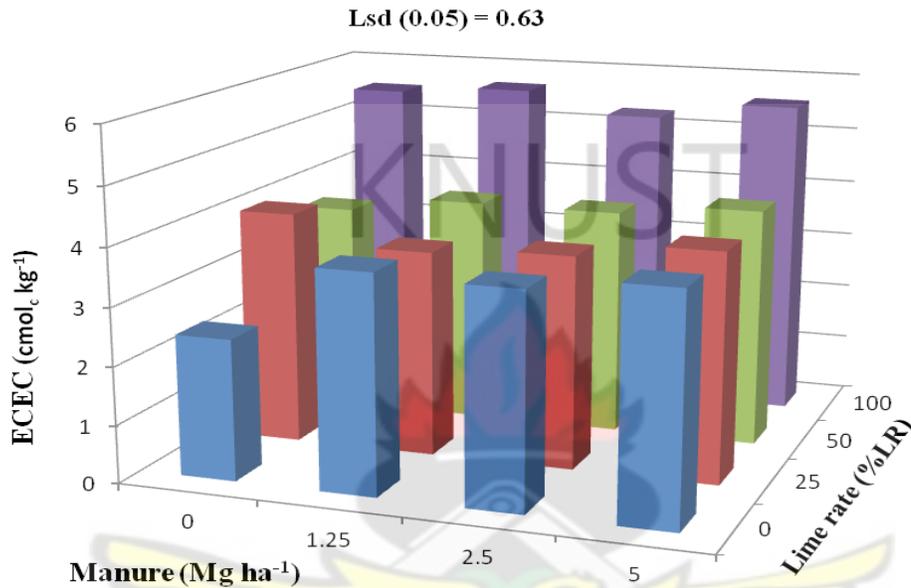


Figure 4.10: Interactive effect of lime and manure on soil ECEC (2013)

4.2.1.1.7 Effect of lime and manure on available phosphorus

Lime application did not significantly affect soil available P as compared to the control in 2012 (Table 4.8). On the other hand, lime application increased soil available P by 32 % for 50 % of LR and only 11 % for 100 % of LR in 2013 (Table 4.9). Manure significantly increased soil available P in both growing seasons relative to the control. The increases in available P due to manure application were 107 % at 1.25 Mg ha^{-1} , 55 % at 2.5 Mg ha^{-1} and 72 % at the application of 5 Mg ha^{-1} in 2012. The figures for 2013 were 70 % at 1.25 Mg ha^{-1} , 59 % at 2.5 Mg ha^{-1} and 123 % at 5 Mg ha^{-1} . There was no significant difference between the soil P level of 1.25 Mg ha^{-1} , 2.5 Mg ha^{-1} and 5 Mg ha^{-1} in 2012 and no significant difference between 1.25 Mg ha^{-1} and 2.5 Mg ha^{-1} in 2013.

The interaction between lime and manure was significant in both seasons. The lowest soil available P was obtained with 50 % LR+5 M (15.28 mg kg⁻¹) and the highest with 100 % LR+5 M (38.02 mg kg⁻¹) in 2012 (Figure 4.11). The lowest soil available P was observed with 25 % LR+2.5 M (11.89 mg kg⁻¹) and the highest with 100 % LR+5 M (31.49 mg kg⁻¹) in 2013 (Figure 4.12).

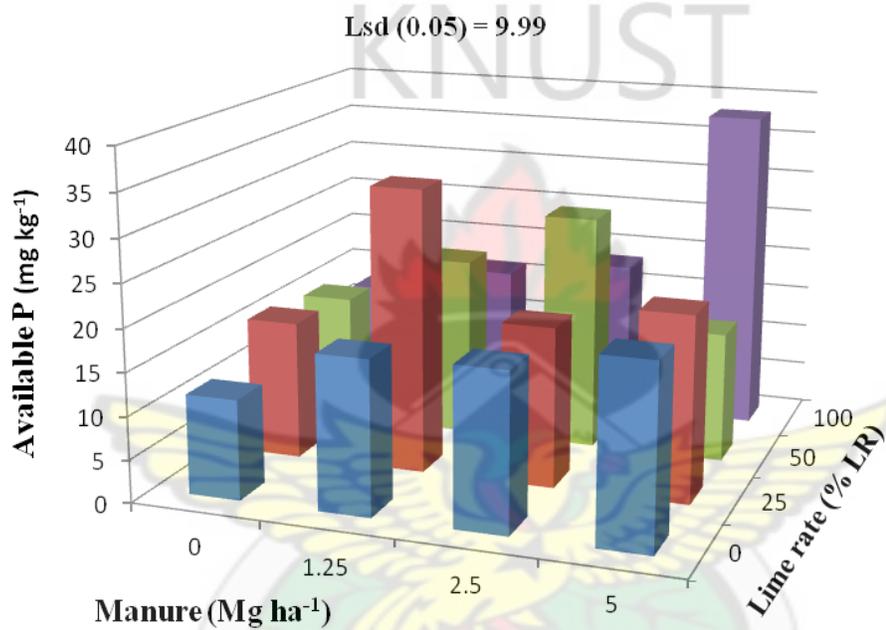


Figure 4.11: Interactive effect of lime and manure on available P (2012)

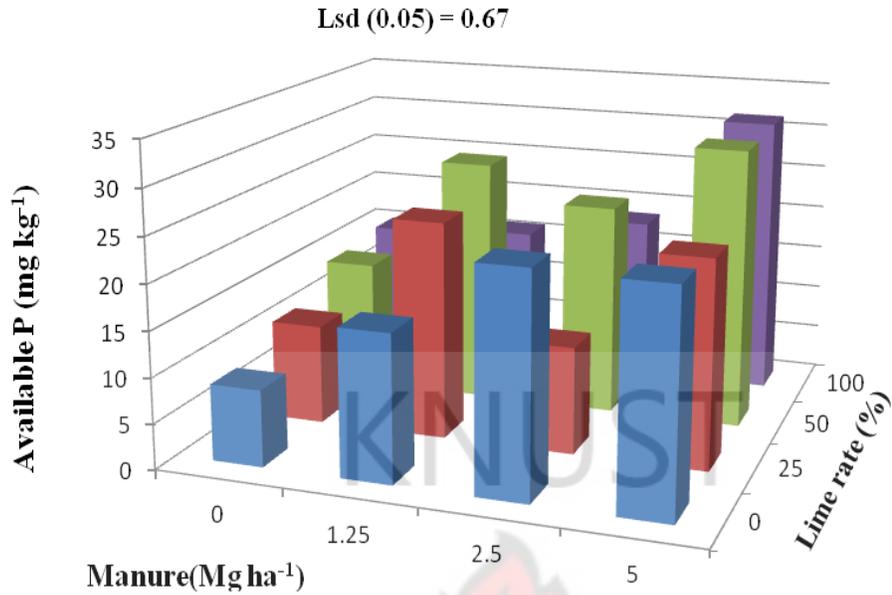


Figure 4.12: Interactive effect of lime and manure on soil available P (2013)

4.2.1.1.8 Effect of lime and manure on organic carbon content

Lime application did not significantly ($P > 0.05$) affect soil organic carbon content in both growing seasons as compared to control (Tables 4.8 and 4.9). Manure application did not significantly influence soil organic carbon content in 2012. On the other hand, in 2013, manure application significantly increased soil organic carbon by 20 % with 1.25 Mg ha⁻¹ and 40 % with 5 Mg ha⁻¹ as compared to the control. However, there were no significant differences between the SOC content among the different rates of application. The interaction between lime and manure on soil organic carbon was not significant in both growing seasons.

4.2.1.1.9 Correlation between some soil factors and soil pH after harvesting

Table 4.10: Relationship between soil factors and soil pH after harvesting

Growing season	2012 Growing season	2013 Growing season
Soil factors	Soil pH (1:1, H ₂ O)	Soil pH (1:1, H ₂ O)
Exch. Ca	0.76 ^{***}	0.50 ^{***}
Exch. Mg	0.72 ^{***}	0.52 ^{***}
Exch. K	0.09 ^{NS}	0.41 ^{***}
Exch. acidity	-0.37 [*]	-0.59 ^{***}
Organic C	-0.09 ^{NS}	-0.08 ^{NS}
C/N ratio	-0.01 ^{NS}	-0.03 ^{NS}
Total basic cation	0.77 ^{***}	0.52 ^{***}

NS: not significant, * significant at P<0.05, ** significant at P<0.01 and ***significant at P<0.001

Soil Ca, Mg and K were positively correlated to soil pH as illustrated in Table 4.10. There was also positive correlation between soil pH and the sum of basic cations in both growing seasons. As expected, the soil exchangeable acidity was negatively correlated to soil pH. The linear correlation between soil organic carbon and soil pH was negative but not significant in the two growing seasons. A similar trend was observed between soil C/N ratio and soil pH.

Table 4.11: Regression equations and coefficients of correlation of the relation between pH and exchangeable acidity of amended soil with lime and/or manure

Amendment	2012 Growing season		2013 Growing season	
	Regression equation	Correlation coefficient (r)	Regression equation	Correlation coefficient (r)
Lime	$Y=-21.121x +8.2622$	-0.96*	$Y=-8.7937x +6.5477$	-0.98*
Manure	$Y=-0.8376x +4.9435$	-0.46NS	$Y=-2.9292x + 5.2815$	-0.49NS
Combination	$Y=-18.519x+7.5211$	-0.84*	$Y=-8.2522x +6.7491$	-0.73*

*significant at $P>0.05$, NS: not significant at $P<0.05$ Where: soil pH and x: lime and/or manure

Table 4.11 shows the regression equations and coefficients of correlation of the relation between pH and exchangeable acidity of amended soil with lime or manure and their combinations. There was a strong negative correlation between soil pH and exchangeable acidity of lime only amended soil ($r:-0.96$ and $r:-0.98$). A similar trend was observed with lime combined with manure in both growing seasons. Manure was negatively correlated with pH. On the contrary, the correlation was negative but not significant with manure only amended soil in the two growing seasons.

4.2.1.2 Effect of lime and manure on maize growth

Table 4.12: Maize height and stem girth as affected by lime and manure

Growth parameters	2012 Growing season		2013 Growing season	
	Height (m)	Girth (mm)	Height (m)	Girth (mm)
Lime (% of LR)				
0	2.32	20.64	2.23	21.34
25	2.48	21.26	2.41	22.09
50	2.45	20.52	2.46	22.84
100	2.58	21.52	2.41	22.06
F.pr	<0.001	0.30	<0.001	0.01
Lsd (0.05)	0.08	1.25	0.08	0.90
Manure (Mg ha ⁻¹)				
0	2.39	19.27	2.27	20.70
1.25	2.51	21.87	2.40	22.30
2.5	2.48	21.97	2.40	22.64
5	2.46	20.83	2.44	22.63
F.pr	0.02	<0.001	0.002	<0.001
Lsd (0.05)	0.08	1.25	0.08	0.90
Interaction				
F.pr(L*M)	0.009	0.002	<0.001	<0.001
Lsd (0.05)	0.17	2.50	0.17	1.07
CV(%)	3.9	7.2	4.3	4.9

4.2.1.2.1 Effect of lime and manure application on maize height

The application of lime and manure significantly ($P < 0.05$) increased maize height in both growing seasons (Table 4.12). The improvement in maize height following the addition of lime was 7, 6 and 11 % in 2012 as compared to 8, 10 and 8 % in 2013 by the application of 25, 50 and 100 % of LR respectively. The highest increase was observed with 100 % of LR in 2012 but there was no significant difference between the lime amended soils in 2013. The improvement in maize height following the application of manure was 5, 4 and 3 % in 2012 following the application of 1.25, 2.5 and 5 Mg ha⁻¹ respectively. The corresponding figures for 2013 were 6, 6 and 8 %. Plant height did not differ significantly among the manure rates but was greater than the control. The interaction between lime and manure was significant in the two seasons. The lowest height was recorded under the combined application of 50 % LR+5 M (2.3 m) and the highest with 100 % LR+1.25 M (2.62 m) in 2012. In 2013, the lowest plant height was obtained with the combined application of 100 % LR+1.25 M (2.28 m) and the highest with 25 % LR+5 M (2.61 m) as shown in Figures 4.13 and 4.14.

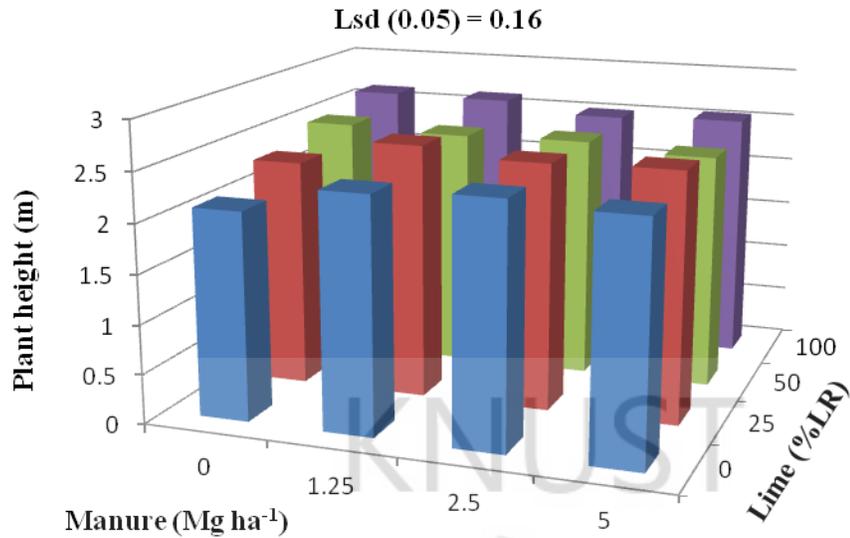


Figure 4.13: Interactive effect of lime and manure on maize height (2012)

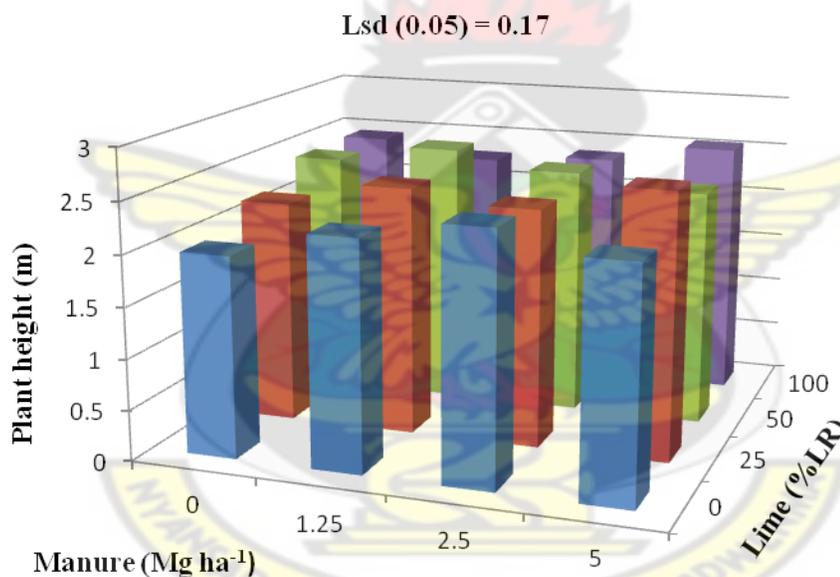


Figure 4.14: Interactive effect of lime and manure on maize height (2013)

4.2.1.2.2 Effect of lime and manure on maize stem girth

The application of both lime and manure significantly ($P < 0.05$) increased maize stem girth relative to the control (Table 4.12). The percentage increases were however very low for both lime and manure. The application of lime significantly increased stem girth in 2013, but not in 2012. The application of only 50 % of LR significantly ($P < 0.001$)

increased stem girth by 7 % in 2013. The improvements of maize stem girth following the use of manure were 15, 14 and 8 % in 2012 as compared to 8, 9 and 9 % in 2013 by the application of 1.25, 2.5 and 5 Mg ha⁻¹ respectively. However, there was no significant difference among the different rate of application in both seasons. The interaction between lime and manure was significant for the two growing seasons. The lowest stem girth was recorded by the combined application of 50 % LR+5 M (18.66 mm) and the highest with 25 % LR+1.25 M (23.3 mm) in 2012 (Figure 4.15). In 2013, the combined use of 100 % LR+2.5 M gave the lowest stem girth (20.96 mm) while the combination of 50%LR+1.25M provided the highest (24.50 mm) (Figure 4.16).

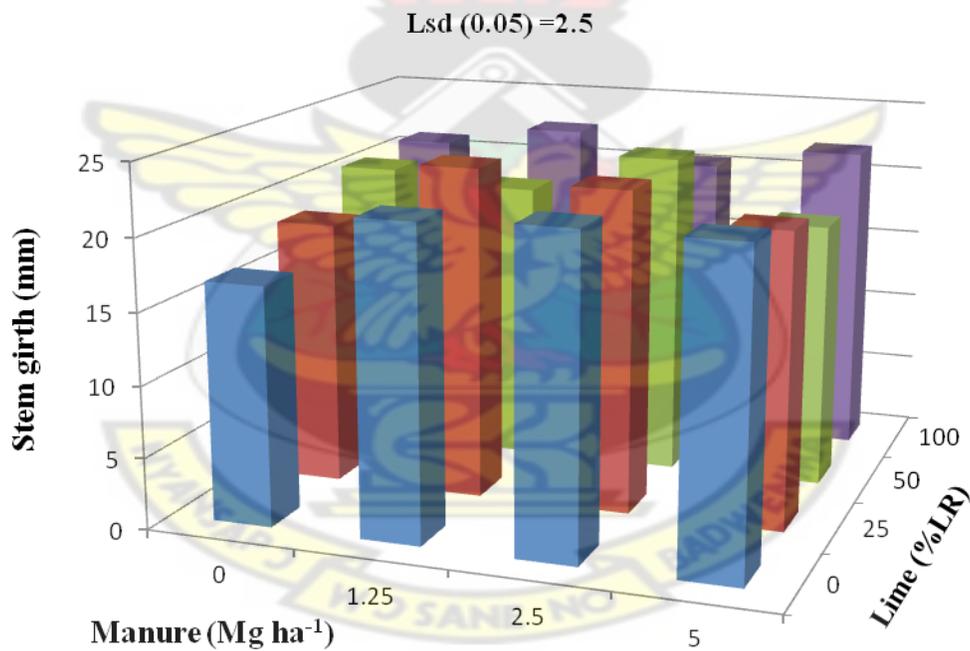


Figure 4.15: Interactive effect of lime and manure on maize stem girth (2012)

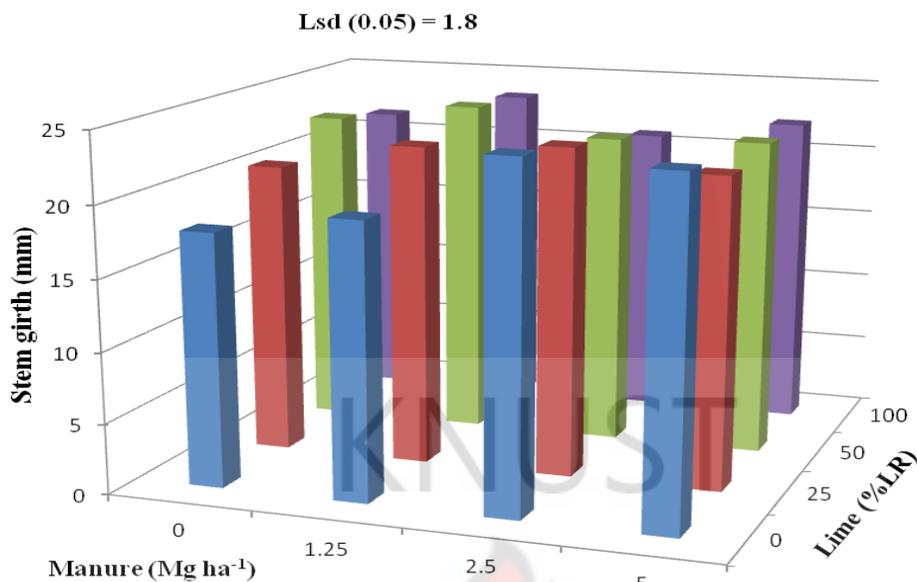


Figure 4.16: Interactive effect of lime and manure on stem girth (2013)

4.2.1.3 Effect of lime and manure on maize yields

4.2.1.3.1 Effect of lime and manure on maize biological yield

Biological yield represents the total amount of above ground biomass accumulated by the crop. The effects of lime and manure and their interaction are presented in Table 4.13. Both lime and manure significantly ($P < 0.05$) increased maize biological yield in the two growing seasons as compared to the control. The biomass produced in 2013 was about 1.6 times greater than that produced in 2012 for each amendment.

In 2012, the increases in biomass yield due to lime application were 17 % for 25 % LR, 18 % for 50 % LR and 22 % for 100 % LR. The corresponding figures in 2013 were 20, 18 and 50%. The biomass yield increases following the application of manure were 11, 13 and 20 % under 1.25, 2.5 and 5 Mg ha⁻¹ respectively. The corresponding figures in 2013 were 34, 39 and 55 %. There was no significant difference between rates of lime applied in 2013. On the other hand, the difference between manure rates was significant

in the two seasons. The highest grain yield was produced by the full rate of manure in 2013 (12969 kg ha⁻¹) but in 2012 there was no significant difference between manure amended soils. The differences between lime amended soils were not significant in both seasons.

Figures 4.17 to 4.18 showed the combined effect of lime and manure on biomass yields in the two growing seasons. The combined use of manure and lime significantly increased biomass yield in both seasons. The biomass yield ranged from 5625 to 8542 kg ha⁻¹ for the combination of 100 % of LR +50 % of manure and 100 % LR +5 Mg ha⁻¹) respectively in 2012. The corresponding range for 2013 was from 12083 to 15417 kg ha⁻¹ for 25 % of LR+1.25 Mg ha⁻¹ and 100 % LR+ 5 Mg ha⁻¹ respectively.

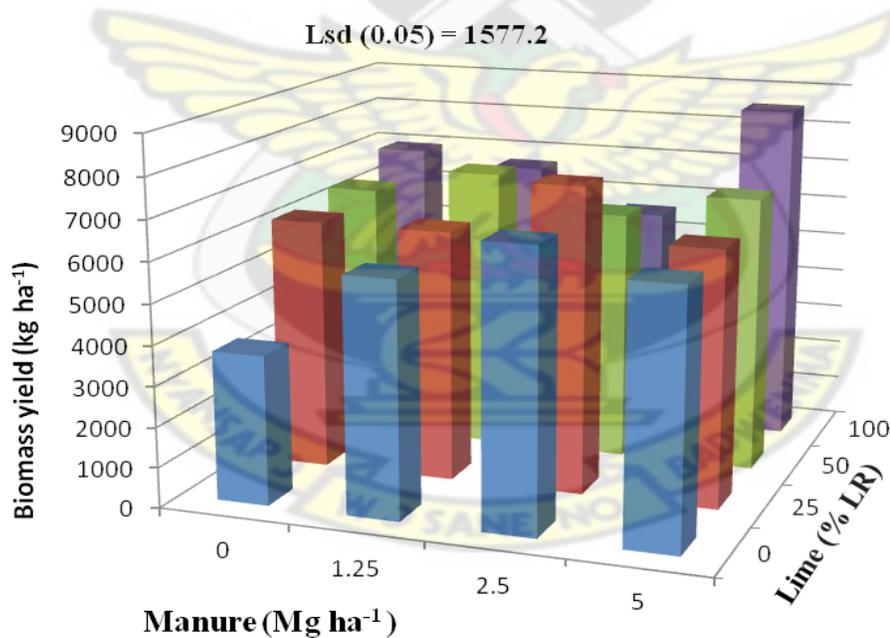


Figure 4.17: Interactive effect of lime and manure on maize biomass yield in 2012

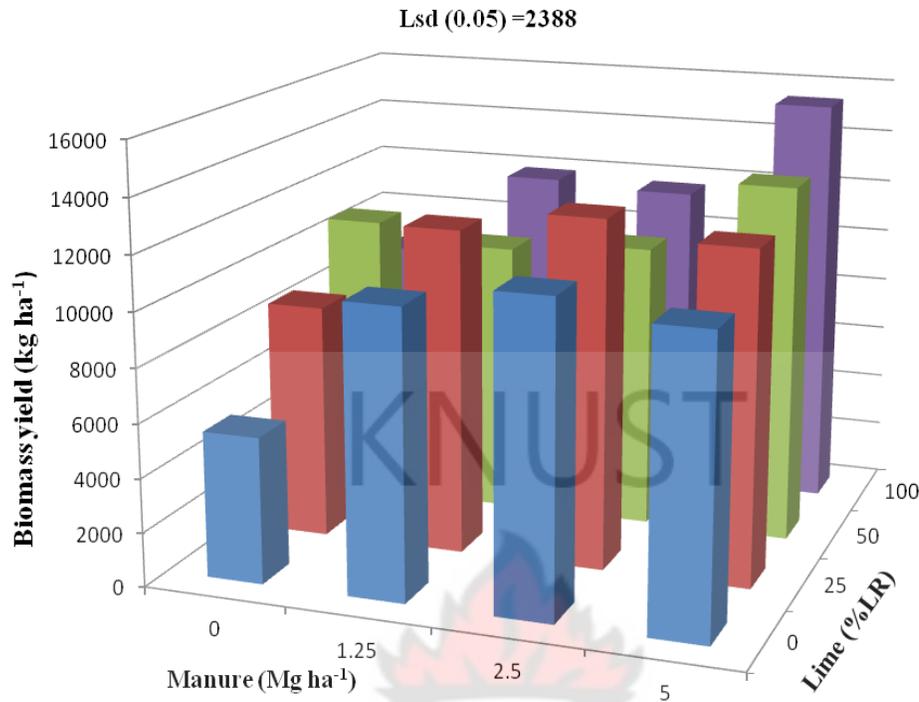


Figure 4.18: Interactive effect of lime and manure on maize biomass yield in 2013

4.2.1.3.2 Effect of lime and manure on maize grain yield

The application of both lime and manure significantly increased maize grain yield as compared to the control in the two growing seasons (Table 4.13). The grain yield produced in 2013 was about 1.5 times greater than that produced in 2012 for both lime and manure application.

In 2012, on the average over the four levels of manure, the application of lime increased the grain yield by 19 % for 25 % LR, 25 % for 50 % LR and 34 % for 100 % LR. The grain yield improvements following the application of manure were: 19 %, 12 % and 36 % under 1.25, 2.5 and 5 Mg ha⁻¹ respectively. The application of lime in 2013 led to increases in grain yield of 23, 22 and 23 % by the application of 25, 50 and 100 % LR respectively. Improvements in grain yield attributable to the application of manure were

31, 21 and 49 % at the rate of 1.25, 2.5 and 5 Mg ha⁻¹ respectively. The highest grain yields were produced by the application of 5 Mg ha⁻¹ of manure in both 2012 (3206 kg ha⁻¹) and 2013 (4844 kg ha⁻¹).

Figures 4.19 and 4.20 show the combined effect of lime and manure on grain yields in two growing seasons. The combined use of manure and lime significantly increased the grain yield in 2012 from 2817 kg ha⁻¹ (25 % of LR+1.25 Mg ha⁻¹ of manure) to 4000 kg ha⁻¹ (100 % LR+ 5 Mg ha⁻¹). Despite the no significant interaction between lime and manure in 2013, the highest grain yield was obtained by the combination of 100% of LR and 5 Mg ha⁻¹ of manure (5542 kg ha⁻¹).

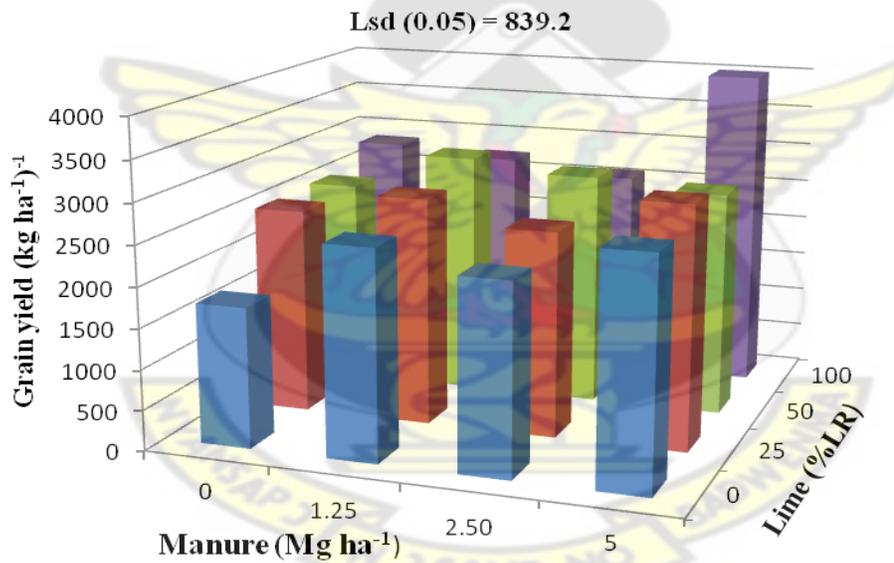


Figure 4.19: Interactive effect of lime and manure on grain yield in 2012

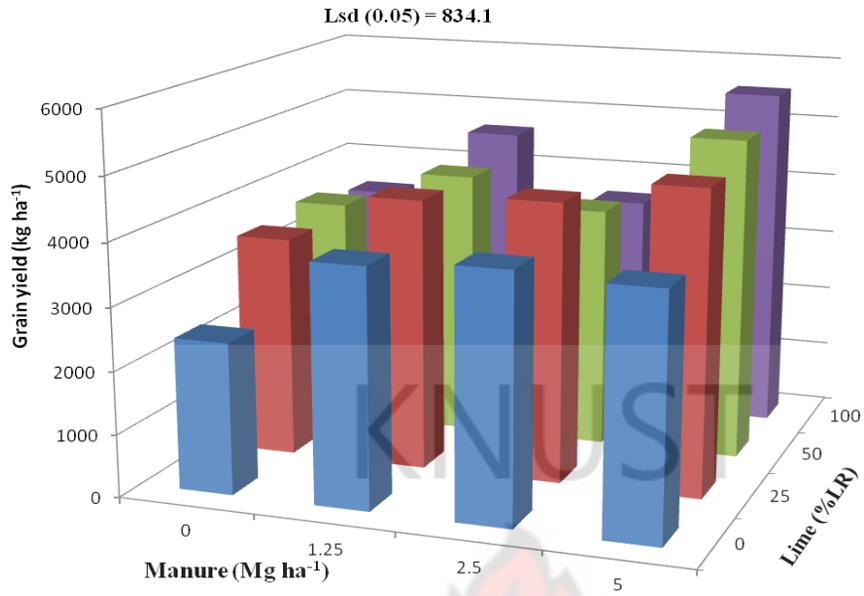


Figure 4.20: Interactive effect of lime and manure on maize grain yield in 2013

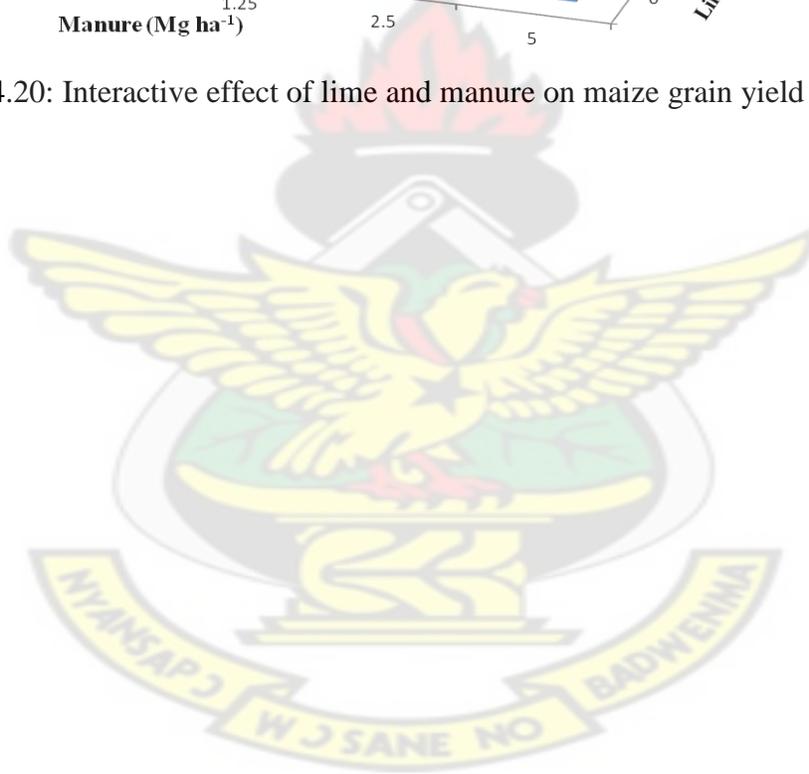


Table 4.13: maize grain and biomass yield as affected by lime and manure

Yields	2012 growing season		2013 growing season	
	Grain yield	Biomass yield	Grain yield	Biomass yield
-----kg ha ⁻¹ -----				
Lime (% of LR)				
0	2253	5667	3490	9583
25	2685	6604	4292	11510
50	2819	6667	4250	11250
100	3040	6958	4302	11875
F.pr	<0.001	0.01	<0.001	0.002
Lsd (0.05)	294.9	788.6	417.4	1194
Manure (Mg ha⁻¹)				
0	2311	5844	3271	8385
1.25	2754	6458	4260	11198
2.5	2591	6583	3958	11667
5	3144	7000	4844	12969
F.pr	<0.001	0.04	<0.001	<0.001
Lsd (0.05)	294.9	788.6	417.4	1194
Interaction				
F.pr(L*M)	<0.001	0.006	0.08	0.01
Lsd (0.05)	839.2	1577.2	834.1	2388
CV (%)	13.0	14.6	12.3	13.0

4.2.1.4 Correlation between maize yield, biomass yield, plant growth parameter and some soil factors after harvesting

Table 4.14: Relationship between maize yield, growth parameters and soil factors

Soil Factors	Grain yield		Biomass		Stem girth		Plant height	
	2012	2013	2012	2013	2012	2013	2012	2013
pH (1:1, H ₂ O)	0.38**	0.57***	0.24 ^{NS}	0.41**	0.02 ^{NS}	0.52**	0.36 ^{NS}	0.43**
T.N	0.07 ^{NS}	0.10 ^{NS}	0.15 ^{NS}	0.02 ^{NS}	0.15 ^{NS}	0.19 ^{NS}	0.05 ^{NS}	0.13 ^{NS}
Av. P	0.39**	0.56***	0.25 ^{NS}	0.52***	0.31*	0.40**	0.13*	0.50**
Exch.K	0.06 ^{NS}	0.55***	0.06 ^{NS}	0.53***	0.08 ^{NS}	0.28*	0.04 ^{NS}	0.32**
Exch.ac	-0.52***	-0.58***	-0.43**	-0.59***	-0.34*	-0.52***	-0.61***	-0.62***
Exch.Ca	0.24 ^{NS}	0.39**	0.32*	0.4***	0.07 ^{NS}	0.24**	0.34*	0.40**
Exch.Mg	0.27*	0.17 ^{NS}	0.32*	0.31*	0.07 ^{NS}	0.23 ^{NS}	0.33*	0.34 ^{NS}

NS: not significant, * significant at P<0.05, ** significant at P<0.01 and ***significant at P<0.001

Table 4.14 shows the relation between grain yield, selected growth parameters and some chemical properties. The exchangeable acidity was negatively correlated to grain yield in 2012 (r:-0.52) and 2013 (r:-0.58). Conversely, soil pH and available P were positively correlated to grain yield in 2012 (r: 0.38) and 2013 (r: 0.57). Soil exchangeable K and Ca were significantly correlated positively to grain yield in 2013 but not in 2012. Soil exchangeable Mg was significantly correlated to grain yield in 2012. The trend for biomass was similar to that of grain yield with some exceptions: biomass yield was not significantly correlated to pH in 2012. Also, both Ca and Mg were positively correlated to biomass in both seasons. A multiple regression function describing the relationship between grain yield and soil factors is indicated by Equations 4.5 and 4.6. The grain yield was not significantly correlated to SOC, total N, exchangeable Ca, Mg and K in

both seasons. However, the exchangeable acidity decreased the grain yield in both seasons. Conversely the grain was increased by the soil pH in both seasons and available P in 2012 as shown in Tables 4.15 and 4.16 and Equations 4.5 and 4.6

The soil exchangeable acidity was negatively correlated to plant height in both growing seasons. Soil pH was positively correlated to plant height in two seasons. Soil available P and exchangeable Ca were positively correlated to plant height in both seasons. The exchangeable K was positively correlated to plant height in 2013 while Mg in 2012. The trend for stem girth was similar to that of height except that exchangeable Ca and Mg were not significantly correlated to stem girth in 2012.

Table 4.15: Multiple regression of Grain yield with soils factors (2012)

Soil parameters	Coefficients	Standard Error	Significance
Constant	1256.17	715.95	0.08
pH (1:1, H ₂ O)	257.38	124.17	0.04
OC	-139.19	548.61	0.80
T. N	7848.20	9794.11	0.42
Av. P	28.13	7.54	<0.001
Exch. ac	-1444.90	519.92	0.008
Exch. Ca	-85.15	77.12	0.27
Exch. Mg	-94.75	718.01	0.89
Exch. K	-1167.85	1132.57	0.30

$$\text{Grain yield} = + 28.13(\pm 7.54)\text{Av.P} - 1444.89(\pm 519.93)\text{Exch.ac.} + 257(\pm 124)\text{pH}$$

Equation 4.5

$$(R^2=0.52, P<0.001)$$

Table 4.16: Multiple regression of Grain yield with soils factors (2013)

Soil parameters	Coefficients	Standard Error	Significance
Constant	1673.97	1192.03	0.16
pH (1:1, H ₂ O)	386.65	193.48	0.05
OC	-995.12	1314.99	0.45
T.N	-3900.89	11599.37	0.73
Av. P	20.28	17.09	0.24
Exch. ac	-2373.49	1104.72	0.03
Exch. Ca	111.01	166.58	0.50
Exch. Mg	-1587.74	1212.59	0.19
Exch. K	4474.19	3316.69	0.18

Grain yield= -2373.48(±1104.72) Exch.ac + 386.65(±193.47) pH
(R²=0.56, P<0.001) Equation 4.6

4.2.1.5 Effect of lime and manure on chemical composition of maize straw

The Tables 4.17 and 4.18 show the straw concentration of selected nutrients influenced by the application of lime and manure. The interactions between lime and manure on straw nutrients content are presented in Table 4.19. The concentration of nutrients was higher in 2013 as compared to 2012. Significant (P < 0.05) differences were observed in N, P, K, Ca, Mg concentrations of maize straw after addition of lime and manure as compared to the control. Straw N concentration ranged from 0.66 to 1.20 % and 0.7 to 1.1 % respectively for manure and lime in both seasons. Lime application did not significantly increase straw N uptake in 2012; but in 2013 the increase was significant and the highest value obtained by addition of 100 % LR. On the other hand, manure increased significantly straw N uptake for both growing seasons and the straw N

concentration was higher with 5 Mg ha⁻¹ application of kraal manure. The interaction between lime and manure on straw N concentration was significant only in 2013. The lowest concentration in N was provided by the combined application of 25 % LR+5 Mg ha⁻¹ (0.67%) while the highest with 100 % LR+5 Mg ha⁻¹ (1.86%).

Both lime and manure significantly ($P < 0.05$) increased straw P for the two growing seasons as compared to control. The straw P concentrations ranged from 0.7 to 1.97 % for manure and from 0.7 to 1.97 % for lime. Lime and manure had significant effect on P concentration of straw for both growing seasons and the high value were obtained at higher rate of application. The interaction between lime and manure on straw content in P was significant ($P < 0.05$) only in 2013. The combined use of 100 % LR+2.5 Mg ha⁻¹ gave the lowest P straw (1.73 %) while 100 % LR+5 Mg ha⁻¹ provided the highest (2.1 %).

The K concentration ranged from 0.96 to 1.45 % and from 0.94 to 1.33 % respectively, for manure and lime. The application of lime had no significant effect on straw K concentration in 2013. Conversely, K concentration was increased by the lime application in 2012 and the highest value was obtained with 100 % LR. Manure increased significantly ($P < 0.05$) maize straw K concentration in the two growing seasons and the higher K concentrations were obtained with 5 Mg ha⁻¹. Lime and manure interaction on maize straw K concentration was significant for both seasons. The lowest content was obtained under the combined application of 25 % LR+5 Mg ha⁻¹ (1.02 %) and the highest with 100 % LR+5 Mg ha⁻¹ (2.29 %) in 2012. In 2013, the lowest straw K content was obtained with the combined application of 50 % LR+2.5 Mg ha⁻¹ (1 %) and the highest with 100 % LR+5 Mg ha⁻¹ (1.51 %).

Manure application significantly ($P < 0.05$) increased Ca concentration of maize straw in both growing seasons while lime increased it only in 2012. The straw concentrations in Ca ranged from 0.05 to 0.22 % for lime and from 0.07 to 0.24 % for manure. The use of manure significantly increased maize straw Ca concentration and the higher values were observed under 5 Mg ha⁻¹ in 2013 and 1.25 Mg ha⁻¹ in 2012. The straw Ca concentration was higher with addition of 100 % LR in 2012. The interaction between lime and manure on straw Ca concentration was significant ($P < 0.05$) for both seasons. The lowest straw content in Ca was measured by the combined application of 25 % LR+2.5 Mg ha⁻¹ (0.07 %) and the highest with 100 % LR+5 Mg ha⁻¹ (0.16 %) in 2012. In 2013, the combined use of 50 % LR + 2.5 Mg ha⁻¹ gave the lowest Ca concentration (0.14 %) while the combination of 100 % LR+5 Mg ha⁻¹ provided the highest (0.37 %).

The straw Mg concentration of maize ranged from 0.14 to 0.82 % for manure and from 0.15 to 0.8 % for lime. The straw Mg concentration was significantly increased by application of manure in 2012 and lime in 2013. The straw Mg concentration was higher with addition of 2.5 Mg ha⁻¹ of manure (2012) and 100 % of LR (2013). Lastly, lime and manure interaction on maize straw Mg concentration was significant for both seasons. The lowest (0.13 %) straw content in Mg was obtained by the combined application of 50 % LR+5 Mg ha⁻¹ and the highest (0.19 %) with 25 % LR+1.25 Mg ha⁻¹ in 2012. In 2013, the combined use of 100 % LR+2.5 Mg ha⁻¹ gave the lowest Ca concentration (0.54 %) while the combination of 100 % LR+2.5 Mg ha⁻¹ provided the highest (0.96 %).

Table 4.17: Effect of lime and manure on the chemical composition of maize straw (2012)

Parameters	Total N	Total P	Total K	Total Ca	Total Mg
	-----%-----				
Lime rate (% of LR)					
0	0.80	0.70	0.83	0.05	0.15
25	0.70	0.98	1.11	0.09	0.16
50	0.70	0.89	1.32	0.12	0.15
100	0.80	1.13	1.53	0.14	0.15
F.pr	0.30	0.004	<0.001	<0.001	0.70
Lsd (0.05)	0.12	0.21	0.20	0.01	0.02
Manure (Mg ha⁻¹)					
0	0.70	0.70	0.95	0.08	0.14
1.25	0.75	0.80	1.23	0.12	0.16
2.5	0.98	0.90	1.22	0.11	0.17
5	0.66	1.31	1.39	0.10	0.14
F.pr	0.006	<0.001	0.002	<0.001	0.02
Lsd (0.05)	0.12	0.21	0.20	0.01	0.02
Interaction					
F.pr (L*M)	0.06	0.06	<0.001	0.005	0.002
Lsd (0.05)	0.25	0.43	0.40	0.03	0.05
CV (%)	20.4	28.2	20.9	17.1	20.3

L:lime, M: Manure

Table 4.18: Effect of lime and manure on the chemical composition of maize straw (2013)

Parameters	Total N	Total P	Total K	Total Ca	Total Mg
	-----%-----				
Lime rate (% of LR)					
0	0.69	1.44	1.29	0.15	0.57
25	1.76	1.82	1.20	0.22	0.77
50	0.77	1.61	1.29	0.17	0.77
100	1.11	1.97	1.30	0.26	0.80
F.pr	<0.001	<0.001	0.50	<0.001	0.009
Lsd (0.05)	0.11	0.19	0.17	0.15	0.15
Manure (Mg ha⁻¹)					
0	0.66	1.54	1.15	0.18	0.69
1.25	0.84	1.86	1.28	0.20	0.67
2.5	0.82	1.82	1.25	0.20	0.82
5	1.20	1.82	1.40	0.22	0.70
F.pr	<0.001	0.19	0.04	<0.001	0.20
Lsd (0.05)	0.11	0.008	0.17	0.04	0.15
Interaction					
F.pr (L*M)	<0.001	0.02	0.007	<0.001	0.02
Lsd (0.05)	0.23	0.31	0.34	0.09	0.31
CV (%)	17.4	19.1	16.3	26.7	26.0

L: Lime, M: manure

Table 4.19: Interactive effect of lime and manure on maize straw content in nutrients

Interaction	2012 Growing Season					2013 Growing Season		
	K	Ca	Mg	N	P	K	Ca	Mg
	-----%-----							
0LR*0M	0.53	0.02	0.10	0.56	0.83	0.81	0.10	0.33
25LR*0M	0.95	0.08	0.15	0.70	1.14	1.05	0.14	0.91
50LR*0M	1.19	0.10	0.17	0.65	1.28	1.08	0.22	0.79
100LR*0M	1.16	0.13	0.16	0.73	1.81	1.37	0.25	0.93
0LR*1.25M	0.69	0.07	0.17	0.67	1.05	1.54	0.18	0.66
25LR*1.25M	1.39	0.13	0.19	0.94	1.80	1.37	0.31	0.93
50LR*1.25M	1.62	0.15	0.14	0.83	1.78	1.12	0.12	0.67
100LR*1.25M	1.18	0.14	0.15	0.93	1.86	1.40	0.21	0.55
0LR*2.5M	1.19	0.09	0.25	0.81	1.03	1.09	0.20	0.56
25LR*2.5M	1.06	0.07	0.14	0.73	1.74	1.78	0.21	0.96
50LR*2.5M	1.17	0.14	0.15	0.80	1.89	1.00	0.18	0.90
100LR*2.5M	1.45	0.15	0.16	0.97	1.73	1.62	0.22	0.54
0LR*5M	0.93	0.04	0.10	0.74	1.68	1.29	0.14	0.71
25LR*5M	1.02	0.09	0.16	0.67	1.88	1.20	0.23	0.65
50LR*5M	1.32	0.12	0.13	0.81	1.98	1.28	0.14	0.79
100LR*5M	2.29	0.16	0.13	1.86	2.10	1.51	0.37	0.65
Fpr	<0.001	0.005	0.002	<0.001	0.02	0.007	<0.001	0.02
Lsd(0.05)	0.40	0.03	0.05	0.23	0.31	0.34	0.09	0.31
CV(%)	20.9	17.1	20.3	17.4	19.1	16.3	26.7	26.0

4.2.1.6 Financial profitability of the application of lime and manure

The returns on investments in lime and manure application on the acid soil were evaluated with Net Farm Benefit (NFB) and the Value Cost Ratio (VCR) as illustrated in Table 4.15 and Figure 4.20. Apart from the sole application of 25 % LR (3.14), 1.25 Mg ha⁻¹ of manure (4.25) and the combined application of 25 % LR+1.25 M (2.36); the VCR estimates were less than the economic viability threshold 2 in 2012 (Figure 4.20). Moreover, the combinations of 100 % LR+1.25 M, 100 % LR+2.5M and the sole application of 50 % LR yielded net negative returns as the VCR estimates were less than 1.

In 2013, only the combination of 100 % LR+2.5 M yielded net negative returns as the VCR was less than 1 (0.8), all application of lime, manure and their combination yielded net positive returns (VCR:1-4.32). Moreover, the sole application of manure at 1.25M (6.9) and 2.5M (3.8), the sole application of lime at 25 % LR (4.32) and 50 % LR (2.4) were greater than the economic viability threshold. Likewise the VCR estimates obtained from the combined application of 50 % LR+1.25 M, 25 % LR+2.5 M, and 50% LR+5M were also greater than the threshold.

The addition of manure at 1.25 Mg ha⁻¹ and lime at 25% LR were the most economically viable in sole application while 25 % LR+1.25 M in combined application for both growing seasons (VCR= 2.36-4.16) and the mean of years (not plotted). The combined use of 100 % LR+2.5 M gave the lowest NFB (272250-529000 F CFA) while the highest was provided by 25 % LR+1.25 M (584000-965625 F CFA) in both seasons as illustrated in Table 4.15.

Table 4.20: Net farm benefit of manure and lime application

Treatments	Lime	Manure	Variable cost	Net Benefit F (CFA)	
	kg ha ⁻¹	kg ha ⁻¹	F (CFA)	2012	2013
0LR+0M	0	0	0	433,250.00	604,250.00
25LR+0M	325	0	65750	571,000.00	819,750.00
50LR+0M	650	0	131500	507,750.00	785,250.00
100LR+0M	1300	0	263000	444,500.00	601,500.00
0LR+1.25M	0	1250	51875	592,000.00	896,125.00
25LR+1.25M	325	1250	117625	584,000.00	965,625.00
50LR+1.25M	650	1250	183375	571,000.00	889,625.00
100LR+1.25M	1300	1250	314875	363,500.00	841,375.00
0LR+2.5M	0	2500	103750	478,500.00	875,500.00
25LR+2.5M	325	2500	169500	461,500.00	945,000.00
50LR+2.5M	650	2500	235250	483,500.00	733,500.00
100LR+2.5M	1300	2500	366750	272,250.00	529,000.00
0LR+5M	0	5000	207500	483,000.00	750,750.00
25LR+5M	325	5000	273250	467,500.00	935,000.00
50LR+5M	650	5000	339000	349,000.00	952,750.00
100LR+5M	1300	5000	470500	519,000.00	915,000.00

LR: Lime requirement, M: manure

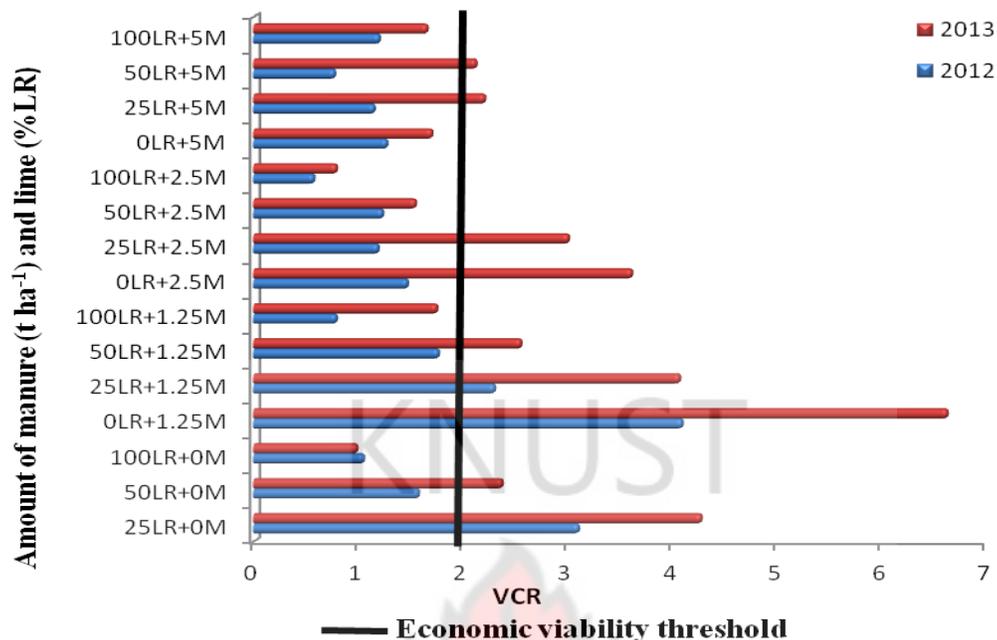


Figure 4.20: Value cost ratio of manure and lime application in two seasons (2012-2013)

4.2.2 Discussion

4.2.2.1 Effect of manure and lime on selected soil chemical properties

4.2.2.1.1 Effect of lime and manure on soil pH

Soil pH is indicative of soil reaction and determines the availability of soil nutrients for plant. The high pH value at higher rate of both lime and manure is attributable to the low buffering capacity of soil due to its low organic matter content and its sandy nature. However, the high soil pH observed in the field (6.1 and 6.8) compared to incubation study (5.3) following the application of lime at 100 % LR may be due to the duration of the two experiments. The relatively longer duration of six months in field experiment allowed greater fraction of the lime applied to react as opposed the shorter duration of one month in the incubation study. As expected, the increase in soil pH after lime addition was due to the high content in Ca and Mg of lime. The effect of lime on soil pH

has been well know and documented. The dissolution of agricultural limestone release basic cations particularly Ca and Mg which increase the base saturation of the soil solution and then increase pH (Hue *et al.*, 1998; Scott *et al.*, 2000; Opala, 2007; Andric *et al.*, 2012). The initial higher content of Toukoto limestone in Ca and Mg (Table 4.1) confirmed this result.

The ability of manure to increase the pH of acid soil as observed in this study has been demonstrated by many workers (Noble *et al.*, 1996; Hue *et al.*, 1998; Hayes and Mokolobate, 2001; Wong and Swift, 2003; Ano and Ubochi, 2007). The increase in pH of manure amended soil is attributable mainly to the initial pH (7.9) and the high content in basic cations (particularly Ca and Mg) of manure applied. Other several mechanisms may play important role in the liming effect of kraal manure (Haynes and Mokolobate, 2001). These could include proton consumption capacity (Wong *et al.*, 1998), specific adsorption of organic molecules (Hue *et al.*, 1986), and ammonification of organic nitrogen (Yuan *et al.*, 1996; Pocknee and Summer, 1997).

The basic cations produced by the rates 2.5 and 1.25 Mg ha⁻¹ were almost similar statistically and this can explain party the similarly between soil pH of these treatments observed in 2013. The optimum pH for maize growth is ranged from 5.5 to 7.0 (Lidon and Barreiro, 2002) so the pH levels for lime amended soil (5.54-6.75) and manured soil (5.62-5.84) were adequate.

4.2.2.1.2 Effect of lime and manure on soil exchangeable acidity

The decline in exchangeable acidity observed of the soil with the application of limestone and manure is primarily attributable to the precipitation of soluble Al with increases in pH (Kamprath, 1970; Noble, 1996; Pocknee and Sumner, 1997). Accordingly the relationship between soil pH and exchangeable acidity was strongly negative for soils amended with lime ($r=-0.96$ and -0.98) and lime with manure ($r=-0.8$ and -0.73) but poorly negative for those treated with manure ($r= -0.46$ and -0.49) in both growing seasons. The poor relationship between soil exchangeable acidity and soil pH of manure amended soil (Table 4.9) implied that, factors other than increase soil pH contributed to Al detoxification in manured soil. These results were consistent with those reported by other workers such Hue *et al.* (1989), Naramabuye (2004), and Opala (2011) could partly be attributed to the complexation of Al by organic matter.

Moreover the complexation of soluble Al by organic molecules especially organic acid from added manure may play an important role in declining of soil exchangeable acidity (Hue and Amien, 1989; Makolobate and Haynes 2001). Also the precipitation of Al by the greater levels of P compounds (P: 3.03 %) presents in added manure may contribute to reduce soil acidity (Hellums *et al.*, 1989; Shahandeh *et al.*, 2004; Tang *et al.*, 2007). The decrease in concentration of exchangeable Al, which is an important reserve of Al labile, reduces the potential of soil to supply soluble Al in soil solution.

The increase in soil exchangeable acidity with the reduction of lime rate is attributable to the decrease of soil pH after reduction of lime rate. On the other hand, the lack effect of the reduction of manure rate on soil exchangeable acidity may be explained partly by the fact that the amount of organic compounds of manure decomposition was probably

sufficient to reduce soil acidity at different rate of application (1.25, 2.5 and 5 Mg ha⁻¹). These results showed that the rate of 1.25 Mg ha⁻¹ was sufficient to reduce soil exchangeable acidity to non toxic level for plant growth. It has been reported that the mean of manure rate applied by farmer in Mali is ranged from 1 to 1.3 Mg ha⁻¹ (Kante *et al.*, 1998; Doumbia *et al.*, 2003; Samaké, 2007) and from 1.3 to 3.8 Mg ha⁻¹ in West Africa (William *et al.*, 1995). Consequently the amount of manure at the disposal of smallholder farmers in Mali and West Africa could adequately improve the exchangeable acidity level of their soils.

4.2.2.1.3 Effect of manure and lime on exchangeable basic cation content and ECEC

Both lime and manure significantly influenced the concentrations of soil exchangeable bases and hence the effective cation exchange capacity (ECEC) after application. The trend was not similar for lime and manure in the two growing seasons. The higher content of Ca and Mg in limestone is mainly responsible of the increased content in exchangeable basic cations and consequently soil ECEC. However, the low content of K in lime may explain the lack of effect of lime application on exchangeable K content.

The effect of kraal manure on exchangeable Ca, Mg and K in soil depends on its initial concentration that is mainly influenced by the feed fed to the animal. The release of basic cations after decomposition contributes to raise soil base content (Naramabuye and Haynes, 2007; Ano and Ubochi, 2007). However the absence of effect of manure application on exchangeable base of the soil in 2012 may be partly due to their washing out by flood water observed during this season. The use of manure did not increase the Mg concentration of the soil in 2013; the low content in Mg and the nutrient uptake by crop which occurred during plant growth may be partly responsible (Naramabuye,

2004). On the contrary, other authors such as Wong *et al.* (1998), Muhrizal *et al.* (2003) have reported significant increases in exchangeable Ca, Mg and ECEC following the application of organic materials.

The optimal levels for cereals production of exchangeable K ($0.22-0.33 \text{ cmol}_c \text{ kg}^{-1}$), exchangeable Ca ($2-6 \text{ cmol}_c \text{ kg}^{-1}$), exchangeable Mg ($0.68-1.02 \text{ cmol}_c \text{ kg}^{-1}$) (Manson *et al.*, 1993) and ECEC ($12-40 \text{ cmol}_c \text{ kg}^{-1}$) so soil level of Mg ($0.24-0.56 \text{ cmol}_c \text{ kg}^{-1}$), K ($0.13-0.16 \text{ cmol}_c \text{ kg}^{-1}$) ECEC ($2.23-4.39 \text{ cmol}_c \text{ kg}^{-1}$) and were low whilst those of Ca ($1.62-4.99 \text{ cmol}_c \text{ kg}^{-1}$) was adequate.

4.2.2.1.4 Effect of lime and manure on organic carbon and available phosphorus

The low content of limestone in organic carbon and phosphorus explains mainly its non effect on soil organic carbon and available phosphorus content. These results are consistent with the reports by Curtin and Syers (2001) and Opala (2011) which attributed the lack of effect of lime on soil available P by the inability of lime to mobilize or prime the P already fixed in the soil. Manure had high content of OC and consequently increased SOC content after application in season 2013. The kraal manure used as organic input may contain carbon resistant to microbial attack (lignin, cellulose) that needs more time for further decomposition (Vanlauwe, 2002) and contribute to increase SOM pool, even this improvement may be short-lived. Indeed, it is worth noted that a major product of plant decay is nitrogen (N) while the undigested portion is primarily carbon (C). But in 2012, the repetitive water logging and the washing out of fine particles (organic compounds) may explain the non effect of manure on soil organic content at harvesting. The no significant difference observed among the manure rates suggesting an intense decomposition of manure applied at higher rates (2.5 and 5 Mg ha^{-1}

¹) of application leading to the decay of soil organic carbon at *C stabilisation level* (Vaulauwe, 2002) or *steady-state condition* (David, 2004). However, at lower rate (1.25 Mg ha⁻¹), the C input may compensate the decay. These results were consistent with those reported by Bertrand and Gigou, (2000); Angers *et al.* (2010) but contrasted with the findings of Mubarak *et al.* (2009) the addition of farmyard manure increased SOC by 53 % of an acid sandy loam soil.

SOM is the main source of soil phosphorus, nitrogen and others nutrients for plant growth. Manure application has been reported to increase soil concentrations of both total and available P (Ylivaino *et al.*, 2008; Waldrip-Dail *et al.*, 2009). Indeed, the trends and their explanations for available phosphorus were similar to those of organic carbon in both growing seasons. The optimal levels for cereal production of extractable P ranged from 15-25 mg kg⁻¹ (Manson *et al.*, 1993) so soil level of P (17-27 mg kg⁻¹) was adequate in the two seasons.

4.2.2.2 Effect of manure and lime on maize growth

. The observed increases in plant height and girth following the application of manure and lime in both seasons could be due to the reduction in soil acidity, which reduced the soluble Al content of the soils to non toxic levels. The increases of nutrient availability and their uptake through the increase in soil pH following the addition of lime and manure contributed to improve maize growth (Costal *et al.* 2003; Opala, 2011; Fageria and Baligar, 2008). These results were in agreement with those reported by Agdebe *et al.* (2008) who found a significant increase of crop growth parameters (height and stem girth) after the addition of manure and they attributed these improvements to the cumulative improvement of soil physical, chemical and biological properties. The

absence of significant difference between the rate of application for both lime and manure may be due to their ability to reduce Al to non-toxic level. However the performance of some combinations (25 %LR+1.25M, 50%LR+1.25M for girth and 100%LR+1.25, 25%LR+5M for height) could be attributable to the positive interaction between lime and manure resulting in an increase of nutrient uptake.

4.2.2.3 Effect of lime and manure on maize yield (biomass and grain)

The biomass yield followed the similar trend as grain yield, and they were influenced likely by the same factors in both growing seasons. As matter as fact, the observed high yield of the control may be due to the relative tolerance of the cultivar to Al toxicities and associated factors. However, several strategies including both Al exclusion or avoidance and Al tolerance mechanism have been involved (Yost, 2000; Kochian *et al.*, 2004; Maron *et al.*, 2008). The yields produced in 2013 were much higher than those in 2012. The flooding water and consequently the temporary inhibition of nutrients uptake by crop occurred in 2012 were partly the reason for substantially higher yields obtained in 2013 compared to 2012 for each amendment (lime and manure) rate applied (Steffens *et al.*, 2005; Saisam *et al.*, 2008). As illustrated in Tables 4.17 and 4.18, the nutrients content of maize straw were much higher in 2013 than 2012. Moreover, it was observed the symptoms characteristic of N (yellowing of leaves in “V” shaped pattern), P (lower leaves purpling), and K (yellow and brown coloration of leaf margins) (Sawyer, 2004) in 2012 despite the application of mineral fertilizer at recommended rate. Furthermore, the residuals effect of the first year input (Tables 4.8 and 4.9) had probably contributed to increase the maize grain performance in the second year (Kisinyo *et al.*, 2011; Nekaso, 2007; Opala *et al.*, 2011).

The yields produced by manure were higher than those from limestone in sole application. Manure provided slowly plant nutrients to support growth and yield of maize (Roig *et al.*, 2012). For example SOM release available N that may be better synchronized with the demand for N by crop than fertilizer N (Vanlauwe, 2002). Also SOM content increases the use efficiency of N and P (Vanlauwe, 2002). For these reasons manure produced more yields than limestone in sole applications. These results are in line with the recent findings reported by Opala *et al.* (2014) who found that the application of quality manure ($N > 1.8$) increased maize yields over the lime application alone or in combination with TSP due to the ability of manure to reduce Al toxicity while providing a range of nutrients. Furthermore, the synergetic interaction between organic and mineral fertilizer in which mineral fertilizer supplied adequate levels of macronutrients, while manure furnished micronutrient absent in mineral input and soil solution contributed to higher maize biomass and grain yields (Velthof *et al.*, 1998; Sanginga and Woome, 2009). Besides, manure increases also soil pH over 5.5 that make nutrients more available and then reduce soil acidity even at lower rate. Lime not only increased soil pH while decreasing Al toxicity, but also provided Ca and Mg which enhanced crop nutrition in these nutrients in acid soil (Yost, 2000). Several studies have shown that lime reduced Al toxicity; increased soil pH, available P, Ca, Mg uptake of N and P consequently improved maize productivity (Kanyanua *et al.*, 2002; Kisinyo, 2011; Opala, 2010). The high performance of manure compared to lime in this study contrasted with the reported by Naramabuye (2004), that higher grain yield were produced by lime than manure and explained by the high ability of lime to reduce Al in solution as compared to manure. Besides, the relative limited effect of the sole

application of lime or manure may be attributable to the high amount supplied of mineral fertilizer at recommended rate.

The higher soil pH, the lower level of soil exchangeable acidity, the higher nutrients (P, K, Ca) content and uptake are responsible of the yield performance of all amended treatment relative to control and the higher yield of treatments receiving full rate of manure and lime (100 % LR + 5 M) than other treatments. This is confirmed by the positive correlation ($R^2=0.52$ and 0.56) between these soils factors and maize yields (Tables 4.15, 4.16, equations 4.5 and 4.6). Besides, the negative correlation between grain yield and exchangeable acidity expresses the depressed effect of exchangeable acidity on maize grain yield. The reduction of soil exchangeable acidity not only reduces the depressive effect of Al but can also boost nutrient uptake (Watanabe and Osaki, 2002), and then plant yield. Bennet and Breen (1989) reported that Aluminium at low concentration can stimulate the root growth in tolerant genotypes of *Zea mays* due to an increasing activity of the apical meristem. These findings are consistent with those reported by Mengel *et al.* (2001) who reported that the efficiency of added N, P and K fertilizers was very low in acid soil. The positive interaction between dolomite and manure increased nutrient uptake and consequently maize biomass and grain yields. These results were in consonance with those reported by Opala (2011). The soil pH for 100 % of LR with 5 Mg ha^{-1} of manure was 6.5 in 2013 and 6.8 in 2013; at this range of soil pH soil nutrients are available and Al non toxic for plant growth (Brady and weil, 1999; Yost, 2000). The nutrient content of treatment including the 1.25 Mg ha^{-1} of manure was not higher than those of other treatment this suggest other factors were responsible of the performance these treatments. The increasing of soil pH above 5.5

and the decreasing of exchangeable acidity may explain the performance of manure applied at 1.25 Mg ha^{-1} in sole or combined application with lime. Manure increases also grain yield by amelioration others physical and biological properties particularly the soil water and nutrients holding capacity (Diana *et al.*, 2008; Mtambanengwe and Mapfumo, 2006).

4.2.2.4 Effect of lime and manure on nutrients concentration of maize Straw

The much higher nutrients concentration of maize straw in 2013 than 2012 confirms the temporary inhibition of nutrients uptake occurred in first season due to water flooding. Steffens *et al.* (2005) reported that an aerobic aeration, oxygen deficiency caused sub-optimum nutrient supply (N, P, K, Mn, Cu and Zn). The higher nutrients concentration of maize straw of amended soils as compared to the control is partly attributable to the reduction of Al content in soil (Watanabe and Osaki, 2002). The superiority in straw nutrients content of the combination including 100 % LR +5M can be explained by the higher nutrient provided and the reduction of Al concentration in soil. The lime initially had very low content in N, P and K and the effects of this amendment on P, N and K concentration in maize straw can be attributable only to its influence on nutrient availability through soil pH increasing and the reducing of Al (Merino *et al.*, 2010). The repetitive temporary inhibition of nutrients uptake and may be the leaching of N, P and K (Smaling, 1993) by water flooding may explain why lime had no effect on N, P and K uptake in 2012. On the other hand, the increasing availability of these nutrients by the increasing soil pH improves their uptake by crop in 2013. However, the increasing effect of lime on P uptake is in contrast with its non effect on soil available P. The manure had high content in P and N and their release after mineralisation increase soil N

and P status. The increasing of soil pH, and thus the availability of N and P improve greatly plant N and P uptake. Similar results were reported Baquerol and Rojas (2001); Mtambanengwe and Mapfumo (2006).

The dolomite lime had much higher content in Ca (36.7 %) and Mg (11.2 %), which contributed to increase firstly soil pH and then nutrients availability and secondly improve soil solution content in Ca and Mg. For these reasons lime application increase Ca and Mg uptake and the effect is higher at higher rate of application. The increasing effect of manure application on straw Ca, Mg and K uptake is mainly attributable to the initial higher content of manure in these nutrients. The increasing effect of manure on soil pH may also contribute to improve straw K, Ca and Mg concentration. The positive interaction between dolomite lime and manure increased nutrients uptake by maize through furnishing nutrients and increasing soil pH that improves nutrient availability. These results are in consonance with the findings of Mtambanengwe and Mapfumo (2006), Mubarak *et al.* (2009).

The adequate nutrients status of maize leaf is as follows P (0.2-0.5 %), K (1.5-3 %), Ca (0.2-1 %), Mg (0.2-1 %) according to Chistensen as Cited by Andric *et al.* (2012) and so the straw level of Ca (0.07-0.24 %), K (1.04-1.45 %), and Mg (0.14-0.82 %) and are low whilst those of P (0.8-1.97 %) are adequate for amended soil.

4.2.2.5 Returns benefit of lime and manure application

The findings that return on investments were lower in 2012 as compared to 2013 for sole and combined application of lime and manure support the assertion of nutrients uptake inhibition by crop that lead to reduced maize yield. The negative returns obtained

from the combined application of 100 % LR + 5 Mg ha⁻¹ of manure (VCR<1) in both growing seasons implied that the yield obtained from this combination could not offset the investment made on the acquisition and application of these material (FAO, 2006). This combination is not attractive despite the highest yield produced for both growing seasons. The high cost of lime is mainly responsible of the negative VCR of this combination.

The higher profitability of the application of manure at 1.25 Mg ha⁻¹ is attributable to the synergetic effect of manure and mineral fertilizer (Palm *et al.*, 1997; Giller, 2002) which was applied at recommended rate (100kg of DAP and 150 kg of urea) and the low cost of manure incorporation (Williams *et al.*, 1995). Opoku (2011) showed the synergetic interaction between organic and inorganic fertiliser on grain yield that lead to high economic profitability (VCR: 2.3-7.7). In addition the actual high price of maize grain has contributed to increase the economic profitability (Abdoulaye and Sanders, 2005; Vitale and Sanders, 2005). This result shows the key role of organic matter in soil fertility and crop production and reinforced the assertion of the economic profitability of the mean rate of manure (1-1.3 Mg ha⁻¹) applied in Mali by farmer. The high profitability of 25% of LR (325 kg ha⁻¹) reinforced the assertion that application of low amount of lime on weathered acid soil increases crop yield by improving nutrient uptake rather than increasing soil pH (Brady and Weil, 1999). It also indicates the need to apply locally available lime for integrated soil fertility management. These results were an agreement with the findings of Mulungu *et al.* (2013) that the application of lime at reduced rate increased farm profit up to 50 %.

The high profitability of the combined application of lime and manure at $1.25 \text{ Mg ha}^{-1} + 25\%$ of LR is attributable to the greater synergism between lime, organic and mineral input which led to increase maize grain yield. Mulungu *et al.* (2013) reported that the synergism between lime and manure facilitate the release of nitrogen held initially by manure. The low cost of incorporation contributed to increase the economic profitability of this combination. Because of the intensification of soil acidification, the high cost of lime, the scarcity of manure the combined application of 25 % of lime requirement + 1.25 Mg ha^{-1} of manure and mineral fertilizer at recommended rate (100 kg of NPK+ 150 kg of urea) would be an appropriate strategy for optimizing management of weathered acid soil at a reasonable cost.

4.2.3 Conclusions

Kraal manure can improve acid soil infertility by providing various crop nutrients, increasing soil pH while decreasing soil exchangeable acidity (Al + H). The ability of cattle manure in ameliorating soil exchangeable acidity is likely to be attributable to the increase in soil pH but mostly by the capacity of organic compounds to complex with soluble Al rendering them insoluble. Kraal manure by ameliorating acid soil infertility increase significantly maize growth and grain yield. Manure at 1.25 Mg ha^{-1} was the most economic viable in sole application (VCR= 4.25-6.88).

The Toukoto limestone was an excellent ameliorant for soil acidity. The Toukoto lime increased soil pH; decreased soil acidity leading to improved maize growth and grain yield but this increase in grain yield was lower than that of kraal manure. The sole application of lime at 25 % of LR (325 kg ha^{-1}) was the most profitable (VCR= 3.14-4.32).

The combined application of Toukoto lime and manure ameliorate acid soil properties and maize growth and yield from 46 (25 % of LR +2.5 Mg ha⁻¹) to 130 % (100 % of LR +5 Mg ha⁻¹) in 2012 and 48 (100 % +2.5 Mg ha⁻¹) to 130 % (100 % + 5 Mg ha⁻¹) in 2013. However, the combination of 25 % of LR with 1.25 Mg ha⁻¹) is likely to be the most financially profitable and the most affordable for poor farmer (VCR= 2.35-4.16).

4.3 Assessment of the efficiency of the combined application of lime with precision addition of fertilizer

4.3.1 Results

4.3.1.1 Effect of lime and fertilizer on selected soil properties

4.3.1.1.1 Effect of lime and fertilizer on soil pH

The effect of lime and fertilizer application methods on soil pH is presented in Tables (4.21 and 4.22). The banding of lime had no significant ($P > 0.05$) affect on soil pH as compared to control in the two seasons. However, the soil pH between ridges was less than those on the ridges (0.15-0.53 unit) and the broadcasting (0.38-0.63 unit) for both growing seasons. The spot application of fertilizer did not significantly affect soil pH as compared to banding. Toukoto lime increased soil pH over the control by 0.28, 0.45 and 1.13 in 2012 as compared to 0.52, 0.89 and 1.09 units in 2013. The increase in soil pH was proportional to the rate of lime application. The interaction between lime method application, fertilizer method application and lime rate was significant only in 2012. The broadcasting of lime with banding of fertilizer and 25 % LR gave the lowest soil pH (4.7) while the banding of lime with spot application of fertilizer and 100 % LR provided the highest soil pH (6.5) as illustrated in Figure 4.22.

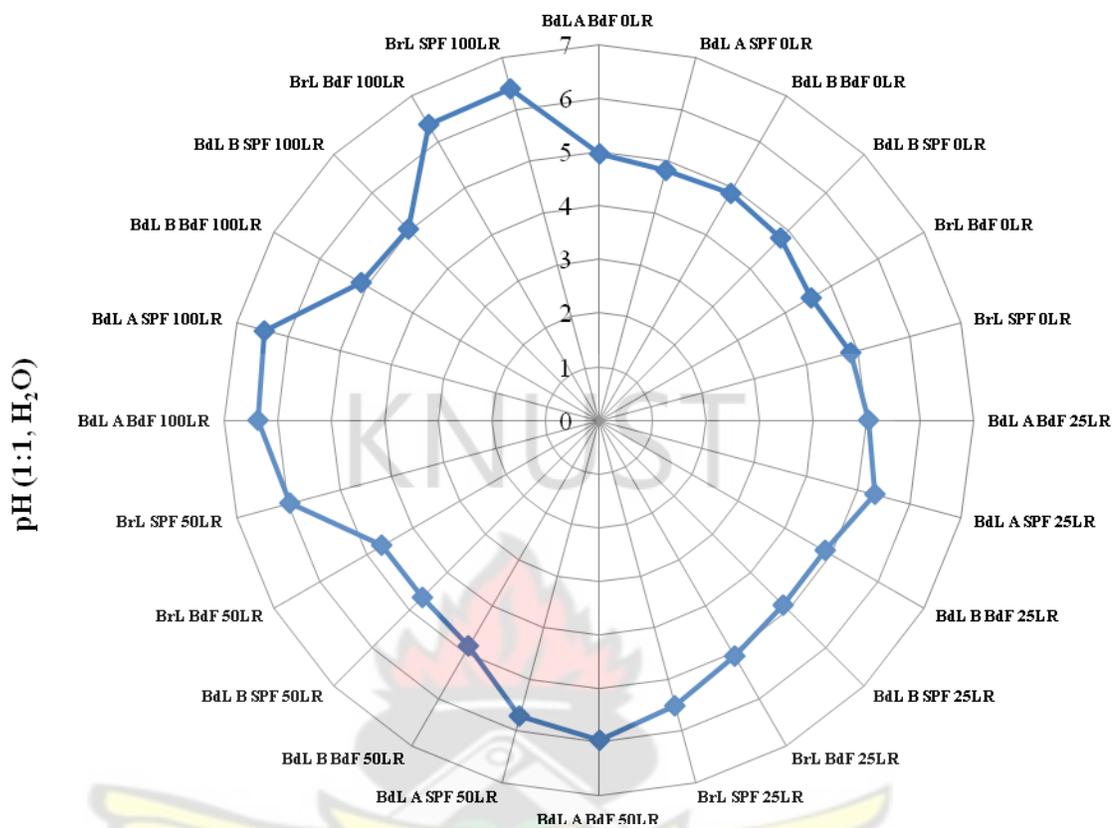


Figure 4.22: Interactive effect of lime and fertilizer on soil pH (2012) Lsd (0.05) = 0.48
 (BrL: lime broadcasting, BdL: lime banding, BdF: Fertilizer banding, SPF: Fertilizer spot application, LR: Lime requirement, A: on ridge, B: between ridge)

4.3.1.1.2 Effect of lime and fertilizer on soil exchangeable acidity

The application of lime significantly ($P < 0.05$) reduced soil exchangeable acidity as compared to control in the two seasons (Table 4.21 and 4.22). The decreases in soil exchangeable acidity following the addition of lime were 50 and 58 % in 2012 by the application of 25, 50 or 100 %LR. The corresponding figures in 2013 were 56, 65 and 78 % respectively. However, the banding of lime did not significantly affect soil exchangeable acidity as compared to broadcasting. The spot application of fertilizer did not significantly affect soil exchangeable acidity as compared to banding in both growing seasons. The interaction between lime method, fertilizer method application and lime rate was not significant in both seasons.

Table 4.21: Effect of lime and fertilizer on selected soil properties (2012)

Soil factors	pH (1:1,H ₂ O)	OC %	Av.P mg kg ⁻¹	Ex.K cmol kg ⁻¹	Ex.Ca cmol kg ⁻¹	Ex.Mg cmol kg ⁻¹	Ex.Ac cmol kg ⁻¹	ECEC cmol kg ⁻¹
Lime application method								
Broadcasting	5.42	0.32	16.8	0.16	2.00	0.32	0.16	2.81
Banding A	5.58	0.37	17.8	0.17	2.83	0.56	0.14	3.61
Banding B	4.89	0.36	7.80	0.15	2.47	0.56	0.16	3.19
F.pr	<0.001	0.42	0.04	0.25	0.01	0.07	0.29	0.01
Lsd (0.05)	0.16	0.10	8.37	0.03	0.43	0.23	0.03	0.44
Fertilizer application method								
Banding	5.23	0.40	15.20	0.18	2.53	0.47	0.15	3.24
Spot.App	5.36	0.30	12.80	0.14	2.34	0.48	0.15	3.16
F.pr	0.29	0.001	0.19	0.04	0.36	0.66	0.90	0.69
Lsd (0.05)	0.29	0.03	4.00	0.03	0.46	0.04	0.02	0.46
Lime rate (% of Lime requirement)								
0	4.83	0.37,	6.50	0.14	2.10	0.40	0.26	0.76
25	5.11	0.33	12.00	0.16	2.42	0.50	0.13	3.12
50	5.28	0.36	9.90	0.18	2.51	0.47	0.11	3.27
100	5.96	0.34	27.70	0.17	2.72	0.52	0.11	3.65
F.pr	<0.001	0.11	<0.001	0.03	0.006	0.005	<0.001	<0.001
Lsd (0.05)	0.16	0.03	8.06	0.02	0.32	0.07	0.03	0.33
Interaction								
F.pr	0.001	0.19	0.42	0.75	0.22	0.002	0.57	0.21
LM*FM*Lr								
Lsd (0.05)	0.48	0.13	18.5	0.06	0.89	0.25	0.07	0.63
CV (%)	4.6	19.4	24.8	19.8	20.0	23.2	30.1	15.3

LM: lime application method, Lr: lime rate, FM: fertilizer application method, banding A: on ridge, banding B: between ridge, Spot. App: spot application of fertilizer.

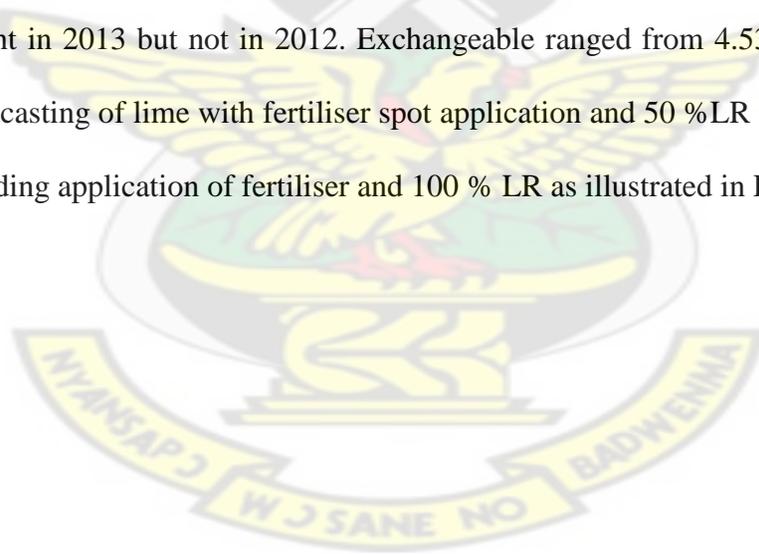
Table 4.22: Effect of lime and fertilizer on selected soil properties (2013)

Soil factors	pH (1:1,H ₂ O)	O C %	Av.P mg kg ⁻¹	Ex.K cmol kg ⁻¹	Ex.Ca cmol kg ⁻¹	Ex.Mg cmol kg ⁻¹	Ex.Ac cmol kg ⁻¹	ECEC cmol kg ⁻¹
Lime application method								
Broadcasting	5.32	0.23	12.78	0.22	4.40	1.28	0.12	6.15
Banding A	5.55	0.26	10.16	0.21	4.88	0.92	0.11	6.43
Banding B	5.17	0.24	9.33	0.16	4.52	1.17	0.12	5.78
F.pr	0.03	0.18	<0.001	0.02	0.16	0.03	0.48	0.10
Lsd (0.05)	0.27	0.05	0.63	0.03	0.57	0.25	0.02	0.63
Fertilizer application method								
Banding	5.43	0.24	11.24	0.19	4.46	1.17	0.11	6.02
Spot.App	5.26	0.25	10.25	0.20	4.75	1.07	0.12	6.22
F.pr	0.18	0.66	0.01	0.24	0.06	0.06	0.42	0.22
Lsd (0.05)	0.28	0.02	0.73	0.03	0.30	0.11	0.02	0.34
Lime rate (% of Lime requirement)								
0	4.71	0.24	10.62	0.19	3.86	0.75	0.23	5.07
25	5.23	0.25	11.06	0.20	4.63	1.06	0.10	6.08
50	5.60	0.25	10.37	0.20	4.73	1.16	0.08	6.26
100	5.80	0.28	10.94	0.18	5.19	1.52	0.05	7.06
F.pr	<0001	0.32	0.46	0.34	<0.001	<0.001	<0.001	<0.001
Lsd (0.05)	0.28	0.04	0.95	0.02	0.59	0.21	0.02	0.43
Interaction								
F.pr	0.77	0.55	0.001	0.36	0.005	0.85	0.88	0.04
LM*FM*Lr								
Lsd (0.05)	0.69	0.11	2.19	0.06	0.88	0.50	0.05	1.08
CV (%)	7.9	28.6	13.2	18.5	10.9	28.3	24.4	10.4

LM: lime application method, Lr: lime rate, FM: fertilizer application method, banding A: on ridge, banding B: between ridge, Spot. App: spot application of fertilizer.

4.3.1.1.3 Effect of lime and fertilizer on exchangeable calcium

The application of lime increased significantly ($P < 0.05$) soil exchangeable calcium as compared to control in both growing seasons (Tables 4.21 and 4.22). The improvement in exchangeable Ca attributable to the addition of lime was: 15, 20 and 30 % in 2012. The corresponding figures in 2013 were 20, 23 and 34 % respectively. The increases in exchangeable Ca content were proportional to the increases in lime rate of application. Banding of lime increased soil exchangeable Ca over the broadcasting in 2012 but not in 2013. There was also no significant difference between soil exchangeable Ca on ridge and between ridge. Conversely, the spot application of fertilizer did not significantly ($P > 0.05$) affect soil exchangeable Ca as compared to banding in both seasons. The interaction between lime method, fertilizer method application and lime rate was significant in 2013 but not in 2012. Exchangeable ranged from 4.53 to 5.73 $\text{cmol}_c \text{ kg}^{-1}$ for broadcasting of lime with fertiliser spot application and 50 %LR and banding of lime with banding application of fertiliser and 100 % LR as illustrated in Figure 4.23.



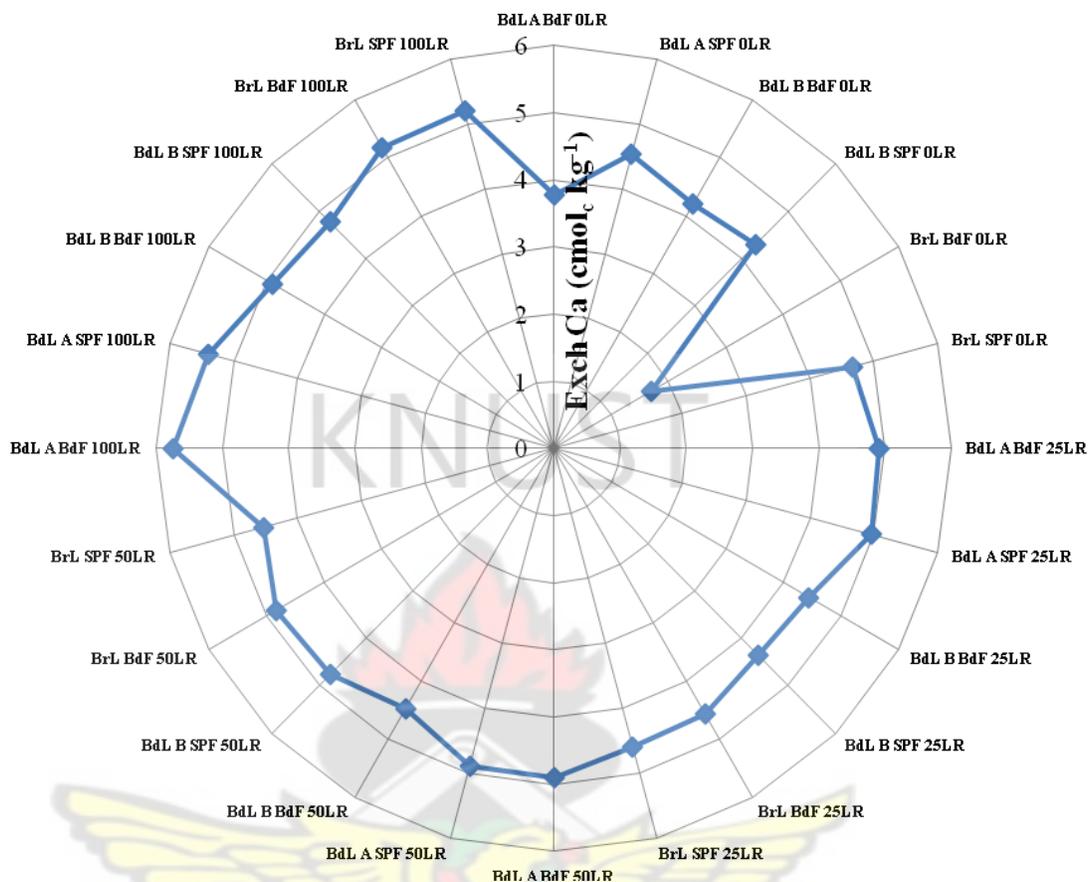


Figure 4.23: Interactive effect of lime and fertilizer on soil exchangeable Ca (2013) Lsd (0.05)= 0.88 (BrL: lime broadcasting, BdL: lime banding, BdF: Fertilizer banding, SPF: Fertilizer spot application, LR. Lime requirement, A: on ridge, B: between ridge)

4.3.1.1 .4 Effect of lime and fertilizer on exchangeable Magnesium

The application of lime significantly ($P < 0.05$) increased soil exchangeable magnesium over the control in 2012 (Table 4.21) and 2013 (Table 4.22). The increases in soil exchangeable Mg attributable to lime rate were: 25, 18 and 30 % in 2012 as compared to 41, 55 and 102 % in 2013 by the application of 25, 50 and 100 % of LR respectively. Exchangeable Mg increased with the increase of lime rate in two seasons. In consistence with previous soil parameters the spot application of fertilizer had no significantly affect on soil exchangeable Mg relative to banding in both growing seasons. On the other hand the banding of lime increased exchangeable Mg than broadcasting only in 2012.

However, the interaction between lime method, fertilizer method application and lime rate was significant in 2012 but not in 2013. The broadcasting of lime with banding of fertilizer and 50 % LR gave the lowest soil exchangeable Mg ($0.25 \text{ cmol}_c \text{ kg}^{-1}$) while the banding of lime with banding of fertilizer and 100 % LR provided the highest soil exchangeable Mg ($0.77 \text{ cmol}_c \text{ kg}^{-1}$) as illustrated in Figure 4.24.

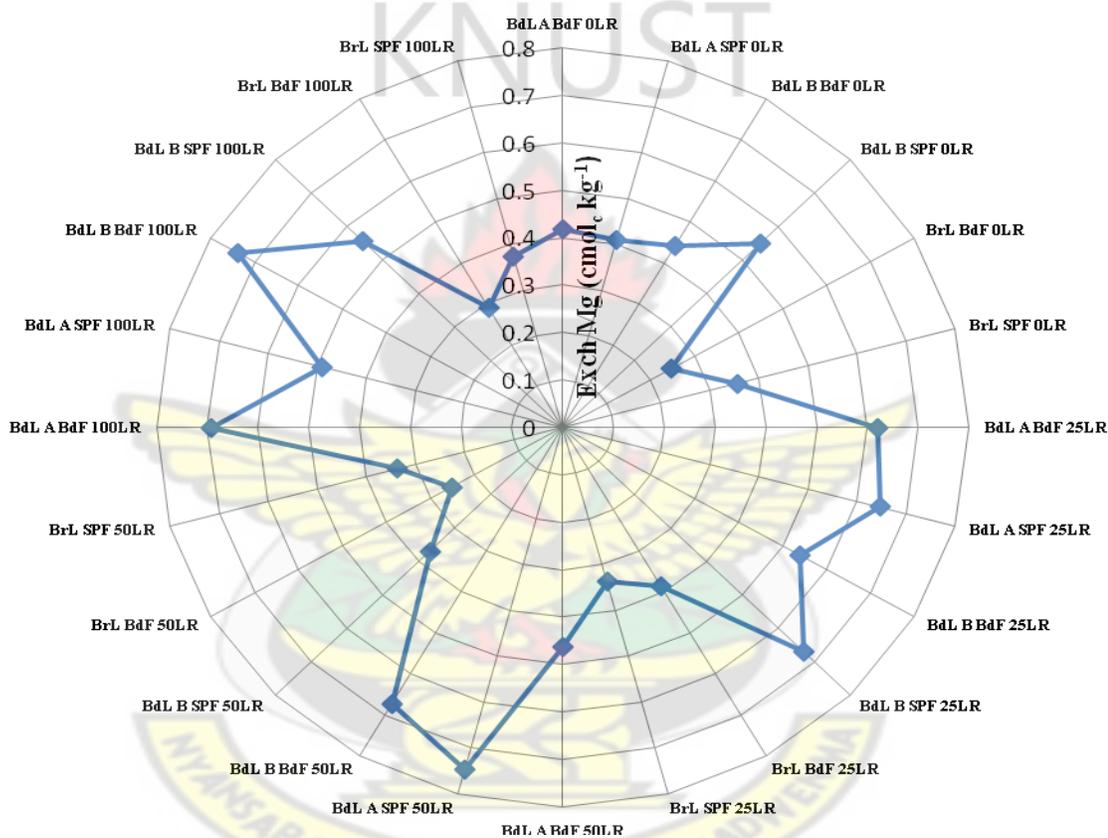


Figure 4.24: Interactive effect of lime and fertilizer on soil exchangeable Mg (2012) Lsd (0.05)= 0.25 (BrL: lime broadcasting, BdL: lime banding, BdF: Fertilizer banding, SPF: Fertilizer spot application, LR. Lime requirement, A: on ridge, B: between ridge)

4.3.1.1 .5 Effect of lime and fertilizer on exchangeable Potassium

The lime application (rate and method) increased significantly ($P < 0.05$) exchangeable potassium in 2012 but not in 2013 (Tables 4.21 and 4.22). Lime increased the soil exchangeable K in order of 15, 18 and 22 % by the application of 25, 50 and 100 % of

LR respectively. The spot application of fertilizer reduced exchangeable by K 22 % in 2012. As compared to broadcasting, the banding of lime did not significantly affect exchangeable K in both growing seasons. The soil exchangeable K was higher on ridge than between ridges. The interaction between lime method, fertilizer method application and lime rate was not significant in both growing seasons.

4.3.1.1.6 Effect of lime and fertilizer on Effective Cation Exchange Capacity

The addition of lime significantly ($P < 0.05$) increased soil ECEC over the control (Table 4.21 and 4.22). The improving of soil ECEC attributable to lime were 13, 18 and 32 % in 2012 as compared to 19, 23 and 38 % in 2013 by the application of 25, 50 and 100 % of LR respectively. The increases in ECEC were proportional to the increases of lime application rate. The spot application of fertilizer had no significant affect on soil ECEC as compared to banding. The banding of lime increased soil ECEC by 29 % in 2012 as compared to broadcasting. There was significant interaction between lime method application, fertilizer method application and lime rate in 2013. The broadcasting of lime with spot application of fertilizer and 50 % LR provided the lowest ECEC ($6.13 \text{ cmol}_c \text{ kg}^{-1}$) while the highest ECEC ($7.85 \text{ cmol}_c \text{ kg}^{-1}$) was obtained by the banding of lime with banding of fertilizer and 100 % of LR as illustrated in Figure 4.25.

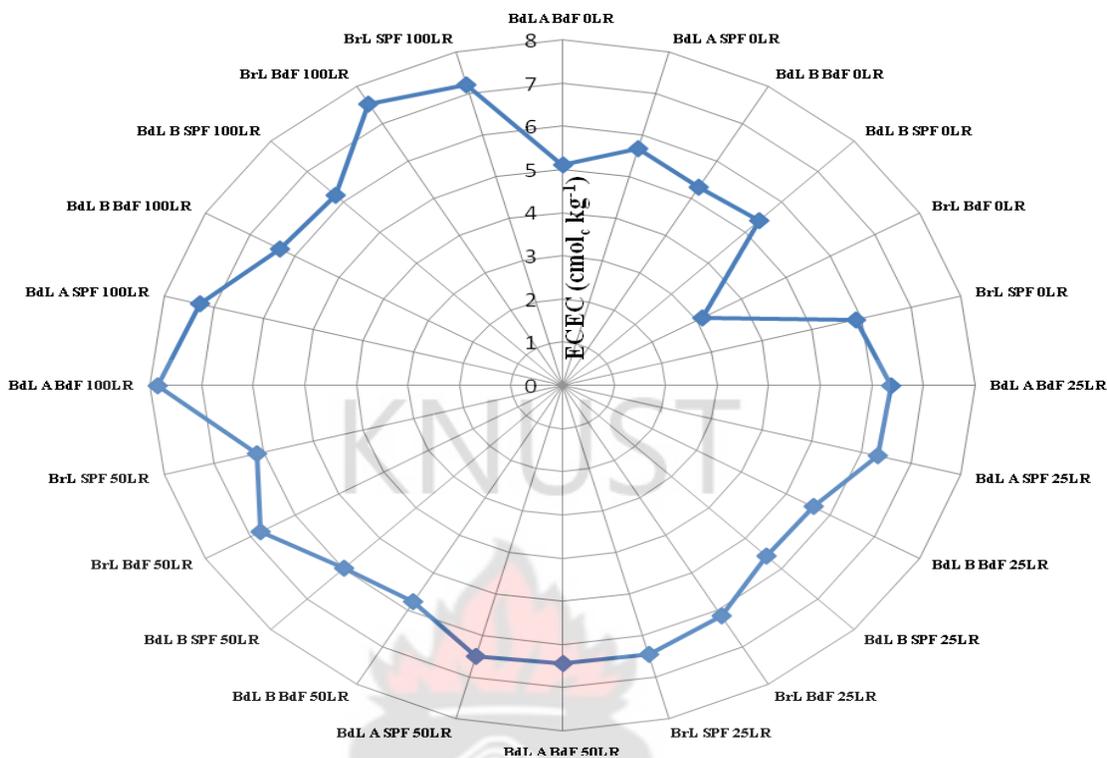


Figure 4.25: Interactive effect of lime and fertilizer on soil ECEC (2013) Lsd (0.05)= 1.08 (BrL: lime broadcasting, BdL: lime banding, BdF: Fertilizer banding, SPF: Fertilizer spot application, LR: Lime requirement, A: on ridge, B: between ridge)

4.3.1.1.7 Effect of lime and fertilizer on soil organic carbon

Lime application (method and rate) did not significantly ($P > 0.05$) affect soil organic carbon as compared to control in both growing seasons as shown in Tables 4.21 and 4.22. The spot application of fertilizer significantly ($P < 0.05$) decreased SOC by 33 % as compared to banding in 2012. Conversely it had no significant effect on SOC in 2013. Banding of lime did not significantly ($P > 0.05$) affect SOC in both growing seasons. The interaction between lime method, fertilizer method application and lime rate was not significant in two growing seasons.

4.3.1.1 .8 Effect of lime and fertilizer on available P

Application of lime significantly ($P < 0.05$) increased soil available P over the control in 2012 but not in 2013 (Tables 4.21 and 4.22). The application of lime in 2012 led to increases in soil available P in the order of 85, 53 and 326 % by the addition of 25, 50 and 100 % of LR respectively. The increase in soil available P was proportional to the increases of lime rate applied. The spot application of fertilizer decreased soil available P in 2012 but not in 2013. The banding of lime reduced significantly soil available P in 2013 as compared to broadcasting. There was significant interaction between lime methods, fertilizer method and lime rate in 2013 but not in 2012. The available P ranged from P 6.6 to 14.07 mg kg⁻¹ for banding of lime + banding of fertilizer and 50 % LR and broadcasting of lime + fertilizer banding and 50 % LR as illustrated in Figure 4.26.

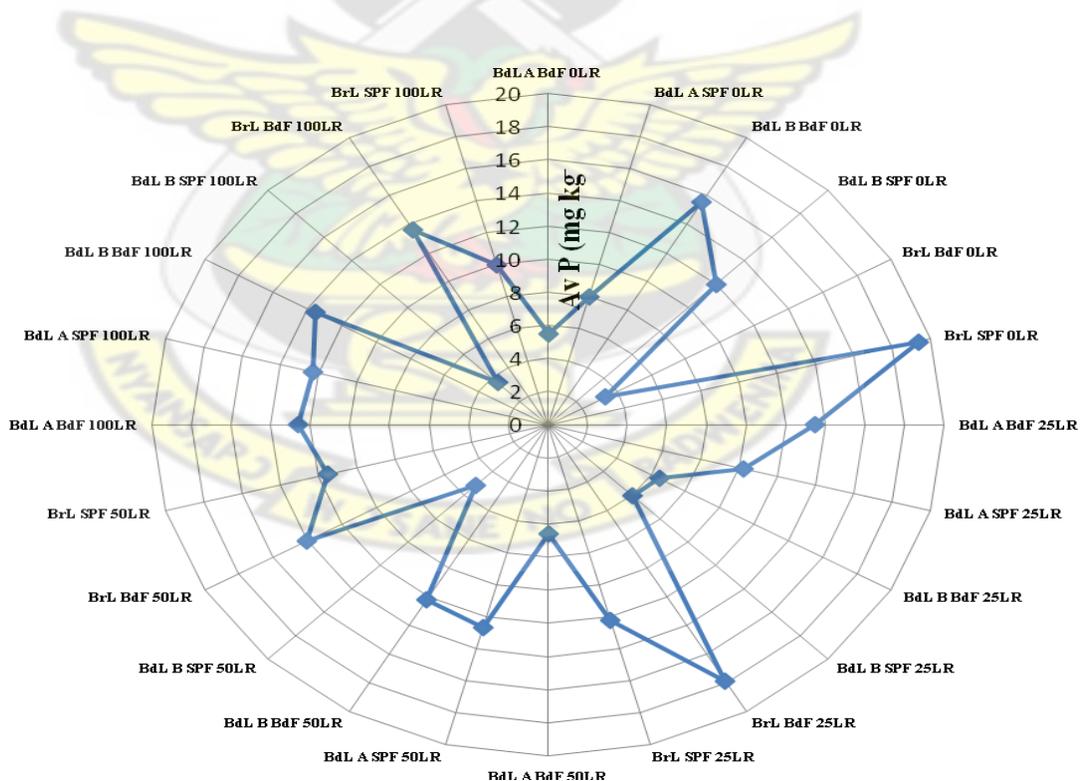


Figure 4.26: Interactive effect of lime and fertilizer on soil available P (2013) Lsd (0.05)= 2.19 (BrL: lime broadcasting, BdL: lime banding, BdF: Fertilizer banding, SPF: Fertilizer spot application, LR: Lime requirement, A: on ridge, B: between ridge)

4.3.1.2 Effect of lime and fertilizer on maize grow parameters

4.3.1.2.1 Effect of lime and fertilizer on maize height

The Table 4.23 showed the effect of lime (method and rate application) and fertilizer (method application) on maize height. The banding of lime increased slightly maize height in 2013 but this increase was not statistically significant ($P > 0.05$). The spot application of fertilizer significantly ($P > 0.05$) increased maize height by 3 % in 2012 and 5 % in 2013 over the banding. The addition of lime increased maize height over the control but the difference between lime rates was not significant. The increases were 4, 5 and 8 % in 2012 by the application of 25, 50 and 100 % of LR respectively. The corresponding figures were 5 % for all rates in 2013. The interaction between lime methods, fertilizer method and lime rate application was not significant in both growing seasons.

4.3.1.2.2 Effect of lime and fertilizer on maize stem girth

The Table 4.23 showed the effect of lime (method and rate of application) and fertilizer (method application) on maize stem girth. Lime did not increase significantly ($P > 0.05$) maize stem girth over the control in 2012. Conversely in 2013, lime increased stem girth by 9 and 7 % with the application of 25, 50 or 100 % of LR respectively. The application of 25 % of LR was the most effective in increasing stem girth. Despite the slight increase, the banding of lime did not increase significantly maize stem girth in the two seasons as compared to the broadcasting. The spot application of fertilizer did not significantly affect maize stem girth over the banding in both two seasons. The interactions between lime methods, fertilizer method and lime rate were not significant for both growing seasons.

Table 4.23: Effect of lime and fertilizer on maize growth

Growth parameters	2012 Growing season		2013 Growing season	
	Height (m)	Girth (mm)	Height (m)	Girth (mm)
Lime application method				
Broadcasting	2.47	20.40	2.53	23.85
Banding	2.47	20.80	2.39	22.37
F.pr	0.80	0.70	0.13	0.20
Lsd (0.05)	0.12	5.09	0.25	3.58
Fertiliser application method				
Banding	2.44	20.29	2.40	23.45
Spot. App	2.50	21.31	2.51	22.76
F.pr	0.008	0.20	0.03	0.30
Lsd (0.05)	0.03	0.83	0.09	1.63
Lime rate (%Lime requirement)				
0	2.37	20.74	2.37	21.85
25	2.47	20.42	2.48	23.83
50	2.48	19.9	2.49	23.41
100	2.55	21.35	2.49	23.35
F.pr	0.01	0.30	0.05	0.04
Lsd (0.05)	0.09	1.58	0.10	1.40
Interaction				
F.pr (LM*FM*Lr)	0.40	0.11	0.44	0.09
Lsd (0.05)	0.18	4.05	0.23	3.29
CV (%)	4.7	9.2	5.0	7.2

LM: lime application method, Lr: lime rate, FM: fertilizer application method, banding A: on ridge, banding B: between ridge, Spot. App: spot application of fertilizer.

4.3.1.3 Effect of lime and fertilizer on maize yields

4.3.1.3.1 Effect of lime and fertilizer on maize biological yield

The Table 4.24 shows the effect of lime (method and rate of application) and fertilizer (method of application) on maize biomass yield. Despite an increase (1701 kg ha⁻¹) the banding of lime did not significantly ($P > 0.05$) improve maize biomass yield in two seasons. Conversely the spot application of fertilizer led to increases maize biomass yield by 13 % in 2012 and 28 % in 2013 over the banding. The improving of maize biomass yield following the addition of lime was 28, 18 and 34 % in 2012 for 25, 50 and 100 % of LR respectively. The corresponding figures were 26, 36 and 67 % in 2013. The interactions between lime methods, fertilizer method and lime rates were not significant in both seasons.

4.3.1.3.2 Effect of lime and fertilizer on maize grain yield

The Table 4.24 shows the effect of lime (method and rate of application) and fertilizer (method of application) on maize grain yield. In general the grain yields produced in 2013 were higher as compared to 2012 for each factor. There was a slightly increase (229-370 kg ha⁻¹) of maize grain yield with banding of lime but this increase was not significant ($P > 0.05$) statistically in both growing seasons. Maize yield was not significantly affected by the spot application of fertilizer in 2012. Despite the wilting of some maize shoots during the temporary water stress, the spot application of fertilizer significantly increased maize grain yield by 32 % as compared to the banding only in 2013. Lime application increased maize yield by 22, 25 and 35 %, in 2012 following the application of 25, 50 and 100% respectively. The corresponding figures in 2013 were

22, 25 and 40 %. Indeed the higher yield was obtained with the full rate of LR in the two seasons.

The Fig 4.27 shows the combined effect of lime method, fertilizer method and lime rate application on maize grain yields for two growing seasons. The grain yield of combined application ranged from 2063 kg ha⁻¹ to 4236 kg ha⁻¹ in 2013. The lowest yield was obtained with the combination of lime broadcasting + fertilizer banding + 25%LR while the combination of lime broadcasting + spot application of fertilizer + 100 % LR gave the highest grain yield in 2013. The grain yield ranged from 2500 kg ha⁻¹ to 3507 kg ha⁻¹ in 2012 and the highest was obtained with lime banding + fertilizer spot application + 100 % of LR despite the no significant interaction among lime methods, fertilizer method and lime rate application (Figure 4.27).

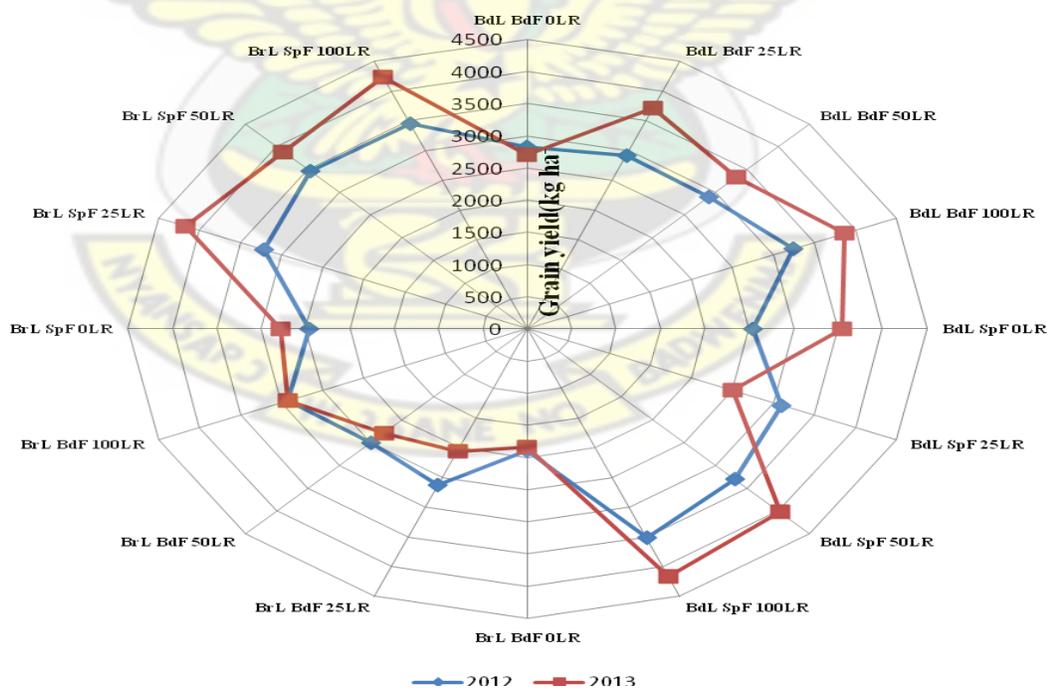


Figure 4.27: Combined effect of lime method, fertilizer method and lime rate on maize yield (BrL: lime broadcasting, BdL: lime banding, BdF: Fertilizer banding, SPF: Fertilizer spot application, LR. Lime requirement)

Table 4.24: Effect of lime and fertilizer on maize yields

Yield parameters	2012 Growing season		2013 Growing season	
	Grain yield kg ha ⁻¹	Biomass kg ha ⁻¹	Grain yield kg ha ⁻¹	Biomass kg ha ⁻¹
Lime application method				
Broadcasting	2815	7078	3113	6643
Banding	3044	7375	3483	8344
F.pr	0.36	0.68	0.39	0.18
Lsd (0.05)	845.1	1763.4	1421.9	1889.4
Fertilizer application method				
Banding	2729	6802	2841	6575
Spot. App	3130	7651	3754	8411
F.pr	0.09	0.20	0.01	0.04
Lsd (0.05)	510.7	1094.4	504.3	639.5
Lime rate (% of Lime requirement)				
0	2432	6031	2715	5667
25	2964	7719	3292	7146
50	3040	7083	3385	7713
100	3283	8073	3799	9448
F.pr	0.001	0.01	<0.001	<0.001
Lsd (0.05)	391.6	1255.1	419.9	1115.1
Interaction				
F.pr (LM*FM*Lr)	0.88	0.79	<0.001	0.37
Lsd (0.05)	882.1	2374.4	1145.2	2183.2
CV (%)	15.9	20.6	15.1	15.1

LM: lime application method, Lr: lime rate, FM: fertilizer application method, banding A: on ridge, banding B: between ridge, Spot. App: spot application of fertilizer.

4.3.1.4 Correlation between maize yield, biomass yield plant growth parameter and some soil factors after harvesting

Table 4.25: Relationship between maize growth, yield parameters and soil factors

Soil factors	Grain yield		Biomass yield		Stem girth		Plant height	
	2012	2013	2012	2013	2012	2013	2012	2013
pH (1:1,H ₂ O)	0.58 ^{***}	0.33 [*]	0.28 ^{NS}	0.25 ^{NS}	0.10 ^{NS}	0.27 ^{NS}	0.35 ^{**}	0.17 ^{NS}
T. N	0.11 ^{NS}	0.34 ^{NS}	0.01 ^{NS}	0.04 ^{NS}	0.07 ^{NS}	0.11 ^{NS}	0.20 ^{NS}	0.02 ^{NS}
Av. P	0.27 ^{NS}	0.07 ^{NS}	0.14 ^{NS}	0.07 ^{NS}	0.1 ^{NS}	0.06 ^{NS}	0.34 [*]	0.18 ^{NS}
Exch. K	0.21 ^{NS}	0.06 ^{NS}	0.18 ^{NS}	0.17 ^{NS}	0.01 ^{NS}	0.06 ^{NS}	0.06 ^{NS}	0.05 ^{NS}
Exch. aci	-0.45 ^{**}	-0.46 ^{***}	-0.41 ^{**}	-0.35 [*]	-0.57 [*]	-0.32 [*]	-0.55 ^{***}	-0.25 ^{**}
Exch.Ca	0.26 ^{NS}	0.46 ^{***}	0.30 [*]	0.43 ^{**}	0.14 ^{NS}	0.40 ^{**}	0.20 ^{NS}	0.16 ^{NS}
Exch.Mg	0.48 ^{NS}	0.50 ^{NS}	0.44 [*]	0.28 [*]	0.31 [*]	0.19 ^{NS}	0.54 ^{***}	0.29 [*]

NS: not significant, * significant at P<0.05, ** significant at P<0.01 and ***significant at P<0.001

Table 4.25 shows the relation between grain yield, biomass and selected plant parameters and some key factors of acid soil. The soil pH was positively correlated while the exchangeable acidity was negatively correlated to grain yield in both growing seasons. Conversely, soil total N, available P, exchangeable Ca, Mg and K were not significantly correlated to grain yield in both seasons. The biomass yield was negatively correlated to soil exchangeable acidity meanwhile it was positively correlated to soil exchangeable Ca and Mg for both seasons. Lastly, there was no significant correlation between biomass produced and soil pH, total N, available P and exchangeable K in both seasons. A multiple regression function describing the relationship between grain yield and soil factors is indicated by Equations 4.7 and 4.8. Exchangeable acidity decreased the grain yield in both seasons. Conversely the grain yield was increased by soil pH in

2012 and exchangeable Ca in 2013 as illustrated in Tables 4.26 and 4.27 and Equations 4.7 and 4.8.

Soil exchangeable acidity was negatively correlated to maize height in both growing seasons. Soil pH, available P and exchangeable Mg were positively correlated in 2012 while only soil exchangeable Mg was positively correlated to maize height in 2013. The soil exchangeable acidity was negatively correlated to plant stem diameter in both growing season. Soil pH, total N, available P and exchangeable K were no significantly correlated to maize stem girth for both seasons. The exchangeable Mg was positively correlated in 2012 while the Ca was positively correlated in 2013.

Table 4.26: Multiple regression of Grain yield with soils factors (2012)

Soil factors	Coefficients	Standard Error	Significance
Constant	2038.97	968.46	0.07
pH (1:1, H ₂ O)	385.06	155.73	0.04
OC	681.17	1107.94	0.55
Av. P	-11.30	4.97	0.57
T.N	8174.28	11339.83	0.49
Exch. ac	-4334.38	1216.22	0.009
Exch. Ca	119.39	105.48	0.29
Exch. Mg	273.54	487.91	0.59
Exch. K	-7316.86	2686.66	0.29

$$\text{Grain yield} = -4334.38 (\pm 1216.22) \text{ exch.ac} + 385.06 (\pm 155.73) \text{ pH}$$

Equation 4.7

$$(R^2=0.92, P=0.002)$$

Table 4.27: Multiple regression of Grain yield with soils factors (2013)

Soil factors	Coefficients	Standard Error	Significance
Constant	1123.34	2030.15	0.58
pH(1 :1, H ₂ O)	297.37	352.656	0.40
OC	-1855.26	1745.83	0.29
Av. P	-65.72	33.77	0.05
T.N	56944.36	17961.16	0.20
Exch. ac	-4421.70	2276.94	0.05
Exch. Ca	340.80	160.51	0.04
Exch. Mg	-491.63	403.87	0.23
Exch. K	-321.32	2687.18	0.90

Grain yield= + 340.80(±160.51) exch.Ca -4421.70(±2276.94) Exch.ac

Equation 4.8

(R²=0.46, P=0.002)

4.3.1.5 Mineral concentration of maize straw as affected by lime and fertilizer

The Tables 4.28 and 4.29 show the straw concentration of selected nutrients related to acid soil infertility. The concentration of nutrients was much higher in 2013 than 2012. Significant differences were observed in N, P, K, Ca, Mg concentrations of maize straw after addition of lime and fertilizer over the control. N concentration of maize straw ranged from 0.57 to 0.82 % in 2012 and from 0.78 to 1.6 % in 2013. The banding of lime had no significant effect on N uptake for both seasons. The spot application of fertilizer was not significant different from banding in 2012 meanwhile it increased the N uptake by 21 % in 2013. Liming increased significantly N uptake by 28, 30 and 44 % in 2012 by the application of 25, 50 and 100 % of LR respectively. The corresponding

figures in 2013 were 32, 47 and 105 % in 2013. The interactions were significant between lime methods, fertilizer method and lime rate application in 2013. The lowest concentration in N was obtained by the combined application of lime broadcasting with fertiliser banding and 25 % LR (0.84 %) and the highest with lime broadcasting with fertiliser spot application and 100 % LR (1.81 %) as illustrated in (Figure 4.28).

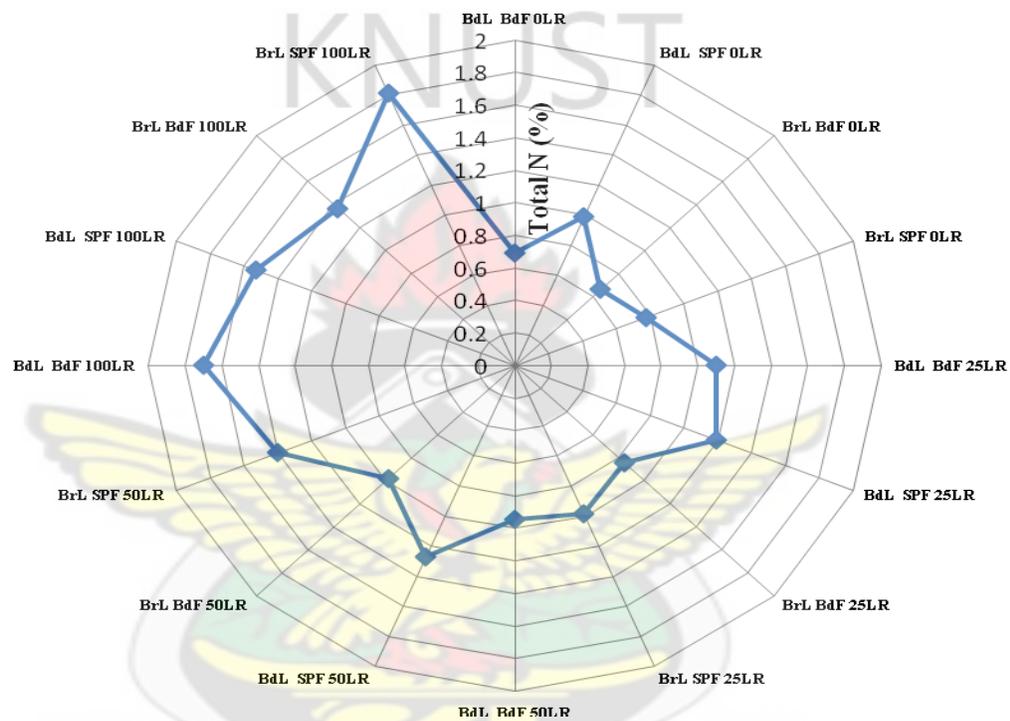


Figure 4.28: Interactive effect of lime and fertilizer on straw N (2013) Lsd(0.05)=0.27 (BrL: lime broadcasting, BdL: lime banding, BdF: Fertilizer banding, SPF: Fertilizer spot application, LR: Lime requirement)

The concentration of P straw ranged from 0.77 to 1.88 % (2012) and from 1.09 to 1.97 % (2013). The banding of lime had no significant effect on P uptake in both seasons. The spot application of fertilizer did not significantly affect P uptake in 2012. On the other spot application of fertilizer increased P uptake by 12 % in 2013 over the banding. Lime significantly increased P uptake over the control by 122, 125 and 144 % (2012) as compared to 16, 47 and 81 % (2013) with the application of 25, 50 and 100 % of LR

respectively. The interaction between lime methods, fertilizer method and lime rate application was significant only in 2013. The lowest concentration in P was provided by the combined application of lime broadcasting with fertiliser banding and 25 % LR (0.95 %) while the highest with lime banding with fertiliser spot application and 100 %LR (2.18 %) as illustrated in (Figure 4.29).

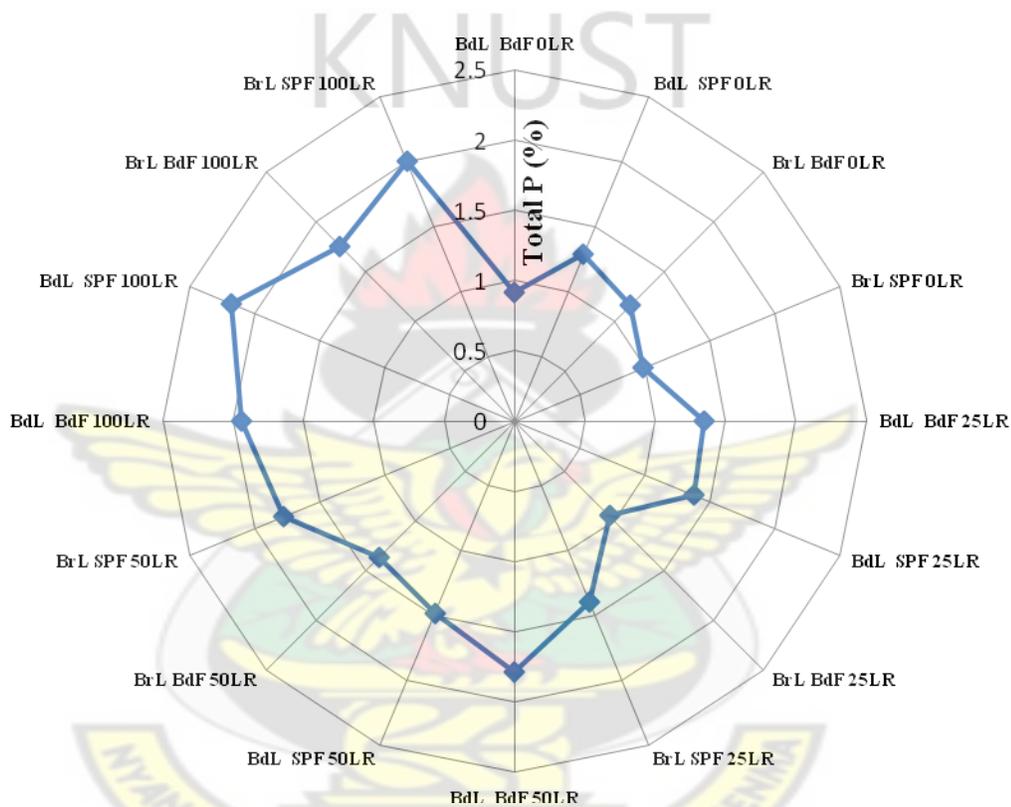


Figure 4.29: Interactive effect of lime and fertilizer on straw P (2013) Lsd(0.05)=0.41 (BrL: lime broadcasting, BdL: lime banding, BdF: Fertilizer banding, SPF: Fertilizer spot application, LR. Lime requirement)

The concentration of K in maize straw ranged from 0.54 to 1.9 % (2012) and from 0.89 to 2.01 % (2013). The banding of lime had no significant effect on K uptake in both seasons. The spot application of fertilizer did not affect significantly K uptake in both seasons. On the other lime application increased significantly K uptake in both seasons

as compared to control. The improvements of K uptake following lime application were 98, 117 and 252 % (2012) as compared to 41, 96 and 129 % (2013) by the application of 25, 50 and 100 % of LR respectively. There was no significant interaction between lime methods, fertilizer method and lime rate application in both seasons.

The concentration of Ca straw ranged from 0.04 to 0.12 % (2012) and from 0.12 to 0.42 % (2013). The banding of lime had no significant effect on Ca uptake in 2012 meanwhile it was increase by 15 % in 2013 compared to broadcasting. The spot application of fertilizer did not significantly affect Ca uptake in both seasons. As expected, lime application increased significantly Ca uptake relative to control by 125, 175 and 200 % in 2012 by the application of 25, 50 and 100 % of LR respectively. The corresponding figures in 2013 were 117, 176 and 250 %. The interaction between lime methods, fertilizer method and lime rate application was significant only in 2013. The combined application of lime broadcasting with fertilizer spot application and 25 % LR gave the lowest concentration in Ca (0.25 %) while the highest was provided by lime banding with fertilizer spot application and 100 % LR (0.47 %) as shown in Figure 4.30.

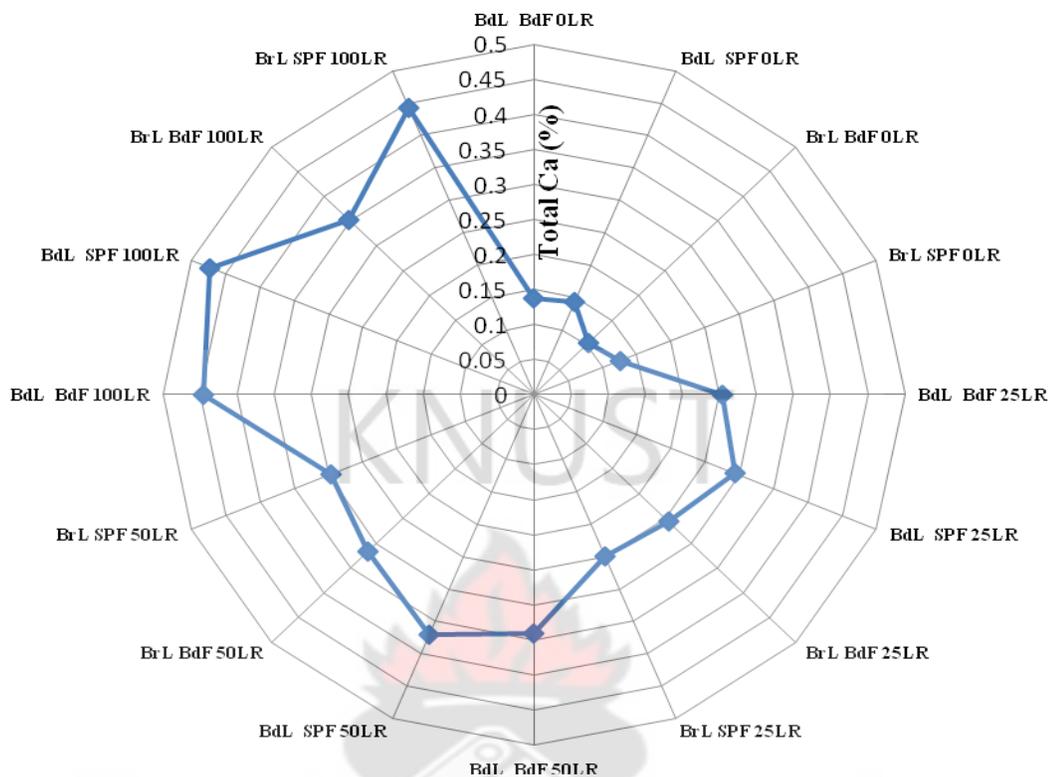


Figure 4.30: Interactive effect of lime and fertilizer on straw Ca (2013) Lsd(0.05)=0.04 (BrL: lime broadcasting, BdL: lime banding, BdF: Fertilizer banding, SPF: Fertilizer spot application, LR: Lime requirement)

The concentration of Mg in maize straw ranged from 0.09 to 0.16 % (2012) and from 0.34 to 1.47 % (2013). The precision application of lime had no significant effect on Mg uptake in 2012, but in 2013 it was increased by 26 % as compared to broadcasting. The spot application of fertilizer had no effect on Mg uptake in both seasons. Lime application increased significantly Mg uptake over the control by 78, 67 and 78 % (2012) as compared to 94, 147 and 332 % (2013) with the application of 25, 50 and 100 % of LR respectively. The interaction between lime methods, fertilizer method and lime rate application was significant in 2013 not in 2012. The combined application of lime broadcasting with fertilizer banding and 25 % LR provided the lowest content in Mg

(0.56 %) while the highest was measured by lime banding with fertilizer spot application and 100 %LR (1.77 %) as shown in Figure 4.31.

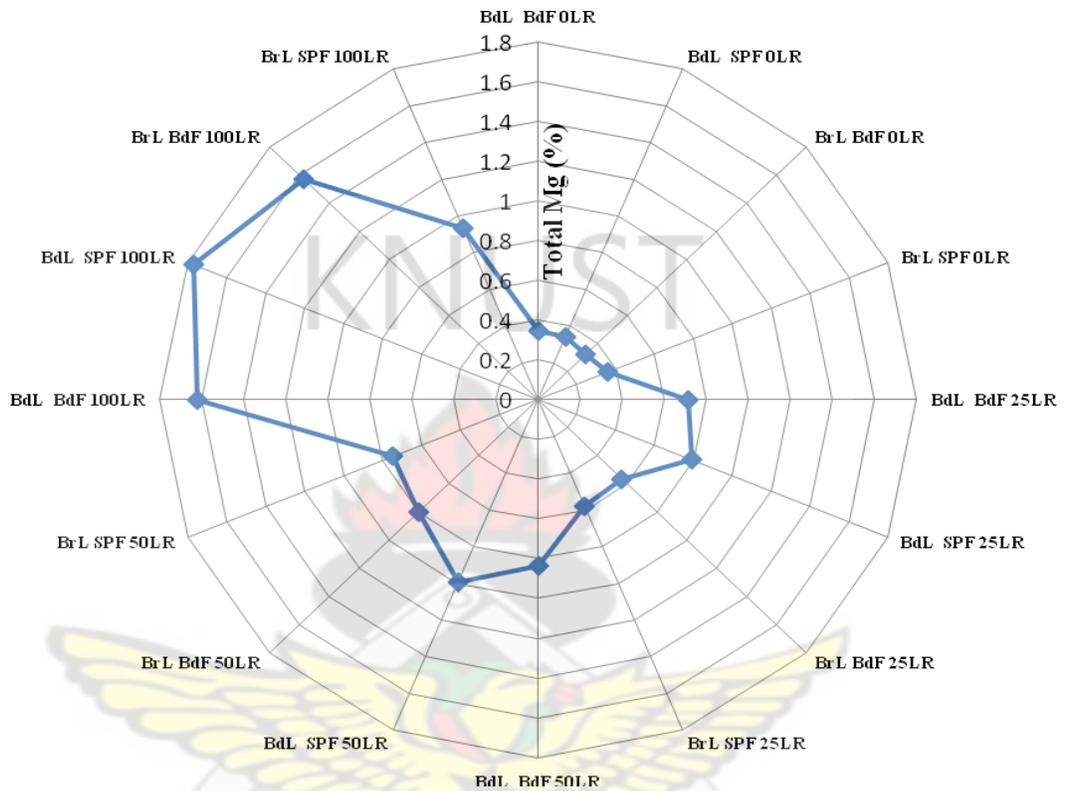


Figure 4.31: Interactive effect of lime and fertilizer on straw Mg (2013) Lsd(0.05)=0.11 (BrL: lime broadcasting, BdL: lime banding, BdF: Fertilizer banding, SPF: Fertilizer spot application, LR. Lime requirement)

Table 4.28: Selected chemical composition of maize straw as affected by lime and fertilizer (2012)

Parameters	Total N	Total P	Total K	Total Ca	Total Mg
-----%-----					
Lime application method					
Broadcasting	0.71	1.51	0.99	0.08	0.14
Banding	0.72	1.50	0.99	0.10	0.14
F.pr	0.65	0.43	0.90	0.09	0.66
Lsd (0.05)	0.10	0.15	0.46	0.02	0.02
Fertilizer application method					
Banding	0.71	1.50	0.94	0.09	0.14
Spot. App	0.73	1.54	1.05	0.09	0.14
F.pr	0.36	0.57	0.12	0.60	0.74
Lsd (0.05)	0.08	0.17	0.16	0.01	0.02
Lime rate (% of LR)					
0	0.57	0.77	0.54	0.04	0.09
25	0.73	1.71	1.07	0.09	0.16
50	0.74	1.73	1.17	0.11	0.15
100	0.82	1.88	1.90	0.12	0.16
F.pr	<0.001	<0.001	<0.001	<0.001	<0.001
Lsd(0.05)	0.08	0.17	0.24	0.01	0.02
Interaction					
F.pr	0.57	0.64	0.99	0.46	0.12
(LM*FM*Lr)					
CV (%)	14.0	14.0	28.7	18.1	20.1

LM: lime application method, LR: lime rate, FM: fertilizer application method, banding A: on ridge, banding B: between ridge, Spot. App: spot application of fertilizer.

Table 4.29: Selected chemical composition of maize straw as affected by lime and fertilizer (2013)

Parameters	Total N	Total P	Total K	Total Ca	Total Mg
-----%-----					
Lime application method					
Broadcasting	1.17	0.15	1.51	0.26	0.73
Banding	1.10	0.14	1.40	0.30	0.92
F.pr	0.22	0.17	0.06	0.001	0.008
Lsd (0.05)	0.17	0.23	0.12	0.006	0.07
Fertilizer application method					
Banding	1.03	1.40	1.47	0.27	0.84
Spot. App	1.24	1.56	1.45	0.29	0.81
F.pr	0.01	0.01	0.48	0.05	0.12
Lsd (0.05)	0.13	0.10	0.06	0.02	0.04
Lime rate (% of LR)					
0	0.78	1.09	0.88	0.12	0.34
25	1.03	1.26	1.24	0.26	0.66
50	1.15	1.60	1.72	0.33	0.84
100	1.6	1.97	2.01	0.42	1.47
F.pr	<0.001	<0.001	<0.001	<0.001	<0.001
Lsd (0.05)	0.14	0.22	0.05	0.20	0.09
Interaction					
F.pr	0.05	0.04	0.16	0.05	0.007
(LM*FM*Lr)					
CV (%)	15.1	18.2	4.6	6.0	13.1

LM: lime application method, LR: lime rate, FM: fertilizer application method, banding A: on ridge, banding B: between ridge, Spot. App: spot application of fertilizer.

4.3.1.6 Financial profitability of the application lime and fertilizer

The Tables 4.30 and 4.31 presented the results of financial analysis of lime (method and rate of application) and fertilizer (method of application) on maize. Lime banding had the highest net benefit compared to broadcasting and the margins were 57250F CFA in 2012 and 92500F CFA 2013. The net benefit for spot application of fertilizer was higher than the banding and the margins were 92750 F CFA in 2012 and 220750 F CFA in 2013. A comparison of lime rate average showed that the application of 25% of lime requirement had the highest net benefit (675250-757250F CFA) followed by 50% of LR (628500- 714750F CFA) and the 100% of LR (557750-671750F CFA) in both growing seasons. It is worth nothing that 25 % and 50 % of LR had higher net benefit relative to control while the 100 % of LR was dominated by the control for the two seasons.

The best treatment was broadcasting of lime with spot application of fertilizer and 25 % of lime requirement with the cumulative net benefits of 722750F CFA for the first season and 962500 F CFA for the second (Table 4.31). The lowest cumulative net benefits were obtained with Broadcasting of lime + banding of fertilizer + 100 % of LR in 2012 (458750F CFA) and broadcasting of lime + banding of fertilizer + 50 % of LR in 2013 (434000F CFA).

Table 4.30: Profitability of lime and fertilizer use on maize

Particulars	Variable Cost	Net Benefit (CFA)	
	(CFA)	2012	2013
Lime application method			
Broadcasting	0	703750	778250
Banding	0	761000	870750
Fertilizer application method			
Banding	7500	674750	702750
spot application	15000	767500	923500
Lime rate (% of LR)			
0	0	608000	678750
25	66750	675250	757250
50	131500	628500	714750
100	263000	557750	671750

Table 4.31: Financial analysis of the combination of lime method, fertilizer method of application and lime rate on maize

Treatments			Variable Cost	Net Benefit (CFA)	
Lime method	Fertilizer method	Lime rate (% LR)	(CFA)	2012	2013
		0	7500	700750	669500
	Banding	25	73250	656000	853750
		50	139000	585000	694250
Banding		100	270500	542000	698250
	Spot	0	13500	622000	872000
	applicatio	25	79250	697000	545750
	n	50	145000	681500	862000
		100	276500	600250	765250
		0	7500	466500	450750
	Banding	25	73250	583000	442500
Broadcastin		50	139000	486000	434000
g		100	270500	458750	458750
	Spot	0	13500	601000	681000
	applicatio	25	79250	722750	962500
	n	50	145000	719500	827250
		100	276500	588000	782500

4.3.2 Discussion

4.3.2.1 Effect of lime and fertilizer on selected soil properties

4.3.2.1.1 Effect of lime and fertilizer on soil pH and exchangeable acidity

The increase in soil pH following liming is due mainly to the improvement of base saturation in soil solution which is higher at higher rate of application. The dissolution of dolomite lime released basic cations which increased soil base saturation and then soil pH (Hue *et al.*, 1998, Opala, 2007, Andric *et al.*, 2012). The dilution of lime with higher volume of soil during ridging may explain the limited effect of lime banding on soil pH compared to broadcasting and then avoids the over liming which was threatened. The lack of effect of the spot application of mineral fertilizer on soil pH may be attributable to inability of spot application to change soil base saturation. These results contrast with the findings of Weligama *et al.* (2008) who reported an increase of soil pH by 0.4 (top layers) and 0.5 (sub layers) units in rhizosphere compared to bulk soil after the localized supply of N and P at crop root zone. This pH rise was attributed to the greater root growth and greater biomass production leading to greater nitrate uptake by plant from that rhizosphere (Poss *et al.*, 1995; Tang *et al.*, 1999; Weligama *et al.*, 2008). The removal of basic cations by crop harvesting (Smaling and Baun, 1996) and the acidity generated by the oxidation of S and N to SO_4^{2-} and NO_3^- (Summer *et al.*, 1991; Qin and Chen, 2005) may be responsible to lowest pH of broadcasting with banding and 50 %. However the increase in base saturation following the addition of 100 % of LR explains the high pH measured with Banding of lime + spot application of fertiliser +100 % LR.

The decreases in soil exchangeable acidity observed with lime soil relative to control is attributable to the much higher ability of lime to increase the pH of soil. The increases in soil pH lead to the precipitation of soluble Al (Noble, 1996; Pocknee and Sumner, 1997; Illera *et al.*, 2004). The decreases in exchangeable acidity are concomitant to the increase in soil pH. The non effect of lime banding and the spot application of fertilizer on soil pH may explain their non effect on soil exchangeable acidity as compared to lime broadcasting and banding of fertilizer. The optimum pH for maize growth ranges from 5.5 to 7.0 (Lidon and Barreiro, 2002) so the pH level for lime amended soil (5.11-5.96) was adequate for 50 % and 100 % of LR.

4.3.2.1.2 Effect of lime and fertilizer on soil exchangeable basic cations and ECEC

The higher content of limestone in Ca (36.7 %) and Mg (11.2 %) is mainly responsible of the increased soil content in exchangeable basic cations and consequently soil ECEC. The dissolution of limestone releases basic cations contains in lime and contributes to increase the soil basic concentration and ECEC. However, the improving of soil K in 2012 may be due to the mobility of K labile as the consequent of soil pH base saturation increasing. The accumulation of exchangeable base during the two years of experimentation explains the higher content in base content observed in 2013 as compared to 2012. Several other workers had reported significant increase in soil base cations by the application of lime (Doumbia *et al.*, 1998; Naramabye, 2004; Opala *et al.*, 2007; Andric *et al.*, 2012). The low levels in exchangeable Ca and Mg, and ECEC observed with treatments of 0 % of LR are attributable to non-addition of lime and the uptake of these exchangeable cations by the crop. Conversely those of combination including lime broadcasting and 50 % of LR are not clear and could not be explained by

crop uptake. However the highest content in soil exchangeable Ca, Mg and ECEC observed with combination including 100% of LR is attributable to the greater content in Ca and Mg of the added lime.

Manson *et al.* (1993) noted that the optimal levels of K, Ca, Mg and ECEC for cereals production are (0.22-0.33 cmol_c kg⁻¹), (2-6 cmol kg⁻¹), (0.68-1.02 cmol_c kg⁻¹) and (12-40 cmol_c kg⁻¹) respectively. However, the soil levels of this study were (0.16-0.20 cmol_c kg⁻¹), (1.62-4.99 cmol_c kg⁻¹), (0.47-0.52 cmol_c kg⁻¹), (1.06-1.52 cmol_c kg⁻¹) and (3.27-7.06 cmol_c kg⁻¹) respectively for K, Ca, Mg and ECEC. It infers that K and ECEC are low for both seasons. Whereas Ca was adequate for both seasons and Mg was only adequate for 2013.

4.3.2.1.3 Effect of lime and fertilizer on soil carbon and available P

The very low content of limestone in organic carbon and phosphorus explain mainly its non effect on soil organic carbon and available phosphorus content (Curtin and Syers, 2001; Opala, 2011). Despite the application of nitrogen fertilizer the C level did not decrease. This suggests that the without C input, mineralisation did not go beyond the *steady state condition* (David, 2004). The increases in soil available P in 2012 may be due to the high mobility of the labile P as the consequent of the abrupt soil pH raising (Opala, 2011). These results are in consonance with those reported by other workers (Andric *et al.*, 2012; Kisinyo, 2011) who observed an increase in soil available P after liming. On the other hand the decreased of available P observed in 2013 may be attributable to the high uptake by crop (Weligama *et al.*, 2008). The contrasting higher P measured for the combination of lime broadcasting with spot application of fertiliser and

OLR in 2013 can be due partly to the accumulation of P applied (Tisdal *et al.*, 1990). The optimal level for cereal production of extractable P ranges (15-25 mg kg⁻¹) (Manson *et al.*, 1993), so soil level of P (9-27 mg kg⁻¹) was low in both seasons.

4.3.2.2 Effect of lime and fertilizer on selected maize grow parameters

The spot application of fertilizer improves maize growth (stem height and girth) by increasing the nutrients availability and use efficiency. The placement of fertilizer at the root zone increases the roots growth (Robinson *et al.*, 1994; Bagayoko *et al.*, 2000) that improves greatly nutrients and water uptake (Weligama *et al.*, 2008) leading to increase height and stem girth. The results relative to maize height growth are consistent with the findings reported by Weligama *et al.* (2008). The Toukoto lime ameliorates the availability and uptake of nutrient via pH raising that increases maize height and stem girth (Onwuka *et al.*, 2009).

4.3.2.3 Effect of lime and fertilizer on maize yield

The effect of lime and fertilizer on maize biomass followed the same trend as grain the explanations for trend are almost the similar. The performance of the control may be due to the relative tolerance of the cultivar to Al toxicities and associated factors and the mechanisms involved were well discussed in section 4.1.2.2. The high grain yield obtained in 2013 compared to 2012 is attributable to the temporary inhibition of nutrients uptake and the residual additive effects of lime and mineral fertilizer as illustrated in Tables 4.21, 4.22, 4.28, 4.29 and discussed in section 4.2.2.4. Lime increased soil pH while reducing Al toxicity and consequently improved the availability and the uptake of nutrients by maize. The strong correlation between grain yield and soil

pH, soil exchangeable acidity, soil Ca ($R^2= 0.92$ and 0.44) indicates that these factors contributed more to improve maize yields. Moreover, this indicates clearly that soil acidity (Al toxicity); exchangeable Ca and Mg were the most limiting factors to crop production in this acid Oxisol (Shen *et al.*, 1993; Bessho and Bell, 1992; Yu and Qin, 1998). The poor correlation between available P, exchangeable K and grain yield indicates that this nutrient was not limiting in soil (Manson *et al.*, 1993). The effect of the soil pH increasing and the soil acidity decreasing on maize yield is discussed in section 4.2.2.4. However, the pH contributed more to grain yield in 2012 (Equation 4.7). This may be explained by the abrupt increase of soil pH in 2012 which reduced aluminium toxicity and improved plant nutrient uptake (Opala, 2011). Dolomite lime provides also Ca and Mg which are deficient in this acid soil. The nutrients status of a plant is mainly responsible for yield (Andric *et al.*, 2012). Lime increases maize yield in both growing seasons by improving maize nutrients uptake and fertilizer use efficiency (Mead *et al.*, 2000). These findings are in agreement with those reported by many workers such Dunn and Stevens (2005); Mengel *et al.* (2001) who proved that lime application results in better soil by improving soil bacterial activity, soil moisture content and reducing soil acidity leading to improve maize yield. According to Andric *et al.* (2012), the application of lime had increased maize grain yield up to 35 %. The lack of significant difference between spot and band application of fertilizer may be attributable to the inhibition of nutrients uptake. These results are similar to those reported by Okalebo *et al.* (1990), Opala *et al.* (2007) who observed no significant increase of yield attributable to spot application of fertilizer. Moreover, some studies showed the superiority of fertilizer banding on maize yield compared to spot application

(Mashingaidze *et al.*, 2012). Conversely, the superiority in yield of spot application compared to banding observed in 2013 may be due to the enhancing of the use efficiency of mineral fertilizer (N and, P) by placing the nutrients in positions where roots contact is most likely. This increases greatly roots growth (mass, number of tips) and proliferation leading to the improvement of nutrients and water uptake by efficient exploration of soil resources (Hue *et al.*, 2003; Hodge, 2004; Weligama *et al.*, 2008). Indeed, the urea was applied at 3 fractions (50-50-50kg) rather the 2 recommended (50-100 kg) and this may reduce the losses of nitrogen and increase the use efficiency of nitrogen and thus other nutrients. Van Beusichen *et al.* (1998) reported that plant N uptake can be responsible for 70 % of total ions uptake by a plant. Other agronomic studies in Africa indicate consistent superiority of spot application compared to banding of mineral fertilizer (Buresh *et al.*, 1997; Fox and Kang, 1978). However the particularly of this study is that the additional mineral fertilizer (urea) was applied with the same method like the homestead fertilizer (DAP). The high concentration of the fertilizer around the root zone may predispose maize to higher levels of moisture stress occurred in 2013 at the top dressing is mainly responsible of the wilting of some shoots (Mashingaidze *et al.*, 2012). Lastly the combination of lime at reduced rate gave optimal yield due to the increased use efficiency of lime and confirmed the findings reported by Mulungu *et al.* (2013).

4.3.2.4 Mineral concentration in maize straw as affected by lime and fertilizer

The higher nutrients concentration of maize straw observed in 2013 compared to 2012 is in agreement with that found in lime manure experiment and confirmed the temporary inhibition of nutrients uptake occurred in 2012 due to water logging (Drew, 1988;

Steffens *et al.*, 2005; Sairam *et al.*, 2008,). The higher nutrients concentration of maize straw of limed soils as compared to the control is partly attributable to the reduction of Al content in soil (Watanabe and Osaki, 2002). The superiority in N, P, Ca and Mg of the combined use of banding lime with spot application of fertiliser and 100 % of LR observed in 2013 can be explained by the addition of higher amount of Ca, Mg and the increasing of nutrient absorption. The application of fertilizer at root zone reduces P fixation, while increases root growth leading to increased nutrient uptake (Bagayoko, *et al.*, 2000). As a result of very low content in N and P, the effect of Toukoto lime on N and P uptake by plant can be attributable only to their influences on nutrient availability through the increasing of soil pH. The banding of lime did not affect soil pH as compared to broadcasting this may explain the non effect of lime banding on N, P uptake. The repetitive temporary inhibition of nutrients uptake and probably the washing of nitrogen and phosphorus (Smaling, 1993) by water logging can explain partly the non effect of spot application of fertilizer on N and P uptake in 2012. On the other hand the spot application of mineral fertilizer increase maize yield in 2013. This improvement in yield may be attributable to the increase in nutrients uptake by crop and nutrients use efficiency (Bagayoko *et al.*, 2000). Similar results were reported by (Weligama *et al.*, 2008) who observed an increase of nutrient uptake, crop growth and yield by application of fertiliser at root zone. Lime by increasing the availability of N and P through soil pH improvement increase N and P uptake by crop in both growing seasons. Similar findings have been reported by other authors (Opala *et al.*, 2007; Andric *et al.*, 2012).

The dolomite lime had higher content in Ca (36.7 %) and Mg (11.2 %), which contributes to increase firstly soil pH and then nutrients availability and secondly

improves soil solution content in Ca and Mg. For these reasons lime application increased Ca and Mg uptake and the effect was more pronounced at higher rate of application. The no effect of lime banding and spot application of fertilizer on Ca and Mg uptake observed in 2012 may be attributable to temporary inhibition of nutrients uptake. On the other hand the increasing of Ca and Mg uptake by lime banding compared to broadcasting in 2013 may be due to the higher content of soil Ca and Mg. These results were in consonance with the findings reported by Andric *et al.* (2012) that liming increased the concentrations of maize leaf as follows: Mg (+34 %), Ca (+10 %) and Mo (+3.4 %).

According to Chistensen as Cited by Andric *et al.* (2012) adequate nutrients status of maize leaf is as follows 0.2-0.5 % for P, 1.5-3 % for K, 0.2-1 % for Ca and 0.2-1 % for Mg; consequently the straw level of Ca (0.09-0.42 %) were generally low whilst those of Mg (0.16-1.47 %), P (1.26-1.97 %) and K (1.07-2.01 %), were adequate for amended soil.

4.3.2.5 Financial profitability of the application lime and fertilizer

The farming practices which are profitable in short-run usually attract farmers' interest and are therefore more likely to be adopted. According to Mulungu *et al.* (2013), the benefits of lime application can be evaluated in terms of how lime affects the returns to capital, labour and land. In this study the application of lime led to higher NFB than the control. The high NFB is due to the much higher increase of maize yield and the low cost of incorporation. The actual high price of maize grain has contributed to increase the economic profitability (Abdoulaye and Sanders, 2005; Vitale and Sanders, 2005). These results are consistent with those reported by Ragnar (1987) and Mitchell *et al.*

(2005) that the financial profitability was higher (VCR greater than 2) for different rates of lime and for different levels of acidity. The banding of lime had highest NFB compared to broadcasting. This is mainly attributable to the higher grain yield produced by banding despite the fact that this increase was not statistically significant. Likewise the higher yield produced by spot application of fertilizer is responsible of its higher NFB compared to banding of fertilizer. The application of 25 % of LR (325 kg ha^{-1}) had the highest NFB due to the lower lime cost and the optimal yield gained. This confirms the findings by Mulungu *et al.* (2013) which indicated that lime applied at reduced rates in precision application gave higher marginal rates of returns and can be more profitable economically in maize production in poor resource farming system. Conversely the higher lime cost explains largely the lowest NFB obtained with 100 % of lime requirement. The combination of broadcasting +spot application of fertilizer + 25 % of LR gave the highest cumulative NFB. This is attributable to the optimal yield produced and the lower cost lime of lime applied.

4.3.3 Conclusions

Lime applied at reduced rate (325 kg ha^{-1}) significantly increase soil fertility and maize yield. It is not necessary to increase the soil pH up to 5.5 for optimal production in poor resource farming system. Lime banding ameliorates soil properties and improves the use efficiency of lime and therefore increase maize yield.

The spot application of fertilizer did not cause the soil nutrient deficiencies when the full recommended rate is applied. Apart from exchangeable K decrease in 2012, spot application of fertilizer maintains or increases soil level in nutrients, the better it increases nutrient uptake by crop. The fractioning of nitrogen may reduce significantly

nitrogen losses and improves its use efficiency that can be a strategy for better nutrient management when the labour is available. However further research must be done to evaluate the effect in long term on soil nutrient flows. The use of broadcasted lime with spot application of fertilizer and 25 % of LR gave the highest cumulative NFB and was the most profitable option.

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CHAPTER FIVE

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

Liming is not a common ISFM practice due to financial and logistic factors and organic materials are not always available at sufficient amount. The overall objective of this research was to develop technologies for sustain soil fertility managements that improve crop production at reasonable cost. The study has contributed to this purpose by: (i) evaluating the effect of some locally available resources on a sandy acidic soil properties, (ii) determining the appropriate rate of lime for localized application, (iii) evaluating the combined effect of the application of lime and manure on some selected soil properties and maize yield, (iv) evaluating the efficiency of localized application of lime and fertilizer on some selected soil properties and maize yield, (v) assessing the financial returns of the application of lime and manure and the precision application of lime and fertilizer on maize.

The development of new strategies and/or the improvement of existing for the use of poor farmer are of the particular importance. The results of this study indicated that the weathered acid and very poor abandoned Regosols could be used successfully for the production of any kind of crop (even sensitive plant) if the soil chemical constraints are addressed. The addition of various locally available resources at different rate showed their ameliorants potential of soil acidity in both laboratory and field experiments. The application of lime and manure at reduced rate that fit to farmer practice increases soil nutrient status and uptake leading to improve crop yield.

5.2 Conclusions

However on the basis of the outcomes of this present study the following conclusions were drawn:

1) Locally available resources such as animal manures, compost, maize residue and ash from maize residue reduced soil aluminium toxicity and can substitute for lime in detoxifying Al at least on a short-term basis if they are available sufficiently. The “Liming” effectiveness of these materials varied with source and rate of application. The ash from maize straw was the most effective both in increasing soil pH and reducing exchangeable acidity. The Tilemsi rock phosphate was the least effective in increasing soil pH but the most in reducing exchangeable acidity after ash and lime. In practice, the lime equivalence of organic material and the lime requirement of soil can be used to determine the application rate of organic amendments for soil acidity correction. These findings confirm the hypothesis that locally available resources (manures, ash from crop residue and rock phosphate) have potential to correct soil acidity and provide crop nutrient.

2) In both banding and broadcasting application of lime, 25 % of the lime requirement (325 kg ha^{-1}) was the appropriate rate of lime for reducing soil acidity significantly to the pH required for optimum maize production. This rate was also the most cost effective. This could be an entry point for promotion of the use of locally available limestone among small holder farmer at least on high value crop (maize, cotton).

3) Farmer usually incorporated manure into soil for ameliorating soil quality. The present study showed that the application of manure increased soil pH, nutrients status and availability and decreased exchangeable acidity. The effect of manure on soil

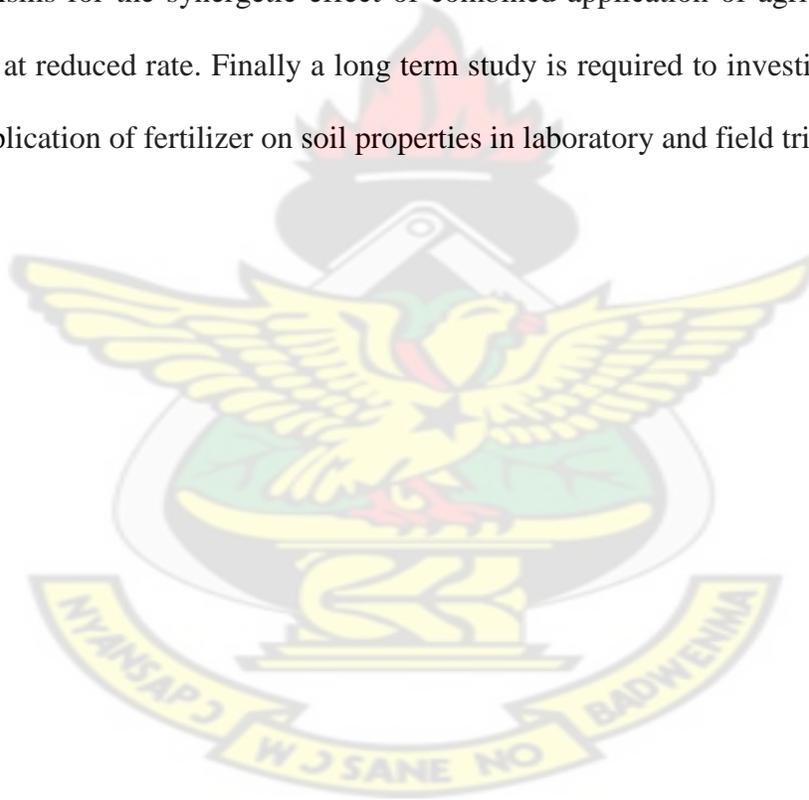
nutrients availability, maize growth and yield was enhanced by mineral fertilization probably due to the synergism between manure and mineral fertilizer. The combined application of dolomitic lime and manure at reduced rate (25 % of LR and 1.25 Mg ha⁻¹) ameliorates acid soil properties and maize growth and yield. These results accept the hypothesis that the optimal combination of low rate of agricultural lime and animal manure improves maize yield and soil fertility.

4) The banding of lime ameliorates soil properties and improves the use efficiency of dolomitic limestone but did not significantly increase maize yields as compared to broadcasting. The spot application of fertilizer at root zone increases nutrients uptake by plant, improves fertilizer use efficiency and maize yield this outcome confirmed the hypothesis that the spot application of lime and fertilizer on high value crop (maize) does not bring about soil nutrient deficiency and improve its yield.

5) In sole application manure at 1.25 Mg ha⁻¹ and lime at 325 kg ha⁻¹ (25 % LR) were the most profitable options with VCR of 3.14-4.32 and 4.25-6.88 respectively. On the other hand the combination of 25 % of LR with 1.25 Mg ha⁻¹ was the most financially profitable and the most affordable for poor farmer (VCR= 2.35-4.16). Lime banding had the highest net benefit compared to broadcasting and the net benefit for spot application of fertilizer was higher than the banding. The best treatment was broadcasting of lime with spot application of fertilizer and 25 % of lime requirement with the cumulative net benefits of 722750 F CFA for the first season and 962500 F CFA for the second.

5.3 Recommendations

This study has adequately addressed some of the pertinent issues in the management of soil acidity by the application locally available resources. However, further research is required for some aspects. Additional studies to assess the effect of these locally available resources on acid soil productivity in field conditions. Future assessment need be carried out to develop site specific application for manure and lime in other agro-ecological conditions. Also studies are required to provide better understanding of the mechanisms for the synergetic effect of combined application of agricultural lime and manure at reduced rate. Finally a long term study is required to investigate the effect of spot application of fertilizer on soil properties in laboratory and field trials.



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APPENDICES

Appendix 1

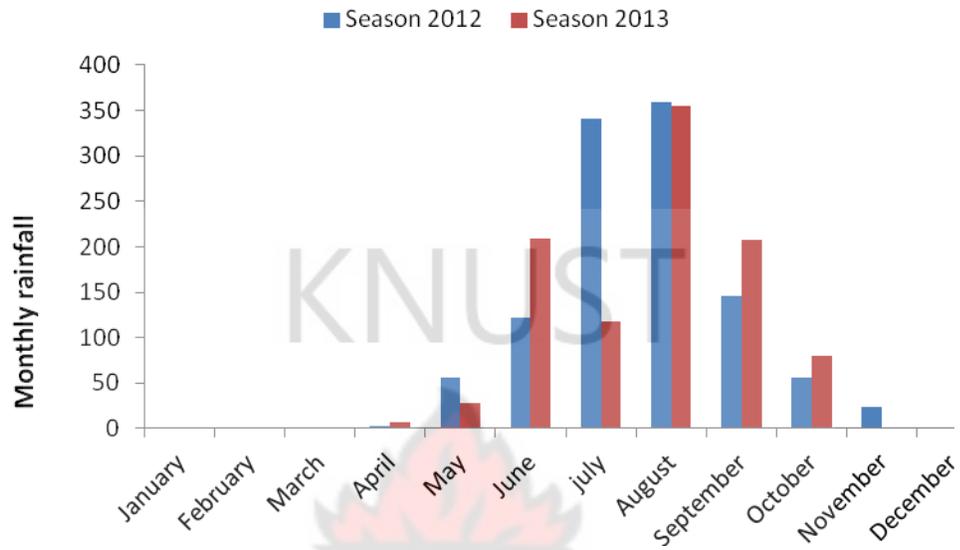


Figure 3.2 : Montly rainfall during the study (2012-2013)

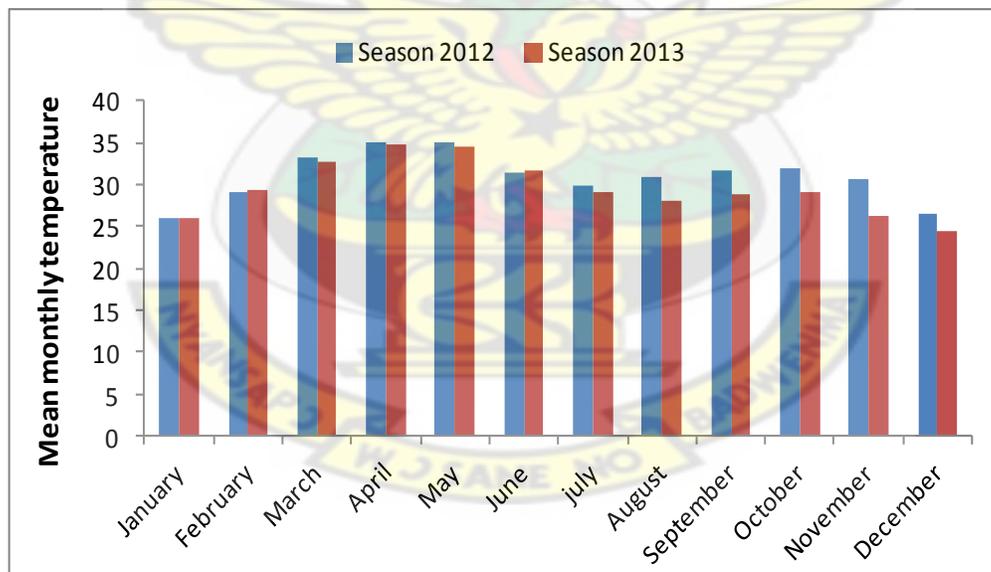


Figure 3.3: Mean monthly temperature (C°) during the study (2012-2013)

Appendix 2

Multiple regression of soil pH with amendments (Manure and compost) factors

	Coefficients	Standard Error	Significance
Constant	3.73	10.04	0.72
pH	0.14	0.45	0.76
Mo	0.09	0.20	0.66
N	-2.58	10.27	0.81
C/N	-0.16	0.42	0.72
CaCO ₃	-0.09	0.11	0.42
PCC	0.08	0.02	0.02
Total base	-0.25	0.17	0.20

Soil pH: 0.02 (± 0.02) PCC

($R^2=0.94$, $P<0.05$)

Equation 4.3

Multiple regression of soil pH with amendments (Manure, compost and maize straw) factors

	Coefficients	Standard Error	Significance
Constant	10.21	2.87	0.005
pH	-0.87	0.33	0.02
Mo	0.07	0.03	0.05
N	-2.01	2.34	0.41
C/N	-0.04	0.06	0.48
CaCO ₃	0.02	0.07	0.72
PCC	0.003	0.004	0.44
Total base	0.24	0.10	0.04

Soil pH: 10.21 (± 0.10) +0.87 (± 0.33) pHCaCl₂ +0.07 (± 0.03) OC+0.24 (± 0.10) Total base. Equation 4.4

(R²=0.73, P<0.05)