MINERALIZATION OF NEEM SEED CAKE AND EFFECT ON GROWTH AND NUTRITION OF SORGHUM IN A NORTHERN GUINEA SAVANNA ALFISOL

BY

MOHAMMED, Kehinde Olayemi

DEPARTMENT OF SOIL SCIENCE
FACULTY OF AGRICULTURE
AHMADU BELLO UNIVERSITY, ZARIA
NIGERIA.

FEBRUARY, 2013

MINERALIZATION OF NEEM SEED CAKE AND EFFECT ON GROWTH AND NUTRITION OF SORGHUM IN A NORTHERN GUINEA SAVANNA ALFISOL

BY

MOHAMMED, Kehinde Olayemi
PH. D./18232/2007-2008

A DISSERTATION SUBMITTED TO THE POSTGRADUATE SCHOOL, AHMADU BELLO UNIVERSITY, ZARIA
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY OF AHMADU BELLO UNIVERSITY, ZARIA.

DEPARTMENT OF SOIL SCIENCE
FACULTY OF AGRICULTURE
AHMADU BELLO UNIVERSITY, ZARIA
NIGERIA.

FEBRUARY, 2013

DECLARATION

I declare that the work in this dissertation entitled "**MINERALIZATION OF NEEM SEED CAKE AND EFFECT ON GROWTH AND NUTRITION OF SORGHUM IN A NORTHERN GUINEA SAVANNA ALFISOL"** was conducted by me in the Department of Soil Science under the supervision of **DR. (MRS.) E. Y. OYINLOLA.** The information provided from literature was duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at any university.

Name of student	Signature and Date

CERTIFICATION

This dissertation entitled "**MINERALIZATION OF NEEM SEED CAKE AND EFFECT ON GROWTH AND NUTRITION OF SORGHUM IN A NORTHERN GUINEA SAVANNA ALFISOL"** by Mohammed Kehinde Olayemi, meets the regulations governing the award of Doctor of Philosophy Degree of the Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

_____	_____
Dr (Mrs.) E. Y. Oyinlola Chairperson, Supervisory committee	Date
_____	_____
Prof. E. O. Uyovbisere Member, Supervisory committee	Date
_____	_____
Prof. A. C. Odunze Member, Supervisory committee	Date
_____	_____
Prof. J. O. Ogunwole Head, Department of Soil Science	Date
_____	_____
Prof. J. A. Adebayo Dean, Postgraduate School	Date

Ahmadu Bello University, Zaria.

DEDICATION

This project is dedicated to my late brother, Abdul Ganiyu Olawale Mohammed who encouraged me to reach higher heights.

ACKNOWLEDGEMENT

For successful completion of my academic pursuit, I owe a great deal to many people. My new and old friends at Ahmadu Bello University, Zaria, University of Ilorin, Kwara State College of Education, Government Day Secondary School, Alore-Ilorin, and Lower Niger River Basin Development Authority, Ilorin, who generously gave their time and shared the benefits of their experience and morals. Some professors assisted me by providing materials ranging from seeds to electronic and hardcopies of journal publications, and my junior colleagues at the Soil Science Department assisted with the interpretation of my findings. Dr (Mrs) E. Y. Oyinlola, Professor E. O. Uyovbisere and Professor A. C. Odunze of the Soil Science Department read the entire dissertation and made sound and helpful suggestions. The technical staffs of the Department Mr Ilu, Dashe, Augustine, Bello and Victor were among many staff of the Department of Soil Science in the Institute for Agricultural Research, Zaria who offered me laboratory assistance with my research. My thanks also go to the Farm Manager of the Institute for Agricultural Research, Samaru and the Farming System Research Program for supporting the field work. My parents, siblings and spouse were my sources of helpful criticism and encouragement. For all these assistance, I express my sincere thanks.

ABSTRACT

Four neem seed cake levels 0, 1, 2 and 4 ton (t) ha^{-1} along with varying rates of inorganic fertilizer recommendation (0, ¼, ½ and full) for sorghum were evaluated in the laboratory, greenhouse and in the field for their mineralization and/or decomposition potentials, impact on soil fertility, productivity and nutrition of sorghum in the Northern Guinea Savanna of Nigeria in a factorial completely randomized design with three replications. Results showed that NSC contained 265.35 g kg^{-1} OC, 45.95 g kg^{-1} N, 2.75 g kg^{-1} P, and 12.35 g kg^{-1} K mean concentration in both years indicating its potential in improving soil fertility and plant growth. Treatments did not significantly ($P \leq 0.05$) increase sorghum growth and dry matter yield (DMY) in the greenhouse. The quarter recommended rate (RR) recorded a higher increase in DMY and plant height while combinations of 2 t ha^{-1} NSC + ¼ RR and 4 t ha^{-1} + FRR gave non-significant increase in stem girth and number of leaves respectively. Treatments showed significant ($P \leq 0.05$) difference in only P concentrations in sorghum tissue. The 4 t ha^{-1} of NSC significantly increased P and K concentrations while combined application of 4t ha^{-1} + FRR recorded the highest N concentration. As regards the effects of treatments on soil properties after cropping, sole NSC and CF treatments resulted in soil pH reduction, implying that application of these materials can lead to soil acidification. Significant ($P \leq 0.05$) increases were observed in the effect of treatments on exchangeable acidity, nitrogen, potassium and calcium. Soil microbial biomass carbon correlated with soil total organic carbon (TOC) ($r = 1$), and was generally positively related to the soil organic matter which implied the ability of the organic material to form stable aggregates. Laboratory incubation study showed an initial rapid cumulative N mineralization rate in the first twenty-one (21) days followed by slower release with time. At 98 days, cumulative N mineralization represented 50 % of total N applied as neem seed cake. N mineralization pattern showed that ammonium-N fraction in the soil far exceeded nitrate-N fraction, accounting for 91.5% of the N mineralized from the NSC. The simple rate constant (h=k) gave a better fit to mineral-N released than the Gompertz function in the laboratory study. However, in the field, cumulative N mineralization with time showed an initial rapid rate in the first six (6) weeks after incubation followed by slower release in 2009 and 2010. N mineralization pattern showed that ammonium-N fraction in the soil slightly exceeded the nitrate-N fraction in 2009, accounting for about 52% of N mineralized from neem seed cake while in 2010 N mineralization pattern showed that nitrate-N fraction in the soil far exceeded the ammonium-N fraction, accounting for 64% of the N mineralized from NSC. Generally, highest concentration of ammonium was observed during the first twenty-eight (28) days of incubation. The best fit for net N mineralization in the field was displayed with the Gompertz function. Weight loss of NSC was rapid within the first twenty-eight (28) days with about 70% lost in 2009. Significant ($P < 0.05$) decrease in dry mass was observed for seven sampling periods in 2010; dry mass loss was rapid during the first fourteen (14) days of decomposition relative to later periods. However, NPK level did not affect dry mass loss of NSC significantly ($P < 0.05$). Decomposition best fit was described by the asymptotic negative exponential model. In the field trial, significant treatment effects were observed on sorghum growth parameters. Leaf number, dry matter yield and plant height increased with simple combined application of the amendments. Effects of the various treatments (regression) on yield was significant, a reflection of the contribution of treatments to soil nutrient status. Combined application of 1 t ha^{-1} + FRR had highest sorghum grain yield. Yield parameters were better enhanced in NSC amended plots in 2009 and 2010 ($P < 0.01$). There was no significant effect of treatments on P and K concentrations in sorghum tissues in 2009. The effect of treatments on soil properties after cropping, sole CF and NSC treatments resulted in soil pH reduction, implying increase in acidity. Significant ($P \leq 0.05$) increases were observed in the effect of treatments on organic

carbon and exchangeable potassium in 2009 and 2010 with sole NSC application while in 2010 significant effect was observed for exchangeable potassium, calcium and exchangeable acidity in sole NPK plots. Non significant treatment effect was observed for tannin content in both years while significant ($P \leq 0.05$) response was obtained for effect of chemical fertilizer in 2009 for crude protein. The present study revealed that NSC has high residue quality and can be used as a nutrient source. Its integration with CF was shown to be an important management strategy for improving fertility and productivity of the savanna soils.

TABLE OF CONTENTS

		Page
Title page		i
Declaration		iii
Certification		iv
Dedication		v
Acknowledgement		vi
Abstract		vii
Table of Contents		ix
List of Tables		xvi
List of figures		xx
CHAPTER ONE		
1.0	**INTRODUCTION**	1
CHAPTER TWO		
2.0	**LITERATURE REVIEW**	4
2.1	The Nigerian Savanna	4
2.1.1	Soils of the Nigerian Savanna	4
2.2	Role of organic materials in improving soil fertility	6
2.2.1	Organic materials as sources of nutrients	7
2.2.2	Effects of organic amendments on soil properties	10
2.2.3	Effect of organic amendments on soil physical properties	11
2.2.4	Effect of organic amendments on soil chemical properties	14
2.3	Neem	15
2.4	Neem seed cake as a source of nutrient	17

2.5	Chemical composition of neem seed cake	19
2.6	Botany and agronomy of sorghum	20
2.7	Nutritional quality of sorghum	21
2.8	Growth and yield components of sorghum	23
2.9	Nutrient requirement of sorghum	26
2.10	Nitrogen, phosphorus, potassium, calcium and magnesium: their interactions and availability	27
2.10.1	Nitrogen in the soil	27
2.10.2	Phosphorus in the soil	30
2.11	Nutrient mineralization and immobilization	35
	2.11.1 Mineralization and immobilization of phosphate	37
	2.11.2 Mineralization and immobilization of nitrogen	41
	2.11.3 Mineralizable soil N-total N content	44
2.12	Nutrient mineralization and crop growth	47
2.13	Effect of soil microbes on substrate decomposition and nutrient Release pattern	49
2.14	Decomposition studies	52
2.15	Decomposition models	55
2.16	Neem seed cake as nitrification inhibitor	60
2.17	Soil acidification	62
2.18	Fertilizer use efficiency	65
	2.18.1 Nitrogen use efficiency	66
	2.18.2 Phosphorus use efficiency	69
2.19	Soil microbial biomass	71
2.20	Particulate organic matter	72

CHAPTER THREE

3.0	**MATERIALS AND METHODS**	75
3.1	Experimental site and climate	75
3.2	Pre-cropping site characterization	75
	3.2.1 Soil sampling and analysis	75
3.3	Characterization of neem seed cake (NSC)	76
	3. 3.1 Analytical method for the neem seed cake	76
3.4	Greenhouse experiment	78
	3.4.1 Soil sample collection and preparation	78
	3.4.2 Treatment and experimental design	79
	3.4.3 Greenhouse techniques	79
	3.4.4 Greenhouse observation and measurement	79
	3.4.5 Analytical method for plant materials	81
	3.4.6 Determination of soil microbial biomass (Analytical method)	81
	3.4.7 Fractionation of organic matter by particle size method	82
	3.4.8 Statistical analysis	83
3.5	Incubation studies (Laboratory and field methods)	83
	3.5.1 Laboratory incubation studies of neem seed cake	83
3.6	Field mineralization experiment (PVC tube experiment)	85
	3.6.1 Sampling procedures for mineralization experiment	85
	3.6.2 Mineralization model	86
	3.6.3 Statistical analysis	87
3.7	Field decomposition study	87
	3.7.1 Treatments, design and experimental details	87
	3.7.2 Time-step retrieval of litterbags	88

3.7.2.1 Determination of Ash free dry weight 90

3.7.3 Data management/ models 90

3.8 Field trials 91

3.8.1 Treatments and experimental design 91

3.8.2 Cultural practices and application of treatments 92

3.8.3 Field observations and measurements 94

3.8.3.1 Dry matter estimation by destructive sampling 94

3.8.3.2 Leaf area measurement 95

3.8.3.3 Leaf area index (LAI) 95

3.8.3.4 Stem girth, leaf number and plant height measurements 95

3.8.3.5 Yields and yield components 96

3.8.4 Nutrient concentration of the sorghum plant 98

3.8.4.1 Analytical methods for grain samples 98

3.8.4.2 Analytical methods for plant samples 99

3.8.5 Statistical analysis 99

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION 101

4.1 Characterization of the study site 101

4.1.1 Soil characteristics and geology 101

4.1.2 Climatic conditions of the study years 103

4.2 Characteristics of the neem seed cake used for the study 105

4.3 Greenhouse experiment 107

4.3.1 Main effect of treatment factors 107

4.3.1.1 Response of agronomic parameters to NPK fertilizer levels 107

4.3.1.2 Response of agronomic parameters to NSC levels 107

4.3.1.3 Interaction of NPK and NSC levels on agronomic parameters 109

4.3.2 Nutrient uptake studies 112

4.3.2.1 Effect of NSC and CF treatments on nutrients concentration of sorghum tissue 112

4.3.2.2 Effect of NSC and CF on nutrient uptake by sorghum in the Greenhouse 116

4.3.3 Effect of NSC and CF on selected soil properties of cropped greenhouse soils 119

4.3.3.1 pH in water 122

4.3.3.2 Exchangeable Acidity (EA) 122

4.3.3.3 Organic carbon (OC) 123

4.3.3.4 Nitrogen (N) 123

4.3.3.5 Phosphorus 124

4.3.3.6 Exchangeable bases (K, Ca, Mg and Na) 124

4.3.4 Inter-relationships of selected soil properties after cropping (Greenhouse experiment) 125

4.3.4.1 Principal component analysis of selected soil properties 125

4.3.5 Soil organic carbon dynamics in cultivated and uncultivated greenhouse pots 129

4.3.6 Comparisons of total soil carbon and selected soil quality parameters 132

4.3.7 Derivations from the greenhouse works 135

4.4 Decomposition and mineralization experiments 137

4.4.1 Laboratory incubation studies using sintered funnel 137

4.4.2 Field incubation studies using PVC tubes 142

4.4.2.1 Cummulative N mineralized 142

4.4.2.2 N mineralization kinetic model and mineralization rates for the field studies 148

4.4.3 Field decomposition studies using litterbags 151

4.4.3.1 Dry matter loss 151

4.4.3.2 Exponential decomposition kinetic model and decomposition rates 154

4.4.4 Derivations from the mineralization and decomposition Experiments 160

4.5 Field agronomic experiments 160

4.5.1 Main effect of treatment factors 160

4.5.1.1 Response of agronomy parameters to NPK fertilizers 160

4.5.1.2 Response of agronomy parameters to NSC levels 164

4.5.1.3 Effect of interaction between NPK and NSC on agronomy parameters 166

4.5.2 Interaction of treatments 168

4.5.2.1 Effects of NPK fertilizer levels on yield parameters 170

4.5.2.2 Effect of NSC levels on yield parameters 172

4.5.2.3 Effect of treatment interaction factors on yield parameters 172

4.5.3 Nutrient uptake studies 175

4.5.3.1 Effect of NSC and CF on nutrient concentration of sorghum tissue 175

4.5.3.2 Effect of NSC and CF on nutrient uptake by sorghum in the field 179

4.5.4 Effect of NSC and CF on selected soil properties 184

4.5.4.1 pH in water and 0.01M $CaCl_2$ 184

4.5.4.2 Organic carbon 189

4.5.4.3 Available phosphorus 190

4.5.4.4 Total nitrogen 191

4.5.4.5 Exchangeable potassium 193

4.5.4.6 Exchangeable magnesium 193

4.5.4.7 Exchangeable sodium 194

4.5.4.8 Exchangeable calcium 195

4.5.4.9 Exchangeable acidity 195

4.5.5 Inter-relationships of soil chemical properties in the field following NSC and NPK incorporation in 2009 and 2010 by factor analysis 196

4.5.5.1 Principal component analysis of selected soil properties in the field following NSC and NPK incorporation in 2009 and 2010 196

4.6 Effect of NSC and CF on nutritional status of sorghum 202

4.6.1 Effect of NSC and CF on crude protein 202

4.6.2 Effect of NSC and CF on tannin content 205

4.7 Correlation between growth, yield and yield components 205

4.8 Fertilizer equivalence of neem seed cake 212

4.9 Effect of NSC and CF on sorghum harvest index and nitrogen use efficiency 219

4.9.1 Response of NPK treatment on harvest index 219

4.9.2 Response of NSC treatment on harvest index 219

4.9.3 Response of treatment interaction on harvest index (HI) 219

4.9.4 Response of NSC and NPK treatment on N-use efficiency 219

4.10 Derivations from the field experiment 223

CHAPTER FIVE

5.0 SUMMARY AND CONCLUSION 225

References 231

Appendices 273

LIST OF TABLES

Table		Page
3.1	Treatment combinations of the greenhouse studies…….…….	80
3.2	Treatment combinations ……	89
3.3	Treatment numbers and combinations used in the field study……	93
4.1	Physico-chemical characteristics of soils of the field experimental site and Greenhouse ……	102
4.2	Monthly summary of weather conditions at Samaru-Zaria for two years of the study……	104
4.3	Selected chemical characteristics of the neem seed cake used in the study for the two years……	106
4.4	Main effects of neem seed cake and chemical fertilizer on sorghum performance in the greenhouse	108
4.5	Interaction of neem seed cake and inorganic fertilizers on sorghum performance in the greenhouse……110	
4.6	Main effects of NSC and CF on nutrient concentrations of sorghum tissue in the greenhouse……..113	
4.7	Interaction of NSC and CF on nutrient concentrations of sorghum tissue in the greenhouse……...114	
4.8	Main effects of NSC and NPK levels on nutrient uptake in the greenhouse	117
4.9	Interaction of NSC and NPK levels on nutrient uptake in the greenhouse	118
4.10	Main effects of NSC and CF on selected soil properties in the greenhouse after cropping	120
4.11	Interaction of NSC and CF on selected soil properties in the greenhouse after cropping	121
4.12	Eigen-value, proportion and cumulative variance explained by factor analysis using correlation matrix of 11 soil properties in the greenhouse	126
4.13	Proportion of variance using varimax rotation and Kaiser normalized, and communality estimates for 11 soil properties (principal component method) in the Greenhouse	127

4.14 Organic carbon dynamics (g kg^{-1}) of cultivated and uncultivated greenhouse pots after wet-sieving into four fractions 130

4.15 Particulate organic matters (POM) statuses of active or labile SOM for cultivated and uncultivated pots receiving different treatments of NSC and/ or inorganic fertilizers 131

4.16 Ammonium-N, nitrate-N and mineral-N mineralized during laboratory incubation of NSC using sintered funnel 138

4.17 Goodness-of-fit statistics and parameter estimates of five mathematical models Fitted to inorganic N mineralized from neem seed cake decomposition in the Laboratory 140

4.18 Pattern of inorganic N mineralization (mg kg^{-1}) of NSC as influenced by NPK treatment over a period of 32 weeks of sorghum growth in the field in 2009 143

4.19 Pattern of inorganic N mineralization (mg kg^{-1}) of NSC as influenced by NPK treatment over a period of 32 weeks of sorghum growth in the field in 2010 145

4.20 Goodness-of-fit statistics and parameter estimates of five mathematical models fitted to inorganic N mineralized from neem seed cake incorporation 149

4.21 Effect of inorganic fertilizer levels on dry matter loss of neem seed cake in 2009 and 2010 152

4.22 Goodness-of-fit statistics and parameter estimates of the four mathematical Models fitted to cumulative dry mass loss (Single exponential model) 155

4.23 Goodness-of-fit statistics and parameter estimates of the four mathematical Models fitted to cumulative dry mass loss (Double exponential Decay model) 156

4.24 Goodness-of-fit statistics and parameter estimates of the four mathematical Models fitted to cumulative dry mass loss (Asymptotic negative exponential Decay model) 157

4.25 Goodness-of-fit statistics and parameter estimates of the four mathematical Models fitted to cumulative dry mass loss (Triple negative exponential Decay model) 158

4.26 Main effects of sorghum growth parameters as affected by neem seed cake and inorganic fertilizer application 161

4.27 Interaction of NSC and CF on sorghum growth 162

4.28 Main effects of NSC and NPK on days to 50% panicle emergence and flowering of sorghum 168

4.29 Interaction of NSC and NPK fertilizer on days to 50% panicle emergence and flowering of sorghum 169

4.30 Main effects of NSC and NPK fertilizer on yield and yield components 171

4.31 Interaction of NSC and CF on sorghum yield parameters 174

4.32 Main effects of NSC and CF on nutrient concentration of sorghum tissue in the field 176

4.33 Interaction of NSC and CF on N, P and K concentration in sorghum tissue 177

4.34 Main effect of NSC and NPK fertilizer on nutrient uptake by sorghum in 2009 and 2010 field study 180

4.35 Interaction of NSC and NPK fertilizer on nutrient uptake in 2009 and 2010 182

4.36a Main effects of NSC and CF on selected soil properties 185

4.36b Main effects of NSC and CF on selected soil properties 186

4.36c Interaction of NSC and CF on selected soil properties 187

4.36d Interaction of NSC and CF on selected soil properties 188

4.37 Eigen value, proportion and cumulative variance explained by factor analysis using correlation matrix of 11 soil in 2009 and 2010 in the field 197

4.38 Proportion of variance using varimax rotation and Kaiser normalized, and communality estimates for 11 soil properties (Principal component method) in 2009 and 2010 in the field 199

4.39 Main effects of neem seed cake and inorganic fertilizer on grain sorghum crude protein and tannin contents 203

4.40 Interaction of neem seed cake and inorganic fertilizer on grain sorghum crude protein and tannin contents 204

4.41a Matrix of simple correlation coefficient between yield, yield components and some growth parameters in 2009 cropping season 206

4.41b Matrix of simple correlation coefficient between yield, yield components and some growth parameters in 2010 cropping season 207

4.41c Matrix of simple correlation coefficient between yield, yield components and some growth parameters for the two years combined 208

4.42 Sorghum grain yield (kg ha^{-1}) and fertilizer equivalence (kg N ha^{-1}) at different Levels of neem seed cake during the 2009 cropping season at Samaru 213

4.43 Sorghum grain yield (kg ha^{-1}) and fertilizer equivalence (kg N ha^{-1}) at different Levels of neem seed cake during the 2010 cropping season at Samaru 213

4.44 Interaction of NSC and NPK on fertilizer equivalence in 2009 217

4.45 Interaction of NSC and NPK on fertilizer equivalence in 2010 218

4.46 Main effects of NSC and CF on sorghum harvest index 220

4.47 Interaction of NSC and CF on sorghum harvest index 221

LIST OF FIGURES

Figure		Page
3.1	Pictures showing how the neem seed cake was obtained	77
4.1	Cumulative total mineral-N, NH_4^+-N and NO_3^-N released during laboratory incubation……	139
4.2	Cumulative total inorganic N, NH_4^+-N and NO_3^-N from field incubation studies using PVC tubes in 2009……	146
4.3	Cumulative total inorganic N, NH_4^+-N and NO_3^-N from field incubation studies using PVC tubes in 2010……	146
4.4	The relationship between percent fertilizer equivalencies and N content of NSC……	215
4.5	Relationship between N applied and N recovery by sorghum at Samaru in 2009……	222
4.6	Relationship between N applied and N recovery by sorghum at Samaru in 2010……	222

CHAPTER ONE

INTRODUCTION

Alfisols and ultisols comprise the dominant soils in the Northern Guinea Savanna and are estimated to cover about 60% of the region (Ojanuga, 1979; Enwezor *et* al., 1990; Odunze *et al*., 1996). These soils have a dominance of low activity clays in the surface horizon (Frye *et* al., 1982; Esu and Ojanuga, 1985) with accompanying low exchange capacity. The soils are fragile and easily degraded under continuous cultivation (Lal, 1975; Jones, 1976; FAO, 1978). Consequently, crop production is not profitable without addition of external inputs.

Good management of agricultural production systems as a soil resource is a response to challenges posed by world food crisis. Dwindling soil fertility has resulted from activities such as annual crop harvests that mine the soil of nutrients, leaching of soil nutrients, loss of biodiversity and retarded biological activities that stagnate nutrient recycling thereby hampering sustainable agriculture in Nigeria. Soil fertility management and improvement strategies using inorganic fertilizers are not only expensive but tend to hasten the degradation of the soil ecosystem with all its attendant effects. Ameliorating such conditions by organic matter application has met with good results.

Grain sorghum (*Sorghum bicolor L. Moench*) production in the savanna zone of Nigeria is limited by the deficiencies of a number of nutrient elements. Soils of this zone in northern Nigeria are generally low in native fertility (Heathcote and Stockinger, 1970). Consequently, under the subsistence or semi-intensive system of agriculture, the average yield of sorghum is generally low (below 0.8t/ha) (Egbe *et al.*, 2009). A possible avenue for yield improvement in this crop is through the use of adapted improved varieties and the use of organic and inorganic fertilizers (Buresh *et al*., 1997; FAO, 1999; Uyovbisere and Elemo, 2000). Organic inputs are

needed to maintain the physical, chemical fertility and biological productivity of the often shallow sandy to sandy loam soils in the West African moist Savanna zone, while inorganic fertilizers are needed to supply sufficient amount of nutrient to the crop (Vanlauwe *et al*., 2001; Tarfa *et* al., 2001; Micheni *et al*., 2004). Lately, the use of local and readily available organic residues as soil amendment in sub-Saharan Africa to improve soil fertility and organic matter status is rapidly gaining widespread support (Agbenin *et al*., 1999). It is pertinent therefore to exploit and evaluate the potentials of locally available organic wastes as soil amendments.

The neem tree, *Azadirachta indica* (dongoyaro), offers great potential for agricultural, industrial and commercial exploitation. It is potentially one of the most valuable of all arid-zone trees. It shows promise for pest control, reforestation, and improving human health (Vietmeyer, 1992). The neem foliage and neem seed cake (NSC), have been demonstrated to have high soil fertilization potential, particularly with respect to nitrogen release (Radwanski, 1969; Kethar, 1974; Kethar and Kethar, 1995; Idris *et al*., 1995; Uyovbisere *et al*., 1999; Agbenin *et al.*, 1999 and 2008; Tarfa, 2001). Consequently, it could be one panacea for the maintenance of soil fertility to sustain crop production which is a major challenge facing agriculture and food security in Nigeria and most other developing countries (Mokwunye, 1991; Murwira *et al*., 2002).

Laboratory studies have shown that NSC increased exchange acidity markedly and decreased soil pH significantly (Agbenin *et al*., 2008). Studies on the reactions of NSC under field conditions are scarce. It is also crucial to note that NSC improves N-use efficiency in soil, provides soil nutrients and increases soil organic carbon (OC) content (Radwanski, 1969; Mishra *et al*., 1975; Vietmeyer, 1992; Kethar and Kethar, 1995). This is particularly important in soils of the Nigerian savanna which are made up of low activity clays (LAC), thus their

ability to retain nutrients and supply to crops is largely dependent on their organic matter contents (Abubakar *et al*., 2004). However, quantification of nitrogen use efficiency requires better understanding of soil N mineralization during the growing season in systems where organic and inorganic forms of N are applied (Dwyer *et al*., 1993).

In view of the aforestated, the objectives of this study are to:

- determine the rate of decomposition and mineralization of neem seed cake (NSC) in soil;
- determine the effect of NSC on growth and nutrition of sorghum;
- evaluate effects of NSC on soil chemical properties;
- Determine the optimum and suitable combinations of NSC and inorganic fertilizer for sorghum production in the soil;
- Recommend appropriate soil management strategies for utilization of NSC.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Nigerian Savanna

Nigerian savanna lies between latitudes 8^0N and 13^0N (Kowal and Knabe, 1972). The climate can be distinctly divided into two seasons, namely, rainy and dry, both of which vary in duration and intensity. Rainy season varies from 0 – 63 days in the north of Nigeria to 180 – 244 days in the south of the country (Kowal and Kassam, 1978). The region can be sub-divided into five bioclimatic or ecological zones (CTA, 1989): the Northern and Southern Sahel, the Sudan and the northern and southern Guinea Savanna.

In some of the ecological zones, vegetation is generally sparse, with very few trees. The intensity of vegetation decreases as one move from the south to the north. Thus, the capacity for organic matter production also decreases as one goes from south to north. Reasons for this include the lower amounts and shorter duration of rainfall. This in turn influence the length of the growing season in the north compared to the south; and the higher temperature regimes and longer dry periods experienced in the north. This could therefore mean that soil nutrient depletion rate is higher as one moves further north. Furthermore, because organic matter production is less in the drier areas, proper soil management measures become more difficult as one moves northwards, making sustainable food production more difficult (Odion *et al*., 2007).

2.1.1 Soils of the Nigerian Savanna

Soils of the savanna are characteristically low in fertility (Jones and Wild, 1975). Most of the soils are under continous cultivation, and result in rapid loss of fertility due to rapid decline in organic matter, leaching of basic cations and high rates of acidification (Jones and Wild, 1975; Ogunwole, 2008). Also, large scale loss of organic matter (OM) as a result of land clearing

during cultivation occur especially with the breakdown of traditional land use system like shifting cultivation and bush fallowing (Kowal and Kassam, 1978). López-Gutiérrez *et al*. (2004b) reported that savanna ecosystems have low primary productivity, strong seasonality and low phosphorus (P) content.

Soils of Nigeria Savanna are made up of low activity clays (LAC), ability of the soils to retain nutrients and supply to crops is largely dependent on their OM contents (Abubakar *et al*., 2004). Kaolinite and iron (Fe) oxyhydroxides are shown to form 80-90% of constituent of the clay fraction of Nigerian Savanna soils (Moberg and Esu, 1991). Soil OM fraction constitutes the major portion of total N, P and S reserves (Nye and Greenland, 1960). Soil OM declines by about two-thirds of initial amounts when soils are continuously cropped which implies a serious decrease in both total reserve and availability of essential plant nutrients (Stangel, 1995). The soils are slightly acidic in reaction, have moderate P fixation properties and exhibit Al toxicity in some cases (Fernandez and Sanchez, 1990).

Savanna soils are largely dominated by alfisols, ultisols, entisols, vertisols and inceptisols (USDA, 1975; Kang and Spain, 1986). This soil accounts for more than 58% of arable lands in West African Savanna (Jones and Wild, 1975). Also, organic P (P_o) of the savanna comprises 50% of total soil P and is plant-available only after mineralization (López-Gutiérrez *et al.* 2004a). These basic characteristics have far reaching implications on the fertility and crop production potentials of soils; main soil constraints in the savanna are more of chemical than physical (Fernandez and Sanchez, 1990; Goladi and Agbenin, 1997). Given these constraints, it is evident that appropriate soil management practices, particularly management of the OM and applied organic materials are crucial for the improvement and sustenance of fertility and productivity of the Nigeria Savanna soils.

2.2 Role of organic materials in improving soil fertility

Soil organic matter (SOM) is any material produced originally by living organisms (plant or animal) that is returned to the soil and goes through the decomposition process (Bot, 2009). It is a complex mixture of organic compounds, representing products of microbial decomposition of plant materials, metabolic products of micro-organisms that feed on plant materials and derive energy, products of secondary synthesis in the form of bacterial plasma and strictly humus substances (Biswas and Mukherjee, 2005). Some of these organic materials are grown and recycled on site, while others are brought in from other sites, and thus constitute an external source of nutrients and organic carbon (OC) (Fernandez and Sanchez, 1990). It is a heterogenous mixture of products resulting from microbial and chemical transformation (humification) of organic debris and is known to have beneficial effects on soil conditions and fertility. The particular significance and agronomic value of OM is the influence it imparts on soil properties. This value is measured with the supply of essential plant nutrients, improvement in the soil physical properties and enhanced soil microbiological life (Mbagwu *et al*., 1994; Mokwunye *et al*., 1996).

A number of studies have shown that incorporation of organic matter affects the pH of soils with low buffering capacity. Organic residues, which contain high amount of S, could decrease soil pH as a result of sulphate addition to the soil. Generally, it has been reported that pH of lighter soils (sandy) change quickly with the addition of organic amendment than heavy soils (clay) (Agbim, 1980).

Inputs of organic material have been reported to enhance nutrient balance by serving as a nutrient reservoir and raising the CEC (Bache and Heathcote, 1969; Lal and Kang, 1982). Crop residues of leguminous plants are generally richer in all nutrients than cereal crop residues

(Balasubramanian and Nnadi, 1980). Added OM plays a major role in supplying nutrients to the soil upon decomposition. Acquaye (1993) stated that OM serves not only as a source of plant nutrients contributing more than 95% of the total N, between 20 to 80% of total P and more than 90% of the total S in tropical soils, and to the CEC. Organic matter also has a stabilizing effect on physical properties and enhancement of microbiological activities especially those of *Rhizobium* in N-fixation, *Nitrosomonas* and *nitrobacter* in mineralization of organic N.

The importance of organic materials to soil physical, chemical and biological properties with implications on nutrient cycling, erosion control, water storage, plant vigour and resultant soil fertility and productivity have been well established (Larson *et al*., 1972; Stevenson, 1982; Swift and Sanchez, 1984; MacRea and Mehuys, 1985; Marchesni *et al*., 1988). Nutrient supply is generally considered the most important in the short term (Lombin *et al*., 1991). On marginal soils, improvements in structure and water retention capacity significantly enhance the prospects for a better soil environment for root development and nutrient uptake. On soils with good structure, however, improved physical properties are secondary to the enhanced fertility status associated with organic input applications (Mbagwu *et al*., 1994). This was also evident in the submission of Avnimelech (1986) in a review of several studies on the use of organic materials where he observed further that application of these materials contribute to plant growth through mechanisms other than their nutrient contents.

2.2.1 Organic materials as sources of nutrients

Organic materials exert their main influence on chemical properties through direct and indirect effects on nutrient supply (Syers and Craswell, 1995). The amount of N and P added by organic residues depend on the chemical composition (Ayuke *et al*., 2004). However, the amounts of nutrients, especially N, P, and K currently returned to soil in organic waste is substantial.

Estimates of various nutrient elements contained in crop residues and animal droppings have been reported in several studies (de Ridder and van Kuelen, 1990; Iwuafor *et al*., 1991; Uyovbisere and Elemo, 2000; Tarfa *et al*., 2001). The ability of organic amendments to supply nutrients required by a crop depends on the nutrient release pattern and amounts of the material applied. Carbonaceous residues with high rates of C: N and C: P ratios have potentials for significant short-term immobilization of N, S, and P (Allison and Kleen, 1962). Application of organic materials generally increases organic N, S, and P in the long-term (Black, 1968).

The C: N ratio is a useful guide to whether net release of N from organic material is likely to occur during the early stages of decomposition (Giller and Wilson, 1991). The C: N ratio also provides an indication of how rapidly a material is likely to be decomposed (Frankenberger and Abdelmagid, 1985). Plant residues with a high C: N ratio (>30: 1) are likely to decompose slowly with initial net immobilization of N, whereas residues with a smaller C: N ratios are likely to decompose more rapidly with a net mineralization of N occurring right from the beginning.

Plants contribute large amounts of structural and non-structural carbohydrates, which along with organic materials, are deposited in the soil. These are readily metabolized by soil microorganisms and are removed from the system. The more resistant lignin and polyphenols change slowly and limit turn over rate of soil C (Minderman, 1968). The lignin and polyphenol represent the partially decomposed OM (Tarfa, 2001). Lignin and cellulose are structural constituents of vascular plants that can make up a substantial part of litter dry mass (Gessner, 2005). Both compounds confer toughness to plant tissues (i.e, compressive and tensile strength). Consequently, plant litter rich in these compounds tends to be highly refractory, with high concentrations particularly of lignin being conducive to slow litter decomposition (Vallis and

Jones, 1973; Frankenberger and Abdelmagid, 1985; Fox *et al*., 1990; Palm and Sanchez, 1991; Gessner and Chauvet, 1994; Berg and McClaugherty, 2003). The (lignin + polyphenol): N ratio can give an excellent prediction of the N mineralization rate of organic residues especially legumes, and decomposition of residues which contained less than 2% N resulted in a net immobilization of N over the first six weeks (Fox *et al*., 1990). Lignin concentration or the lignin/N ratio has also been demonstrated to provide an effective index for N release pattern (Melillo *et al*., 1982; Melillo and Aber, 1984). Berg and McClaugherty (1987) have suggested that N is not released from litter until decomposition of lignin commences.

In many forest species and in some legume species, it has been recognized that nutrient-rich leaf materials may be slow to release N and that this is not associated with lignin concentration. Vallis and Jones (1973) observed that *D. intortum* was slow to release N. They suggested that this was related to the presence of polyphenols in the material. This is plausible since polyphenols are reactive compounds that can form stable polymers with many forms of N (Martin and Haider, 1980; Stevenson, 1986). Palm and Sanchez (1991) obtained similar results from a range of plant leaf materials. Fox *et al.* (1990) in their study using shoots of many tropical legumes observed the best predictor of N mineralization was (lignin + polyphenol)/N. These results; they opined, are consistent with the idea that soil-incorporated plant lignin degrade to polyphenols, which, with other plant and microbial polyphenols, become the main constituents of recalcitrant N-containing humic polymers (Haynes, 1986). Tian *et al*. (1992) found that decomposition was strongly correlated with N, lignin and polyphenol concentrations. In turn, N mineralization was directly related to decomposition rate, and the patterns of release of P, Ca and Mg were similar to that of N.

In recent years, the role OM can play in food production systems has attracted a great deal of academic attention, particularly in light of the fact that little or no chemical fertilizer is used in traditional agricultural practices (Powell and Williams, 1995). There is no doubt that OM is an important contributor to soil fertility, especially in sandy soils with low clay content. The positive effects that OM has on the physical and chemical properties of dry lands are significant (Wild, 2003). Not only does OM have a beneficial effect on moisture holding and cation exchange capacity (CEC) of soil, but the decomposition of OM by micro-organisms in soil is crucial to the recycling of nutrients in the ecosystem. In short, adequate OM is essential to crop productivity, because it plays a vital role in providing the necessary nutrients and buffer properties, and is critical in creating and stabilizing soil aggregates (Wild, 2003).

Stocking and Murnaghan (2001) reported that the level of OM is also a good indicator of a soil's susceptibility to erosion. They explained that where the OM of a soil falls below 2 per cent, the soil is more prone to erosion, because soil aggregates are less strong and individual particles are more likely to be dislodged. The soils of the Northern Guinea Savanna of Nigeria, whose OM content is abysmally low, could therefore be susceptible to erosion. Thus, good soil management practices to boost soil OM through the application of manure and crop residues are pertinent for sustainability.

2.2.2 Effects of organic amendments on soil properties

The fertility of soils is determined by both their physical properties and their nutrient resources (Jones and Wild, 1975). The amount of available nutrients and their ease of release are strongly determined by the physical state of soil, chemical conditions are also critical to sustainability of the soil (Maconachie, 2007). Relatively high biomass yield has been reported to be due to other positive effects of organic materials on soil physical properties (like moisture retention) and

chemical properties (other macronutrients like calcium and magnesium) (Chen and Avnimelech, 1986; Wallace, 1996; Mutuo *et al*., 1999).

2.2.3 Effect of organic amendments on soil physical properties

Application of organic inputs into the soil generally results in improved soil physical conditions. Organic amendments exert this benefit largely through their effects on soil aggregation (Singh *et al*., 1991a; Meelu *et al*., 1994), which in turn influences encrustation, water infiltration, moisture content, drainage, tilth, aeration, temperature, bulk density, run-off, erosion, microbial activities and root penetration. Avnimelech *et al*. (1971) observed a change in soil aggregates from compact (dense) ones to friable aggregates with addition of organic manures. This change they observed allowed for better root penetration, water infiltration and solute diffusion in soil.

Obi and Ebo (1995) found that addition of poultry manure significantly decreased bulk density and increased total porosity and water infiltration in the soil. Mbagwu e*t al.* (1994) submitted that application of swine wastes at relatively low rates enhanced resistance of soil macro-aggregates to disruptive water forces. A decrease in soil organic matter levels following cultivation, or reduced application of soil organic amendments was reported (Papendick, 1994) to lead to a deterioration of soil structure, which creates difficulties with seedbed preparation, seedling emergence and root growth. In heavy soils, the major impact of organic residues is probably the improvement in soil aeration, whereas in sandy soils, the increase in water holding capacity is the most important (Janssen, 1993).

The effects of organic materials on soil physical properties depend on the residence time, quality and placement of the materials (Tisdall and Oades, 1982). The quality of organic nutrient resources has a significant role on the effectiveness of the materials on crop yields. Organic

input quality refers to the nutrient content and the concentration of lignin and polyphenol, two secondary compounds that regulate decomposition and bind with the products of decomposition (Okalebo and Woomer, 1994). Inputs that are higher in nutrients and lower in lignin and polyphenol, especially those with C: N ratios less than 10 will rapidly decompose and release more nutrients into soils. Low quality residues will have a greater and more durable effect on soil physical properties than high quality organic residues (Tian *et al*., 1993). Variations in decomposition and nutrient release patterns may have either positive or negative effects. In fields of fast-growing annual crops such as maize, there is need for rapid nutrient release to adequately provide nutrients at the early stages of growth, thus, the need for synchronization with crop uptake.

On one hand, synchrony can be promoted by manipulating plant demand. This can be done in several ways (for example, by controlling planting date and duration of crop growth, selecting crops with different growth patterns, or using different multiple cropping systems). Alternatively, both the release of nutrients and the efficiency of nutrient availability to the plant can be manipulated by controlling the quantity and quality of organic inputs such as crop residues and manures, which sometimes facilitate the retention of added inorganic inputs, and the timing of the input application (Myers *et* al., 1994). A combination of organic-inorganic nutrient sources is thought to improve the synchronization of nutrient release and subsequent uptake by the crop (Murwira and Kirchmann, 1993).

Decomposition and residual effects are enhanced when low quality organic materials are incorporated with a small amount of mineral N and then ploughed into the seedbed, preferably before the successive crop is planted (Okalebo and Woomer, 1994). The negative effect of these low quality organic materials they explained in terms of nutrient immobilization because the

microorganisms active in organic matter decomposition (e.g. bacteria, fungi) also obtain their nutrient requirements from the decomposing organic materials (Giller and Wilson, 1991). Hence, microbes have "priority access" to applied resources because of their size, abundance, distribution and metabolism (life-sustaining chemical activities).

Similarly, a guideline integrating the physical and chemical characteristics of organic inputs that influence their decomposition and nutrient release patterns could be employed in their handling and application to achieve their maximum effect. A decision tree to guide the allocation of organic resources used as inputs to soil (Giller, 2000; Palm *et al*., 2001) is shown in Figure 1. Soil fertility improvement of the savanna is also constraint by the chemical properties; a review of the effect of organic amendments on these properties is therefore pertinent.

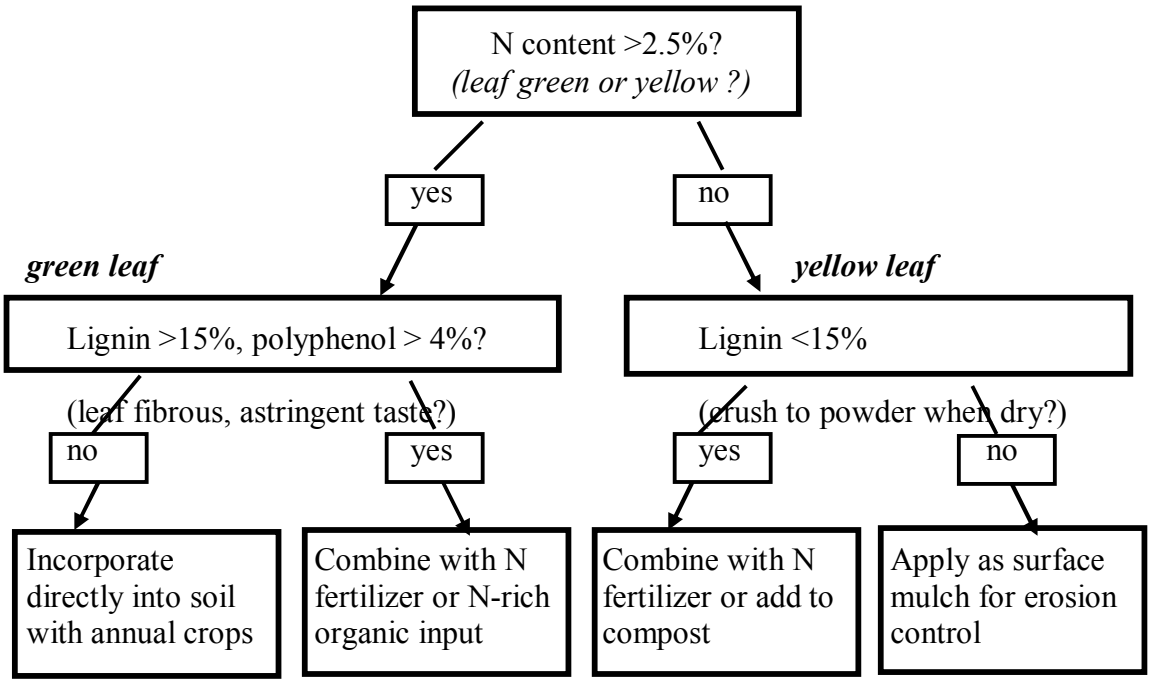


Figure 1: A decision tree to guide the allocation of organic resources used as inputs to soil (after Giller, 2000; Palm *et al*., 2001)

2.2.4 Effect of organic amendments on soil chemical properties

Changes in soil pH due to organic materials are complex (Iyamuremye and Dick, 1996), and are dependent on soil type and conditions, but in general have overall tendency to move the pH towards neutrality (Meelu *et al*., 1994). Decomposition of plant materials can yield various organic acids and carbon dioxide, both tending to lower the pH in neutral and basic soils (Black, 1968). Applications of plant materials to soil have been shown to increase soil solution pH (Bell and Besho, 1993). Under reduced soil conditions, application of organic materials can lead to an increase in pH due to dissolution of solid manganese (Mn) and Fe or by the ligand exchange occurring through replacement of terminal OH^- of Al and Fe hydroxyl oxides by organic anions (Hue and Ameni, 1989). The increase in pH can also be due to the release of ammonia (NH_3) (Hoyt and Turner, 1975) or addition of basic cations (Kretzschmar *et al*., 1991; Tisdale *et al*., 2003) from decomposing organic materials.

Organic residues with high amount of S could reduce soil pH as a result of the addition of sulphate thereby neutralizing the acidity produced by the oxidation of N during decomposition (Obatolu and Agboola, 1993; Van der Meersh *et al*., 1993). The sandy parent materials and low OM content have rendered the savanna soils low in buffering capacity, hence significant changes in the pH are observed with excessive use of nitrogenous fertilizers (Bache and Heathcote, 1969).

Soil OM is the major source of CEC for savanna soil. Cation exchange is the process whereby ions are held by electrostatic forces between the negatively charged clay or OM and positively charged ion (Stocking and Murnaghan, 2001). It affects the ability of soils to hold nutrients in a form that is readily available for plants uptake; and its values are closely related to the soil OM

and clay contents of the soil, both of which are characteristically low in soils of the savanna (Kowal and Kassam, 1978).

Meyer *et al*. (1994) observed that CEC values decline with pH and increase with higher levels of C and clay content. Organic matter content of soil is essential for minimizing erosion, and clay, which carries important minerals, serves as an indicator of fertility (Wild, 2003). The loss of clay results in a reduced capacity of soil to retain nutrients added to it in the form of fertilizers, therefore the clay fraction is crucial to the maintenance of agricultural sustainability. The high sand content characteristic of savanna soils underlies many of the problems associated with soil fertility, soil water availability and soil management (Kowal and Kassam, 1978) in the region. Neem seed cake (NSC) has been demonstrated to have high soil fertility potential, particularly with respect to nitrogen (Radwanski, 1969; Kethar, 1974; Idris *et al*., 1995; Kethar and Kethar, 1995; Agbenin *et al*., 1999 and 2008). However for a better understanding of the fertility potentials of NSC, a brief overview of the source of the material is pertinent.

2.3 Neem

Neem belongs to the family Meliaceae. It is the most versatile, multifarious trees of tropics, with immense potentials. It possesses maximum useful non-wood products such as leaves, bark, flowers, fruits, seeds, gum, oil and neem cake than any other tree species. Biologically neem has numerous bioactive ingredients with diverse applications. These bioactive ingredients are known to have antiallergenic, antidermatic, antifeedent, antiviral, antifungal, anti-inflammatory, antipyorrhoeic, antiscabic, insecticidal, larvicidal, anti-implantation, nematicidal, spermatocidal, and other biological activities (Ogbuewu *et al*., 2011). Neem is a natural source of eco-friendly insecticides, pesticides and agrochemicals (Brahmachari, 2004; Yar'adua, 2007). Neem is considered to be a part of India's genetic diversity (Sateesh, 1998). It is the most researched tree

in the world and is said to be the most promising tree of 21st century. The tree has adaptability to a wide range of climatic, topographic and edaphic factors. It thrives well in dry, stony shallow soils and even on soils having hard clay pan, at a shallow depth. Neem tree requires little water and plenty of sunlight (Sateesh, 1998). The tree grows naturally in areas where the rainfall is in the range of 450 to 1200 mm. However, it has been introduced successfully even in areas where the rainfall is as low as 150 to 250 mm. Neem grows on altitudes up to 1500 m (Jattan et al., 1995; Chari, 1996). It can grow well in wide temperature range of 0 to 49°C (Hegde, 1995). It cannot withstand water-logged areas and poorly drained soils. The pH range for the growth of neem tree lies in between 4 to 10. Neem trees have the ability to neutralize acidic soils by a unique property of calcium mining (Hegde, 1995).

Biologically active principles isolated from different parts of the plant include: azadirachtin, meliacin, gedunin, salanin, nimbin, valassin and many other derivatives of these principles. Meliacin forms the bitter principles of neem seed oil; the seed also contain tignic acid (5-methyl-2-butanic acid) responsible for the distincitive odour of the oil (Schmutterer, 1990; Uko and Kamalu, 2001; Lale, 2002). Neem comprises of 40 different active compounds called tetranortripernoids, or specifically limonoids. Terpenoids are natural products and related compounds formally derived from isoprene units. They contain oxygen in various functional groups. This class is subdivided according to the number of C-atoms in the same manner as are terpenes.

Terpenes are anyone of a group of hydrocarbons with a composition, $C_{10}H_{16}$, found in essential oils of some plants; while compounds having a structure like terpenes are referred to as terpenoidal compounds. The skeleton of terpenoids may differ from strict additives of isoprene units by the loss or shift of a fragment, generally a methyl group. These limonoids create

hormonal disruptions and prevents the insect from feeding, breeding or metamorphosing. The chief ingredient of neem, *Azadirachtin*, belongs to this group of limonoids (Espanol, 2009). The active principles are slightly hydrophilic, but freely lipophilic and highly soluble in organic solvents like, hydrocarbon, alcohols, ketones and esters (Schmutterer and Singh, 1995).

Azadirachtin is a secondary metabolite in neem tree seeds. The molecular formula is $C_{35}H_{44}O_{16}$, and molecular weight of 720.71 g mol^{-1}. It is a highly oxidized tertranortriterpenoid which boasts a plethora of oxygen functionality, comprising an enol ether, acetal, hemiacetal, and tetra-substituted oxirane as well as a variety of carboxylic esters (Wikipedia, 2009). This compound found in the seeds (0.2-0.8 % by weight) is a yellow-green powder, with a strong garlic-sulphur odour. Hazardous combustion products include carbon monoxide and carbon dioxide (Espanol, 2009). Owing to its promise in Agriculture, a review of the NSC as a source of nutrient would be discussed.

2.4 Neem seed cake as a source of nutrient

Neem seed cake (NSC) is the residue left after oil has been extracted from neem fruits and kernel (Vietmeyer, 1992; Wikipedia, 2009) through cold pressing and solvent extraction processes. It could be a major source of organic inputs into the soil; and through decomposition, supply plant nutrients and contribute significantly to the cation exchange capacity (CEC) and buffering capacity of savanna soils. Organo-mineral complexes are prevalent in soils and are important factors in pedogenesis and soil fertility, through formation of chelates. They influence micronutrient availability to plant roots considerably (Agbim and Adeoye, 1991).

Although, neem seeds from different geographical locations vary widely in their chemical composition (Radwanski, 1969), it contains about 7% N and a narrow C: N ratio of less than 10

(Agbenin *et al*., 1999). It has been reported that residue with a low N content or wide C: N ratio is often associated with a slow rate of decomposition while those with high N content or narrow C: N ratios usually decompose faster (Parr and Papendick, 1978). Similarly, residues of wide C: N ratio would decompose more slowly at the soil surface because of possible deficiency of N and other nutrients necessary to sustain microbial growth. When these residues are mixed or incorporated into the soil, such deficiencies are supplemented by the soil.

Although, NSC contains all nutrients needed by plants, it is the N content that is given most attention because of its critical nature in terms of requirement for plant growth (Mishra *et al.,* 1975; Idris *et al*., 1995; Agbenin *et al*., 1999 and 2008). Vietmeyer (1992) reported that NSC increased soil organic matter. This is particularly important in weathered soil because of rapid loss of soil organic matter in the tropics (Agbenin *et al*., 2008). Radwanski and Wickens (1981) found greater concentration of N, phosphorus (P), calcium (Ca), magnesium (Mg), and potassium (K) in NSC than farmyard manure. However, the benefits of NSC in increasing the concentration of N, K and Mg, and maintaining organic carbon (OC) of the soil must be weighed against the consequences of soil acidity, owing to the findings of Agbenin *et al.* (2008); neem seed cake increased exchange acidity markedly and decreased soil pH significantly in a closed-system incubation study.

The NSC is not only useful as a source of N but can increase N-use efficiency in addition to enriching OC of the soil and providing nutrients to crops (Radwanski, 1969; Kethar and Kethar, 1995). N-use efficiency of crops in the savanna is abysmally low (James, 2002) because of rapid leaching of nitrate-nitrogen (NO_3-N). Consequently, measures directed at mitigating nitrification rate will greatly reduce NO_3 leaching and increase N-use efficiency in the savanna. Several studies, particularly in India, have dealt with the use of NSC as a nitrification inhibitor to

improve N-use efficiency (Mishra *et al*., 1975; Parashar *et al*., 1980 and Kethar and Kethar, 1995). The retardation effect of neem residues and extracts on nitrification is due to their active ingredient *azadirachtin* and other di- and triterpenoidal compounds which are toxic to nitrifying bacteria (Singh *et al*., 1991b).

Patrao (1985) reported that neem cake sometimes seems to make soil more fertile than calculations predict. This he attributed apparently to an ingredient that blocks soil bacteria from converting nitrogenous compounds into nitrogen gas invariably lost to the atmosphere. So far, this finding, which might prove to be a major breakthrough, has not been pursued beyond the laboratory. If it proves real in everyday practice, it might boost the effectiveness of fertilizers everywhere - restoring to the soil that part of their power now lost by bacterial action (Vietmeyer, 1992). Due to the significance of the chemical constituents of NSC on its reactions in the soil, the chemical composition shall be reviewed.

2.5 Chemical compositions of neem seed cake.

Neem seed cake is obtained as a by-product during oil extraction of neem seed as well as the *azadirachtin* isolation. This is achieved either from whole fruit, de-pulped seed or kernel using expeller or solvent extraction (Okonkwo, 2005). The quality of NSC is determined by the amount of oil left in it, and also the process by which extraction was done (Espanol, 2009). Neem cake is very useful and contains some chemical compounds useful for agricultural application.

Neem seed cake has adequate quantity of NPK in organic form for plant growth. Being totally a botanical product with NPK content and other essential micro-nutrients as follows: N (2.0-5.0 %), P (0.5-1.0 %), K (1.0-2.0 %), Ca (0.5-3.0 %), Mg (0.3-1.0 %), S (0.2-3.0 %), Zn (15-

60ppm), Cu (4-20ppm), Fe (500-1200ppm), Mn (20-60ppm) (Wikipedia, 2009). In his study, Okonkwo (2005) submitted that the cake contains some important macro-nutrients required for plant growth such as 5 – 25% N, 1.08% P_2O_5 and 1.48% K_2O. It was also found to contain about 13 –35% crude proteins, 26 – 50% carbohydrate, 8 – 26% crude fibre, 2 – 13% fat, 5 – 18% ash and 1 – 17% acid insoluble ash (Vietmeyer, 1992). It is rich in both S-compounds and bitter limonoids. Similarly, Garba (2010) reported the nutrient content of neem seed cake used in his study as follows: N (2.67%), P (3.87%), K (0.21%), Ca (0.54%), Mg (0.32%) and organic carbon (37.40%).

2.6 Botany and agronomy of sorghum

Sorghum is the fifth most important cereal in the world in terms of both production and area planted. An estimated 6 – 6.5 million hectares is currently under guinea corn in the country (Aduayi *et* al., 2002). Nigeria is the second largest producer of sorghum in the world, with an annual production in excess of 8 million metric tonnes (United State Agency International Development, 2008). The bulk of its estimated production of about 8 million tonnes (NAERLS; 1996) are grown in the Northern Guinea and Sudan/Sahel ecologies. This covers states like Kaduna, Kano, Jigawa, Zamfara, Sokoto, Kebbi, Borno, Plateau, Bauchi, Adamawa and Gombe (Aba *et al*., 2005). Sorghum, like other cereals, is an excellent source of starch and protein and can be processed into starch, flour, grits and flakes which can be used to produce a wide range of industrial products (Palmer, 1991).

Sorghum is a vigorous grass that varies between 0.5 – 5.0 m in height. It is usually an annual plant and produces one or many tillers, which emerge initially from the base and later from stem nodes. The root system consists of fibrous adventitious roots that emerge from the lowest nodes of the stem, below and immediately above ground level. Roots are normally concentrated in the

top 0.9 m of soil but may extend to twice that depth and can extend to 1.5 m in lateral spread. The stem is solid, usually erect. Its center can be dry or juicy, insipid or sweet to taste. Center of the stem can become pithy with spaces. Leaves vary in number from 7 – 24, depending on cultivar. They are borne alternately in two ranks. Leaf sheaths vary in length between 15 and 35 cm and encircle the stem with their margins overlapping. The leaf sheath often has a waxy bloom. Leaves are from 30 – 135 cm long and 1.5 – 13 cm wide, with flat or wavy margins. Midribs are white or yellow in dry pithy cultivars or green in juicy cultivars. The flower is a panicle, usually erect, but sometimes re-curved to form a goose neck. The panicle has a central rachis, with short or long primary, secondary and sometimes tertiary branches, which bear groups of spikelet. The length and closeness of panicle branches determine panicle shape, which varies from densely packed conical or oval to spreading and lax. Grain is usually partially covered by glumes. The seed is rounded and bluntly pointed, from 4 – 8 mm in diameter and varying in size, shape and color with cultivar. As the leaves develop, the seedling becomes completely autotrophic and enters a period of intensive vegetative growth. Due to its C4 type of photosynthesis, sorghum has a high rate of dry matter production in relation to quantity of water absorbed (Chantereau and Nicou, 1994). Being a staple food, the tannin and protein content shall be subsumed under the nutritional quality of sorghum.

2.7 Nutritional quality of sorghum

All sorghum varieties contain phenolic compounds, which can influence the colour, appearance and nutritive value of a diet, and they can be divided into three groups: acidic phenolic, flavanoids and tannins. The presence of tannin reduces the nutritional value of a diet, mainly due to a decrease in the use of protein and a reduction in activity of digestive enzymes (Haslam, 1981). In consequence, nitrogen retention in protein and use of amino acids are reduced due to

the retention in protein digestibility (Mitaru *et al*., 1984; Elkin *et al*., 1995). The carbohydrates are also affected by tannin, possibly due to the formation of complex compounds which are difficult to digest (Mahamood and Smithard, 1993). Vitamins and minerals, especially those of the B complex, plus iron and calcium are all affected by the presence of tannin in the diet (Bagepalli *et al*., 1982; Chang *et al*., 1993).

The level of tannin in sorghum grains varies from 1.3 to 3.6 % in high tannin sorghum and from 0.1 to 0.7 % in low tannin sorghum (Myers *et al*., 1994). Hamid (2001) reported that low tannin sorghum increased protein content of grains. The increase in tannin content was attributed to solubilization which occurred as the grain took up water or to synthesis of polyphenols during germination. Although, early literature identified tannic acid as an anti nutritional factor in sorghum grain. However, more recent research indicates that tannic acid is not a sorghum component (Dykes and Rooney, 2006). Some sorghum varieties have pigmented testa containing condensed tannins, polyphenolic compounds that possibly give the seed a bitter taste and have been known to reduce intake, digestibility (particularly of protein), growth, and feed efficiency of livestock (Gilani *et al*., 2005; Waniska, 2000).

Environmental factors including agronomic practices affect grain composition. Grain sorghum protein content differs with the location at which the crop is grown (Deosthale and Mohan, 1970; Deosthale *et al*., 1972; Deyoe and Shellenberger, 1965). The level of nitrogen fertilizer also influences the quantity and quality of protein in sorghum (Deosthale *et al*., 1972; Waggle *et al*., 1967). Warsi and Wright (1973) noted that application of nitrogen fertilizer increased the grain yield and protein. Higher protein in response to fertilizer nitrogen was mainly the result of increased accumulation of prolannin, a poor quality protein, in the grain (Sawhney and Naik, 1969). The level of nitrogen fertilizer had no effect on the mineral composition of grain

sorghum. However, the mineral content of the sorghum increased with increasing levels of phosphorus fertilizer (Deosthale *et al*., 1972).

Tannins have a yellow-white to brown color and a faint, characteristic odour. Exposure to light deepens the color. They all taste bitter and are astringent. Water, acetone, and alcohol dissolve tannins readily, but benzene, ether, and chloroform do not. Heating to 210° C (410° F) causes decomposition, accompanied by formation of pyrogallol and carbon dioxide. The chemical property that provides the basis for most uses of tannins is its ready formation of precipitates with albumin, with gelatin, and with many alkaloidal and metallic salts. The ability of tannins to transform proteins into insoluble products resistant to decomposition leads to their use as tanning agents. Ferric salts react with tannins to give bluish-black products that are useful as inks. Tannins are used as mordants for dyeing cloth, as sizes for paper or silk, and as coagulants for rubber. The precipitating properties of tannins are used in clarifying, or cleaning, wines and beer. Tannic acid is valuable as an external medicine because it is astringent and styptic (Microsoft Premium Student DVD Encarta, 2009).

2.8 Growth and yield components of sorghum

Contributing components to sorghum yield could be divided into three parts: (a) yield components, (b) morphological traits, and (c) physiological traits. Yield differences in sorghum are associated with panicles per square meter or panicles per plant, kernels per panicle and kernel weight (Maman *et al*., 2004). Since yield components are interrelated, have compensatory effects, and develop sequentially at different growth stages, they could be used to characterize yield variations and to expand physiological understanding of crop morphology. Maman *et al*. (2004) found that sorghum grain yield is highly correlated with all the abovementioned yield components. However, selection according to the yield components only, does not give a detailed insight into the physiological basis of the yield difference.

In sorghum, the number of leaves per plant and plant height are among the two most important morphological traits. Leaf number is an important determinant of a sorghum plant leaf area, since it sets the initial benchmark of green leaf area per plant (Borrell *et al*., 2000a). So, if a sorghum plant can maintain higher number of leaves at the grain filling period and as a consequent higher photosynthesis, it may yield more. This is especially the case where the carbohydrate is a main harvest component (Thomas and Smart, 1993). Plant height is associated with the growth and biomass of the crop: the taller the plant, the higher dry biomass yield and, potentially, soluble sugar yield (Sher *et al*., 2011).

From a physiological standpoint, there are two main approaches in order to achieve higher grain yields; that is, increase in harvest index (HI) and increase in dry matter accumulation (Specht *et al*., 1999). DMY is the single most prominent parameter indicating the forage yield of any crop (Sher *et al*., 2011). Grain yield of sorghum may be also described as a function of dry matter accumulation and the amount of the dry matter partitioned to the grain. Assuming there is no water limitation, biomass production is the product of the solar radiation over the duration of the crop period (Q), corrected for the amount of intercepted radiation by the crop canopy (I), and the conversion of this chemical energy into plant dry matter (RUE) (Richards, 2000). This can simply be expressed as:

$$\text{Biomass} = \sum_{\text{sowing}}^{\text{harvest}} Q \times I \times RUE \qquad (1)$$

From equation (1) it is seen that the ways to increase total biomass are as follows: First, to increase the duration of crop photosynthesis so that there is an increase in total solar radiation received. The second term in equation (1), the amount of radiation intercepted by the canopy, is the component of biomass production that is perhaps most amenable to genetic manipulation.

The development of leaf area more quickly early in the season and an appropriate leaf area index (LAI) can contribute to this term (Soufizadeh *et al*., 2006).

Delayed leaf senescence or stay-green is also associated with yield improvement of sorghum (Borrell *et al*., 2000a, b). Green leaf area at physiological maturity (GLAM) has proved to be an excellent indicator of stay-green in this crop (Borrell *et al*., 2000a). This characteristic can be assessed visually by counting the number of green leaves at this stage. Rajcan and Tollenaar (1999) showed that the stay-green characteristic of a newer maize hybrid compared with an older hybrid was associated with a larger source/sink ratio during the grain-filling period. A further step in understanding the physiological basis of yield improvement in this crop is to determine the dry matter allocated to the different plant organs. It has been proved that a crop genotype that invests more photosynthetic assimilates in leaf mass can yield more under potential condition (Soufizadeh, 2005). Such partitioning pattern can best results in higher grain yield if it accompanies with a higher HI. Higher HI indicates a better partitioning of dry matter into reproductive organs. Studies of historical genotypes often show that genetic improvement in yield potential has resulted from increases in HI (Lawes, 1977; Austin *et al*., 1980; Penga *et al*., 2000; Riggs *et al*., 1981), which is associated with ideotype characters, e.g., short stature in wheat (*Triticum aestivum* L.) and the uniculm habit in maize (*Zea mays* L.) and sunflower (Sedgley, 1991). So, increasing the HI at a given biomass is a promising breeding goal. Information on physiological basis of yield improvement in sorghum is limited compared to other cereals such as wheat, barley and maize.

A mechanism of resistance, known as stay-green (Rosenow, 1977), is indicated by maintenance of green stems and upper leaves when water is limiting during grain filling. Green leaf area at maturity is used as an indicator of postanthesis drought resistance in sorghum (Rosenow *et* al.,

1983). Positive relationship between green leaf area duration and grain yield have been observed in a range of cereals, including wheat, maize, oat and sorghum (Henzell *et* al., 1992). Sorghum genotypes with stay-green trait continue to fill their grain normally under drought (Rosenow and Clark, 1981) and exhibit increased resistance to charcoal rot (Rosenow, 1984) and lodging (Henzell *et al*., 1984; Woodfin *et al*., 1988). Increased accumulation of soluble sugars in stay-green types is associated with greater functional leaf area during grain filling; thereby reducing their dependence on stored assimilates from the stem to fill grain (Duncan *et al*., 1981; McBee *et al*., 1983). However, growth conditions will govern the weight of individual grains, i.e. the yield component single grain mass. As growth phases are highly independent of each other, periods of stress can be traced in the poor development of a yield component (Lambert, 1983; Ong and Monteith, 1984).

2.9 Nutrient requirement of sorghum

Samsorg 17 (*SK-5912*) is a medium-maturity semi-dwarf improved pure line variety widely cultivated in the Northern Guinea Savanna of Nigeria (Ogunlela and Yusuf, 1988). Mokunye (1979) submitted that *SK-5912* is one of the most popular and high yielding sorghum varieties grown in Northern Nigeria. It responded up to 22 kg P/ha, twice the recommended rate at Samaru. Striga infestation on plots of this variety is slight (Ogunlela, 1983). Doggett (1965) believed that striga resistant sorghum would produce few striga strains, but that such resistance mechanism operates after germination of the striga seed. Grain sorghum response to K fertilization in the savanna soils is influenced by variety. Although, 50 kg K_2O ha^{-1} was reported to be adequate (Ogunlela and Yusuf, 1988), the optimum K recommendation for sorghum in the Northern Guinea Savanna is 32 kg K_2O ha^{-1}. Ogunlela (1988) also reported that 60 kg N and 11 kg P ha^{-1} will meet the fertilizer requirement of dry land sorghum in savanna soil of northern Nigeria. However, he opined that response to N will depend on yield potential as determined by

factors such as timely planting and rainfall distribution. Nitrogen fertilization is likely to improve the nutritional quality of sorghum grain by improving crude protein content (Ogunlela and Okoh, 1989).

It is pertinent to mention however that the most widely adopted practice in field experiment is the application of P and K before sowing so as to promote root development and good stand establishment in early crop life, where straight fertilizers are used. Owing to the significant effects of N, P and K on growth and nutrition of sorghum, their interactions and availability in soils are subsumed under their occurrence, mineralization and fertilizer use efficiency.

2.10 Nitrogen, phosphorus, potassium, calcium and magnesium: their interactions and availability

A mineral element is considered essential to plant growth and development if the element is involved in plant metabolic functions and cannot complete its life cycle without the element (Tisdale *et al*., 2003).The importance of these mineral elements and their release as nutrient elements (as ions) has since become a central concern of soil fertility studies. The static concept of soil as a box filled with broken-down pieces of rock gave way to a dynamic, evolutionary one. It is now known that nutrients are continually released in the soil in forms plants can absorb and that the role of fertilizers is to supplement this quantity in order to obtain desirable yields (Millar *et al.,* 1965).

2.10.1 Nitrogen in the soil

Nitrogen (N) is a vitally important plant nutrient and is the most frequently deficient of all nutrients. This is because of the relatively large amount required by plants and its mobility in the soil. Nitrogen is of particular interest because it is usually the most limiting nutrient for crop

production, and fertilizer N represents a major variable input cost (Gil and Fick, 2001). Soil N has a variety of pathways for input and outflow and these can have important negative environmental impacts when lost from the production system.

Plants normally contain between 1 and 5% N by weight, which is adsorbed by plants as nitrate (NO_3) and ammonium (NH_4) ions and as urea. In moist, warm, well aerated soils, the NO_3 form is dominant (Tisdale *et al.,* 2003). Ammonium (NH_4^+), being readily adsorbed, is not easily leached, but, under most normal conditions, its rapid conversion to NO_3 or organic forms ensures that the amounts present are generally small (Williams, 1967). Steele and Vallis (1988) in their own opinion submitted that under certain conditions, soil microflora can compete with plants for NH_4 and convert it into microbial proteins, thus immobilizing the N into an organic, temporarily unavailable form. However, plants uptake of NH_4 proceeds best at neutral pH values and is depressed by increasing acidity. Absorption of NH_4 ions by roots reduces Ca^{2+}, Mg^{2+}, and K^+ uptake while increasing absorption of phosphoric ion ($H_2PO_4^-$), sulphate ion (SO_4^{2-}) and chloride (Cl^-) (Tisdale *et al*., 2003). They opined further that rhizosphere pH decreases when plants receive NH_4 ion and are caused by hydrogen ion (H^+) exuded by the root to maintain electro-neutrality or charge balance inside the plant. Differences in two pH units have been observed for NH_4 versus NO_3 ion uptake in wheat. This acidification can affect both nutrient availability and biological activity in the vicinity of roots (Tisdale *et al*., 2003).

The rate of NO_3^- uptake is usually high and is favoured by low pH conditions. When plants absorb high levels of NO_3^-, there is an increase in organic anion synthesis within the plant coupled with a corresponding increase in the accumulation of inorganic cations (calcium (Ca), magnesium (Mg), potassium (K)). The growth medium will become alkaline, and some carbonic

ion (HCO_3^-) can be released from the roots to maintain electro-neutrality in the plant and in the soil solution (Tisdale *et al*., 2003).

Seasonal patterns of soil inorganic N has been reported by Mazzarino *et al*. (1991) and Turner (1997) for natural grasslands. The low soil inorganic N early in the season was attributed to high rates of plant N uptake at that time, as suggested by Wedin and Tilman (1990), and to the low rates of soil N mineralization. Adequate soil moisture and temperature in the late season together with slow growth rate and, consequently, low soil N uptake by the plants, may have been the main reasons for the observed increase in soil inorganic N at that time.

The key to unlocking the tremendous amounts of nutrients that can be generated from NSC for plant use depends in almost all cases on the microbial decomposition of these residues. Microbial growth and activity within the heterogenous highly dynamic soil environment in which many components are subject to rapid change and frequent fluctuations are controlled by soil factors and residue factors (Parr and Papendick, 1978). Ellert and Bettany (1988) and Vanderpitte *et al*. (1995) opined that N mineralization from NSC was not only a function of substrate N concentration but also of the capacity of microbial community to adjust to substrate quality and composition affecting their growth and activity. It has however been submitted that N mineralization is unquestionably influenced by temperature, soil depth, moisture, space, oxygen, pH and availability of substrate (Cassman and Munns, 1980; Stanford and Smith, 1972), all of which affect the growth and activity of microbial community.

With respect to the presence or absence of microorganisms required to mediate the process of mineralization-immobilization, it is generally assumed that a varied suite of organisms is always present and that processes should not be limited by the absence of a particular organism.

However, following the commencement of conditions suitable for a process, there may be a delay in end-products but an increase in specific microbial populations (Myers *et al*., 1994). They submitted further that if moisture and temperature conditions are suitable, N mineralization proceeds at a rate dependent upon the quantity and quality of organic matter. Delays in mineralization occur following the resumption of appropriate moisture or temperature conditions after prior conditions such as prolonged soil drying or extreme temperatures have resulted in a population decline. Similarly, when there is a change in substrate availability (e.g. when organic materials are added), there may be a delay in microbial proliferation. If the nutrient content of the added material is low, but organisms are able to use the substrate as a C source, net immobilization occurs.

Leeper (1964) submitted that information about the rate of NO_3^- production in a soil can be gained by soil sampling in the field at monthly intervals. Also, it can be achieved from test in the laboratory for its 'nitrifying power' by incubating it in a moist state at a moderate temperature (say 22^0C) and analyzing it after two or three weeks for its NO_3^- content. Furthermore, test may be done on the untreated soil, or on soil to which a small amount of ammonium sulphate [$(NH_4)_2SO_4$] or blood (an easily attacked protein) has been added. He opined further that the ability of the soil to nitrify its own protein is the most valuable of the three; it measures simultaneously the quality of the soil's organic matter – which may depend on its recent treatment – and the efficiency of the ammonifying and nitrifying organisms.

2.10.2 Phosphorus in the Soil

Phosphorus (P) is one of the most limiting macronutrients in savannas (López-Gutiérrez *et al*., 2004b), where seasonality strongly affects nutrition processes. P availability in soils is controlled by both the sizes of P pools and the transformation rates among these pools (Zou *et*

al., 1992). Similarly, Jones and Wild (1975) and Uyovbisere (1979) submitted that the availability of P status of savanna soils is a function of P content of the parent material which is low for most of Nigerian savanna.

The total P is generally low with values ranging from 13 to 630 ppm. Average of about 100 to 400 ppm in savanna soils have been reported (Mokwunye, 1979). Of these amounts less than 10% is said to be in active/labile Al-P, Fe-P and Ca-P forms (Uyovbisere, 1979). It is generally recognized also that organic P becomes available to plants only after it has been mineralized and results of Eid *et* al. (1954) and Friend and Birch (1960) have shown that it may then be of considerable importance in plant nutrition. However, changes in specific P mineralization with change in water potential or temperature is not affected by fertilizer application (Grierson *et al*., 1999). This suggests that although specific P mineralization could be greater in fertilized soils, environmental control of P mineralization will be the same for both fertilized and unfertilized soils.

In soils, P may exist in many different forms. In practical terms, P in soils can be thought of existing in three "pools"; solution P, active P and fixed P (Busman *et al*., 2008). Solution P is the immediate readily available form of P in soil and the soils tend to maintain an equilibrium concentration of solution P with the adsorbed P (Van Noordwijk *et al*., 2004). Plants take up inorganic P from the soil solution; P makes up only a minimum fraction of total soil P. Also, solution P is rapidly replenished by P from labile inorganic P (P_i) minerals and by biochemical mineralization of labile organic P (P_o). Tiersen (1991) submitted that the amount of P available to plants is determined by the pool size of labile P_i, the transformation rates between labile and slowly reacting P_i and the amount and cycling rate of mineralizable P_o.

Knowledge about the role of micro-organisms in P cycling at conditions of constant soil respiration rates and constant size of microbially bound P is lacking (Oehl *et al*., 2001); although, numerous laboratory and field studies indicated the important role of microbially bound P (P_{mic}) in soil P dynamics (Brookes *et al*., 1984; Gijsman *et al*., 1997; McLaughlin *et al*., 1988a; Oberson *et al*., 1996). Soil micro-organisms affect P dynamics by their activity (Stewart and Tiessen, 1987; Tiessen *et al*., 1984) and represent an organic P (P_o) compartment which can act as a sink and source of plant-available P (Macklon *et al*., 1997).

Microbial P consists of about 60% of nucleic acids, 20% acid-soluble inorganic P (P_i) and organic P-esters consisting of sugar and nucleotide esters and various phosphorylated co-enzymes and polyphosphates, and less than 10% of phospholipids (Alexander, 1977; Stewart and Tiessen, 1987). The proportion of P in inorganic or organic forms in micro-organisms depends on the P concentration in the soil solution; the cell P content and the age of the cells (Hedley and Stewart, 1982).

During the last two decades, Oehl *et al.* (2001) opined that several methods have been developed to estimate P_{mic} using fumigation extraction methods. Chloroform (Brookes *et al*., 1982; Hedley and Stewart, 1982) or hexanol (McLaughlin *et al.,* 1986) have been recommended as a fumigant. A few years ago, a fumigation-sorption-extraction method was proposed (Morel *et al*., 1996), using deionised water for extraction and correction for sorption during fumigation and extraction. P release from microbes occurs by P_i and P_o efflux (Maloney *et al*., 1987) and by microbial decay (Oehl *et al*., 2001).

The cycling of P includes geochemical dynamics and has received far less attention to the role which this element plays in ecosystem processes. One of the major barriers to studies of P

processes, they reported, is the inadequacy of available analytical techniques (Zou *et al*., 1992). In contrast to N, the atmosphere does not provide P. Instead, orthophosphates, $H_2PO_4^-$ and HPO_4^{2-}, originate largely from primary and secondary minerals and/or from organic sources (College of Tropical Agriculture and Human Resources, CTAHR, 2009). Rehm and Schmitt (1993) submitted that HPO_4^- ion dominates in calcareous soils and is the form of P absorbed when crops are grown in the soil with pH greater than 7.0 while $H_2PO_4^-$ ion dominates in acid soils and is the ionic form absorbed when the soil pH is less than 7.0.

Zvomuya *et al*. (2006) submitted that there is evidence from recent studies that N and P indices obtained by rapid fractionation methods can be successfully used as indicators of plant-available nutrients in organic amendments. As Velthof *et al*. (1998) demonstrated in a pot experiment that plant availability of P from composts, manures, and plant materials could be predicted from iron-oxide-extractable P. Furthermore, sequential P extraction has long been widely used to partition extractable soil P into various functional inorganic and organic fractions (Chang and Jackson, 1957; Hedley *et al.,* 1982). Recently, the fractionation procedure developed by Hedley *et al*. (1982) has been adapted and modified for sequential extraction of soil organic P (Ajiboye *et al*., 2004; Dou *et al*., 2000; Sharpley and Moyer, 2000).

P availability in soils depends on P pool sizes, rates of geochemical P dynamics, and the rates of biologically mediated P transformations. However, studies of P cycling in terrestrial ecosystems have focused on the concentrations of soluble and particulate P fractionation scheme developed by Hedley *et al.* (1982). Furthermore, many workers (Cole *et al*., 1977; Greb and Olsen, 1967; Thompson *et al*., 1954) have cited mineralization rates for soil organic P, but there are few reports specifically of the mineralization rate of plant organic P added to soil (Dalal, 1977).

Similarly, several studies have related the P fractions in tropical soils to plant growth (Guo and Yost, 1998; Oberson *et al*., 1999, 2000; Phiri *et al*., 2001a, and 2001b; Lehmann *et al*., 2001; Buhler *et al*., 2002). The results obtained from these studies suggest that the P in different pools are controlled by physicochemical factors such as sorption and desorption, and by biological reactions such as mineralization and immobilization. However, hypotheses about cycling and transformation in weathered tropical soils underscore the importance of organic P (P_o) in replenishing the plant available P pool (resin extractable P) in low fertilizer P input agricultural systems (Tiessen *et al*., 1984). This is contrary to the findings of Harrison (1987) and Verhoeven *et al.* (1990) who reported that P mineralization may play an important role in plant nutrition in eco- and low input agrosystems.

Although, P release from recently added organic materials can be assessed during decomposition studies (Palm *et al*., 1997; George *et al*., 1999), no accurate method for the quantification of soil P mineralization has been established so far because of the high chemical reactivity of P_i (Frossard *et al*., 1996). In recent years, new analytical techniques have been proposed to handle the problem of immediate P_i sorption. Zou *et al*. (1992) used anion exchange resins to extract P_i recently released from P_o. Frossard *et al*. (1996) used isotopic exchange kinetics and changes in resin-extractable P_i to evaluate the quantities of P mineralized after the addition of specific P_o compounds. Walbridge and Vitousek (1987) and López-Hernandez and Niño (1993) applied isotopic dilution techniques to study gross soil P mineralization assuming that P_i release from non-labeled P_o decreases the specific activity of soil solution measured in the incubation experiment (SA) of P_i in acid fluoride and resin extracts, respectively.

Although ^{32}P (McAuliffe *et al*., 1948) has been used to estimate net P mineralization rates (Walbridge and Vitousek, 1987), information about gross P mineralization and immobilization

rates that underlie such net rates has not been available. The lack of this important information results largely from the limitation of analytical techniques (Zou *et al*., 1992). However, White and Ayoub (1983) suggested that any benefit in P supply to be derived by a crop following the addition of plant residues to soil will depend on the extent to which the crop can make use of the plant P that has been adsorbed by the soil or immobilized by microorganisms. Since, mineralization and immobilization is panacea to nutrient availability by micro-organisms, it shall be subsumed hereunder.

2.11 Nutrient mineralization and immobilization

Mineralization and immobilization are the process of transformation of mineral elements in complex organic molecules into simpler inorganic forms and again conversion of these transformed simple products into complex combinations respectively (Biswas and Mukherjee, 2005). Nutrient release from organic inputs is more gradual and presumably more in synchrony with crop nutrient demand than with the inorganic fertilizers (Kayuki and Wortmann, 2001). Decomposition occurred more rapidly when the plant materials were incorporated compared with surface application, but application method did not affect yields. Mineralization rates of N, Ca and Mg were more dependent on their respective concentrations rather than on other plant tissue characteristics. Plant materials generally contain inadequate P to be a source of nutrients in balance with crop demand and maybe more effectively used in combination with inorganic P (Kayuki and Wortmann, 2001).

Net mineralization consists of different processes: flush effects, basal mineralization, re-mineralization (these three fluxes constitute gross mineralization), and biological immobilization (Mary and Recous, 1994). Flush effects are caused by sequences of drying-wetting or freezing-thawing (Chapin *et al*., 1978; Mary and Recous, 1994). Basal P mineralization can be defined as

the gross P mineralization in the absence of flush effects, that is, at constant soil respiration rate. It presents the basal potential of a soil to deliver P_i from P_o to the soil solution. Re-mineralization takes place due to recycling of microbial P during microbial death and predation and signifies mineralization of recently synthesized P_o. Biological P immobilization corresponds with the assimilation of P by soil microbes (Oehl *et al*., 2001).

All three P mineralization processes include biological and biochemical processes. Biological P mineralization occurs when cell P_i from decaying cells is released to the soil solution and when P_o compounds are hydrolyzed on the outer surface of the living cell membranes (Burns, 1982). The latter is driven by the micro-organisms' need for energy (McGill and Cole, 1981) and for P (Lughtenberg, 1987; Halvorson and Nakata, 1987). Biochemical P mineralization is driven by phosphatase exoenzymes (Burns, 1982; Sinsabaugh *et al*., 1993). Since the functionality of the exoenzymes may be kept through stabilization by sorption and association on soil compounds (Leprince and Quiquampoix, 1996; Burns, 1982), biochemical P mineralization may occur in the absence of biological activity (Zou *et al*., 1992; Seeling and Zasoski, 1993).

Barak *et al*. (1990) reported that the net mineralization of both C and N were S-shaped functions of time, indicating that simple first–order substrate-dependent kinetics were not applicable. Also, they observed that the net mineralization of C and N were strongly correlated with each other and reflect the C/N ratio of the substrate and the C/N ratio and microbial efficiency of the microbial biomass. High quality residue would lead to greater mineralization of nutrients while low quality residue would contribute more to aggregate stability (Agbim and Adeoye, 1991). Crop residue management should therefore aim at synchronizing N release pattern with plant growth demands. Smith and Sharpley (1990) reported that to avoid appreciable suppression of soil N mineralization and concurrently supply the needs of soil microbes during crop residues'

decomposition, minimum N residue contents of 1.5 to 1.7% (C/ N ratios of 30:25) have been suggested (Allison, 1973).

It was submitted further that an initial depression in net N mineralization of both indigenous and fertilizer-derived soil organic N may occur with non-legume residue additions, and the depression is enhanced when the residues are incorporated rather than left on the soil surface. Moreover, the relative depression is greater with the newly formed, fertilizer-derived soil N than the older, indigenous soil N. This, Smith and Power (1985) attributed to the newer soil N being more labile which is preferentially appropriated by the soil microbes in decomposing crop residues.

2.11.1 Mineralization and immobilization of phosphate

In an average soil, approximately 50% of total P is organic. Thus, soil organic P is a very important aspect of the P cycle (CTAHR, 2009). This P fraction however becomes available for plant uptake after it is mineralized (Richardson *et al*., 2000). It has also been reported that P_o mineralization supplies significant amounts of plant P in grasslands (Cole *et al*., 1977), and perhaps in some perennial (Havlin *et al*., 1984) and organic (Oehl *et al*., 2001) agricultural systems. The various sources of organic P include phytin, nucleic acids, and phospholipids. Like N, organic P is converted to inorganic phosphate (PO_4) through the process of mineralization. The immobilization of inorganic PO_4, in contrast, is the reverse reaction of mineralization. During immobilization, micro-organisms convert inorganic forms to organic PO_4, which are then incorporated into their living cells (Oehl *et al*., 2001).

Organic P mineralization results in the accumulation of plant-available P in soils, and this increases the potential for P loss and degradation of aquatic system (Zvomuya *et al*., 2006).

Therefore, regardless of the condition of organic material when soil-applied, there is a need to develop practical methods of predicting plant P uptake from the amendments to better manage P addition for reduced pollution of sensitive ecosystems. P availability from amended-soil can be measured directly using crop uptake in pot and field experiments or indirectly using laboratory incubation of the amendments in soil (Eghball *et al*., 2005). However, these field and laboratory studies have limited practicability because they are time consuming and laborious (Zvomuya *et al*., 2006).

Mineralization and immobilization of P occur simultaneously in the soil. Ultimately, the C: P ratio determines whether there is net mineralization or net immobilization. When the C: P ratio is less than 200: 1, the net mineralization prevails. This indicates that there is enough P in the soil to sustain both plants and micro-organisms. However, when the C: P ratio is between 200: 1 and 300: 1, the net immobilization and mineralization rates are fairly equal. But, when the C: P ratio is greater than 300: 1, net immobilization occurs. During immobilization, there is not enough P to sustain both plants and micro-organisms, and so, micro-organisms scavenge the soil for P (CTAHR, 2009). Nye and Bertheux (1957) also suggested that high C: P and N: P ratios maybe a characteristic of P-deficient regions.

Barrow (1960) affirmed that mineralization of one element also depended on the concentration of the others. Freney and Spencer (1960) and Hesse (1957) observed that the application of inorganic sulphur (S) resulted in an increase in the mineralization of organic S. Consequently, Freney and Spencer (1960) suggested that this effect might well equally apply to other constituents of organic matter (e.g. N and P) and that this would be one of the several beneficial results arising from a more rapid turnover of organic matter. Birch (1961) found that non-extractable plant P_o was not mineralized during three months' incubation. This was also taken as

a first approximation by White and Ayoub (1983) in their study, except that there was a slight increase in the extractable soluble inorganic (P_i) and organic (P_o) in the first 24 hours, before any microbial uptake of P had occurred. This was attributed to hydrolysis of organic phosphates by plant phosphatases, which Barrow (1960) referred to as "premature mineralization".

The significance of the effect of temperature and N and P fertilization on the mineralization of organic P to peasant agriculture cannot be over-emphasized (Acquaye, 1963). This could be attributed to the role it plays in P availability; and the organic P may be visualized as a reservoir for the supply of available inorganic P. Black and Goring (1953) has pointed out that this self-fertilization, arising from the return of organic P in the litter and its subsequent mineralization, constitutes the primary means of increasing P availability from the low level usually found in parent materials. This sort of turnover can be substantial in tropical soils, especially in regions where rains are preceded by a drought (Acquaye, 1963). Thompson *et al.* (1954), however, submitted that because of the fast rate of mineralization under tropical conditions the greater fraction of the organic matter is probably in the form less susceptible to mineralization. The resistance of organic matter to mineralization increases with the degree of decomposition and the increase in resistance is greater with organic P than with organic N (Thompson and Black, 1950). The effect of P and N fertilization appears therefore not only to improve the N and P contents of the litter and thus its mineralization, but also to enhance the mineralization of the organic matter already present in the soil (Acquaye, 1963).

Decomposition processes can further increase P availability by releasing CO_2, which forms H_2CO_3 in the soil solution, resulting in the dissolution of primary P-containing minerals (Tisdale *et al.*, 2003). Also, organic acids released during decomposition may help dissolve soil mineral P (Sharpley and Smith, 1989). In soils with high P-fixing capacities, organic compounds

released during decomposition processes may increase P availability by blocking P-adsorption sites (Easterwood and Sartain, 1990) or via anion exchange (Kafkafi *et al*., 1988). Some amino acids, however, can increase P availability by blocking P-adsorption sites (Kafkafi *et al*., 1988).

Adding plant residues to soil can increase soil test P (Black, 1973; Bumaya and Naylor, 1988; McLaughlin *et al*., 1988a; Li *et al*., 1990; Vanlauwe *et al*., 2000), increase P_o (Dalal, 1979), increase P uptake by succeeding plants (Blair and Boland, 1978; Till and Blair, 1978; Dalal, 1979; Thibaud *et al*., 1988; Vanlauwe *et al*., 2000), and decrease soil P sorption (Singh and Jones, 1976; Bumaya and Naylor, 1988). However, plant P availability do not always increase following green manure incorporation (McLaughlin and Alston, 1986; Groffman *et al*., 1987; Bumaya and Naylor, 1988; McLaughlin *et al*., 1988b) since the soil microbial biomass and soil sorption processes compete for available P (Cole *et al*., 1977; White and Ayoub, 1983). Similarly it was reported that the addition of organic P is expected to increase the mineralization of soil organic P (Acquaye, 1963 and Fabry, 1963). During the decomposition of organic materials, there is usually initial luxury absorption of inorganic P by soil micro-organisms in the soil receiving high levels of soluble PO_4, which is then followed by enhanced mineralization of organic P as incubation proceeded (Enwezor, 1966).

The PO_4 contained in crop residues, or in green manure ploughed into soil, can increase total soil P considerably (White and Ayoub, 1983). But published results on the efficacy of such materials in increasing the availability of P to a subsequent crop are remarkably inconsistent, whether availability is measured by chemical extraction (Chauhan *et al*., 1979, 1981; Floate, 1970) or by plant uptake of P (Burnett and Tackett, 1958; Floate, 1970). This situation arises for one or more of the following reasons: (a) the use of materials of widely different C: P ratio which affects the kinetics of microbial immobilization and remobilization of inorganic P during

their decomposition (Birch, 1961; Enwezor, 1966); (b) the possibility that decomposition products (organic acids and anions) may have altered the availability of native soil P (Nagarajah *et al*., 1970; Struthers and Sieling, 1950); (c) variable mineralization of resistant organic P compounds in the residues (Dalal, 1977); and (d) differences in the P sorption characteristics of the soils used (Singh and Jones, 1976). Most studies report that net P immobilization occurs when the total P concentration of plant tissues incorporated into soil is below 2 to 3 g kg^{-1} (Yadvinder-Singh *et al*., 1992), although Bumaya and Naylor (1988) reported that net P mineralization occurred when plant tissue P concentrations were as low as 1 g kg^{-1}.

The factors affecting mineralization and immobilization of P are the same as that which affect N mineralization and immobilization: temperature, moisture and aeration (CTAHR, 2009). Plants debris containing higher amounts of lignin is resistant to microbial attack and hence mineralization proceeds slowly in organic materials like sawdust (Microsoft student with Encarta Premium 2008 DVD). The lignin content plant-residues may therefore serve as an index of the vulnerability of organic residues to microbial attack.

2.11.2 Mineralization and immobilization of nitrogen

A major difficulty in measuring N mineralization in the field is the leaching of nitrate (Hadas *et al*., 1989). The effect of sub-optimal moisture and temperature on the rate of N mineralization has been established in laboratory studies (Stanford *et al*., 1973; Stanford *et al*., 1975; Stanford and Epstein, 1974) and can be accounted for quantitatively. Hitherto the few studies on incorporated neem seed residue in Nigeria ignore this crucial factor. However, it is important for nitrate movement study to employ techniques which replaces soil samples at their original location in polyethylene bags, thereby disturbing the soil (though not dried, crushed or stored)

and incubating under the varying temperature and aeration conditions of the field (Smith *et al*., 1977; Westerman and Crothers, 1980).

Production of NO_3-N has often been used as the indicator of net mineralization in soils (Cassman and Munns, 1980; Hadas *et al.,* 1989) as NH_4-N concentrations in aerated soils have been found to be small and constant during crop growth (Harmsen and Van Schreven, 1955). The process in which inorganic N is transformed into organic N is defined as N immobilization (Jansson and Person, 1982). The aim of agricultural N management is to enhance net N mineralization at times when plants need N and to synchronize soil N mineralization (N release) with uptake by the plant (Campbell *et al*., 1995; Murwira and Kirchmann, 1993).

Nutrient mineralization patterns during decomposition of organic materials are related to the chemical composition, or quality of the organic inputs (Heal *et al*., 1997); climatic conditions; soil physicochemical environment; and the nature of the soil organisms (Swift *et al*., 1979). Quality characteristics of the organic materials include concentrations of N, lignin, cellulose, hemicellulose, and water soluble C as well as C/ nutrient and lignin/ N ratios (Berg and Staaf, 1981; Melillo *et al*., 1982; Melillo and Aber, 1984; Reinertsen *et al*., 1984; Haynes, 1986; Kachaka *et al.,* 1993). Shiga (1997) opined that the rate of N mineralization is not always related to the C/ N ratio of organic materials. Although, the rate of decrease in C in organic materials are almost the same as that of N in materials with a C/ N ratio of about 10 (Shiga *et al*., 1985); materials with a high C/ N ratio usually have the decrease in C to be greater than that of N.

Nitrogen mineralization can be defined as the process by which soil organic N is transformed into the inorganic forms, NH_3 or NH_4^+, by micro-organisms (Jansson and Person, 1982). If environmental conditions are not limiting, the NH_4^+ is oxidized to NO_3^- almost as rapidly as it is formed (Schmidt, 1982). Thus, NO_3-N is usually the dominant form of plant-available N in most

arid and semiarid regions (Kaboneka *et al*., 1997). Also, Hadas *et al* (1989) submitted that the concentration of NH_4^+ in the soil studied was very low and did not change with time, therefore, NO_3-N concentrations represent the accumulation of mineral N in the soil.

N mineralization is usually attributed to the surface layer of soils where organic N levels are high (Hadas *et al*., 1989). It has however been detected also from deep soil layers in incubation experiments (Cassman and Munns, 1980; Hadas *et al*., 1986). Aerobic or anaerobic laboratory incubation techniques under controlled temperature and moisture conditions have been used to estimate the soil microbial potential to mineralize N. In such incubated samples of subsoil layers, aeration levels and soil bulk densities will favour the microbial processes in situ conditions in the field, thus increasing the rate of N mineralization (Hadas *et al.,* 1989).

These techniques provide information on the microbiological, substrate, and environmental factors that regulate mineralization-immobilization processes. However, there are discrepancies between estimates of net N mineralization estimated by laboratory techniques and from field N budgets (Ma *et al*., 1999). Since, N mineralization is mediated by soil micro-organisms; it depends on the quantity and quality (i.e., chemical composition) of the substrate, which could be organic matter from processed crop residues e.g. NSC as well as on soil environmental conditions such as moisture and temperature (Goncalves and Carlyle, 1994). Owing to the relevance of soil N mineralization from the microbiological mineralization of N bound in organic matter or detritus, the evaluations of mineralizable soil N – total N content as well as organic matter in the soil are pertinent.

2.11.3 Mineralizable soil N – total N content

According to Harmsen and Van Schreven (1955), the total N contents of soils differing in type provide little indication as to the relative capacities of the soils to supply N. However, they submitted that N released during incubation is derived from rather ill-defined and variable organic N sources. Most plant-available N in soils is derived from the microbiological mineralization of N bound in soil organic matter or detritus. Mycorrhizal fungi and plants are also capable of utilizing simple organic N compounds (Lundeberg, 1970; Stribley and Read, 1980; Read, 1983), but the significance of these for total N uptake by plants under field conditions is unknown. Slow rates of N mineralization often limit plant growth resulting in large growth responses to N fertilization.

Quantification of the relationships between soil N mineralization and other ecosystem processes has been restricted by the lack of suitable methods to measure N mineralization under field conditions (Raison *et al*., 1987). A number of techniques have been used to measure field rates of N mineralization or to obtain an index of them, but it has been impossible to assess the reliability of results because of the unknown effects of assay conditions (especially soil disturbance) on rates of mineralization in differing soils. There is no reference method which is known to measure mineralization rates accurately under field conditions. Some would argue that it is impossible to precisely measure these because all methods rely on measuring accumulation of mineral-N in the absence of active roots, and that to achieve this there will be some alteration to soil physical structure, moisture content and rhizosphere processes.

Disturbance of the soil due to cultivation has been reported (Sylvester-Bradley *et al*., 1988) to result in a dramatic release of available soil N two or three months later in acid savanna soils. In the absence of disturbance, virtually the entire mineral N in soils is present as NH_4^+, and

nitrification, which led to substantial leaching losses of NO_3^-, occurred at significant rates only in soil which had been cultivated (Giller and Wilson, 1991). They submitted further that the reason for lack of mineralization and nitrification in undisturbed savanna soil is not fully understood. However, soil disturbance may stimulate mineralization by allowing better aeration of the soil or by creating more exposed surfaces available for microbial attack. This implies that O_2 is a major limiting factor for mineralization in undisturbed soils.

While N uptake by plants must remain the best measure of N-supplying capacity of soils, this approach (Raison *et al*., 1987) will only be useful for studying short-term N dynamics. Measurements of N mineralization under controlled laboratory conditions provide an estimate of the pools of mineralizable N present at the time of sample collection. These pools are however, replenishable under field conditions as a result of inputs of organic N from root and above-ground litter and the slow transformation of the more resistant pools of soil organic N. Laboratory measures of mineralization, especially on disturbed soils, can be an unreliable index of field rates (Lamb, 1980; Hart and Binkley, 1985).

The pattern of soil N mineralization may indicate changes in microbial activity, substrate availability or the balance between gross mineralization and immobilization (conversion of inorganic soil N into organic N). N mineralization is unquestionably influenced by temperature, soil depth, moisture, porosity, oxygen, pH and availability of substrate (Cassman and Munns, 1980; Stanford *et al*., 1974).

Methods used to measure or estimate patterns of N mineralization under field conditions include the following:

i. Exposure of disturbed soil in plastic bags buried in the field (Eno, 1960; Runge, 1974; Westermann and Crothers, 1980; Vitousek and Matson, 1985);

ii. Exposure of relatively undisturbed soil columns enclosed in plastic bags under field conditions (Virzo De Santo *et al*., 1982; Nadelhoffer *et al.,* 1983, 1985; Matson and Boone, 1984). Rapp *et al* (1979) isolated soil columns within thin metal cans pushed into the solum, and Adams and Attiwill (1986) used capped PVC tubes for this purpose;

iii. Measurement of mineral N collected by ion exchange resins placed in the field for extended periods (e.g. Binkley and Matson, 1983; Hart and Binkley, 1985);

iv. Determining the effects of varying temperature and moisture on N mineralization in disturbed soils, and then assuming that these relationships can be linked to field fluctuations in these variables during the year – i.e. modeling approach (Cameron and Kowalenko, 1976; Marion *et al*., 1981; Macduff and White, 1985).

However, of all the above methods, (ii) appears most suitable as it gives reliable measure of net N mineralization in soils (Nadelhoffer *et al*., 1985). Use of relatively undisturbed cores (soil-litter systems) also enables measurement of the significant contributions of macro- and microfauna made to N mineralization from litter (Anderson *et al*., 1985), microbial biomass (Ingham *et al*., 1985) or the important pools of labile N held in light fractions of soil organic matter (Sollins *et al*., 1984).

Measurement of N mineralization potentials by incubation in controlled environment began in the 1940s and has been widely used ever since (Harmsen and Lindenbergh, 1949). These methods allow determination of potential N availability; however, they are carried out in ideal environmental conditions and may overestimate site processes. Eno (1960) introduced the in situ buried bag incubation technique. While this method incorporates in situ soil temperature variations into estimates of net N mineralization and nitrification, soil moisture remains

uncharged during the incubation period. Adams and Attiwill (1986) developed the in situ covered core method for soil mineralization measurements. Their system used unperforated PVC tubes covered with Petri-dishes, which allowed soil moisture as well as temperature to equilibrate with the surrounding soil environment.

As a result of field temperature fluctuations, Carlyle and Malcoln (1986) found greater rates of net N mineralization for laboratory-incubated soil samples than for *in situ* samples. Matson and Vitousek (1981) in their laboratory incubations observed that as soil moisture increased from 15 to 35%, net mineralization also increased. However, soil moisture content did not change in the buried bags, making the initial moisture levels important. However, in soil, clay has a significant influence on protein decomposition. Clay particles of montmorillonite, for example, having high specific surface area, adsorb the proteolytic enzymes which are extracellular and decrease their biochemical activity but kaolinite with low surface area does not (Biswas and Mukherjee, 2005). It could thus be inferred from the aforesaid that soils of the Northern Guinea Savanna of Nigeria being studied, with low surface area, will have an increased net mineralization since they do not adsorb the proteolytic enzymes.

2.12 Nutrient mineralization and crop growth

The turnover of plant residues and the N contribution to subsequent crops may not only be influenced by residue parameters such as the quantitative input and residue quality (Mayer *et al*., 2003). During the decomposition process, the growth of subsequent crops will compete with the microbial biomass for N and other nutrients (Kaye and Hart, 1997), leading to a differentiation in the decomposition process compared to a non-cropped soil (Bottner *et al*., 1999). Plants also affect the residue turnover by excreting easily available organic C and N compounds which can

interact directly with the microbial biomass and affect its size, activity, turnover rate or physiological status (Korsaeth *et al*., 2001).

These interactions can have direct effects on the C and N mineralization of the native SOM and the decomposition of plant residues. Beside well-known adaptation mechanisms for nutrient acquisition such as root morphology, mycorrhiza or release of organic acids and phytosiderophores (Jones, 1998; Marschner, 1995), plants are able to influence the mobilization-immobilization turnover in soils (Cheng and Coleman, 1990; Kuzyakov *et al*., 2000; Zagal, 1994) and on top of that might be differences between plant species (Van der Krift *et al*., 2001). This might lead to differences in competitiveness for mineral N, N immobilization-mineralization and residue N recovery after incorporation of plant residues by contrasting succeeding plant species.

Several authors have reported that above-ground residue incorporation causes an increase in microbial C and N contents followed by a subsequent decrease (Bremner and Van Kessel, 1992; Bending and Turner, 1999; Bending *et al*., 1998; Jensen, 1994a, and 1994b, Jensen *et* al., 1997). Several incubation procedures permit precise measurement of C- and N-mineralization kinetics and evaluation potentials of plant residues under standardized conditions (Quintana *et al*., 1988). The rate of decomposition of plant residues is in fact related to their C: N ratio (Parr and Papendick, 1978; Jenkinson, 1981) and also to the plant biochemical composition, i.e., lignin, cellulose or soluble carbon contents (Iritani and Arnold, 1960; Herman *et al*., 1977; Frankenberger and Abdelmagid, 1985). Gonzaga (1988) reported that under field conditions, the recovery of plant-residue N by succeeding crops maybe extremely variable; being influenced by residue type, residue management, soil environmental conditions and climatic parameters.

After nitrogen stress, phosphorus is the second most widely occurring nutrient deficiency in cereal systems around the world (Ortiz-Monasterio *et al*., 2002). Many soils have large reserves of total phosphorus, but low levels of available phosphorus. Al-Abbas and Barber (1964) reported that total P is often 100 times higher than the fraction of soil P available to crop plants. The activities of soil microbes in relation to nutrient mineralization shall be discussed.

2.13 Effect of soil microbes on substrate decomposition and nutrient release pattern.

The chemical processes that take place within the soil are, for the most part, dependent on the activities of living organisms. High quality organic matter content provides readily available N, energy (carbon), and nutrients to the soil ecosystem, and help retain mineral nutrients (N, S, micronutrients) in the soil and make them available to plants in small amounts over many years as it is mineralized (Arihara, 2001).

One of the chief activities of microorganisms is the mineralization of organic matter. The mineralization of organic matter is the breaking down of plant or animal organic materials into simple inorganic elements or compounds through the activities of the various organisms (Millar *et al*., 1965). While the physical and chemical changes which organic materials undergo when changed to simple compounds by soil organisms are termed decomposition. Soil microbes are valuable not so much because they supply nutrients directly, but because they enhance the synchrony of plant nutrient demand with soil supply by reducing large pools of free nutrients (and consequent nutrient losses from leaching and denitrification). Thus, microbes maintain a buffered, actively cycled nutrient supply (Snapp, 1995). In addition, OM increases soil flora and fauna (associated with soil aggregation, improved infiltration of water and reduced soil erosion), complexes toxic Al and manganese (Mn) ions (leading to better rooting), increases the buffering capacity on LAC soils, and increases water-holding capacity (Arihara, 2001).

The increase in the relative amount of N in organic residues after decomposition can only be explained by the fact that the nitrogenous complexes are rendered resistant to further rapid decomposition (Millar *et al*., 1965). This was attributed to the protein molecules which was believed can adsorb onto the surface of clay minerals and inhibit decomposition, and enzyme that decompose proteins which might also be adsorbed by clay minerals so that the proteins are less susceptible to decomposition. Consequently, it could be inferred that soils high in clay tend to have high organic matter content and explains the low organic matter content characteristics of the Northern Guinea Savanna soils with LAC.

Generally speaking, coarse-textured soils (sands) are lower in organic matter than the fine-textured soils (clays, clay loams and so forth) because the sandy soils do not support dense vegetative growth, because they have better aeration, which promotes more rapid decomposition, and because they are more subject to leaching losses (Leeper, 1964). Since, most of the organic matter is found in the topsoil, any erosion that occurs will result in significant organic matter loss. Furthermore, it is the topsoil that is disturbed by various tillage operations, which greatly increase the loss in organic matter and N.

Also, the organic matter content of sand fractions is generally dominated by plant debris (Christensen, 1987) which exhibits weak stability while that associated with fine fractions (e.g. silt, clay) corresponds, in contrast, to relatively stable components, microbial biomass, and metabolic compounds (Jocteur Monrozier *et al*., 1991). It has been shown (Shields and Paul, 1973; Reid and Goss, 1982; Sparling *et al*., 1982; Christensen, 1985) that the presence of growing plants slows down or decreases the decomposition of organic residues. In contrast, other authors (Bottner *et al*., 1984; Clarholm, 1985; Billes *et al*., 1986) found that the presence

of living roots increased the biodegradation of residues or mineralization of the native soil organic matter.

Several hypotheses have been proposed to explain the depressing effect of plant cover. For Shields and Paul (1973), Jenkinson (1977b) and Christensen (1985), plants modify the soil environment (aeration, temperature or moisture) which affects the decomposition processes. Other possible factors suggested by Reid and Goss (1982) are: Competition between roots and soil microbes for the labeled residues; inhibition of microbial activities by materials produced by roots or by rhizosphere; increased predation around roots of microbes that might otherwise have utilized labeled substrate; and utilization of soil microbes of fresh materials released from the roots in preference to the labeled plant residues. Organic matter (SOM) is related to crop yields. SOM is derived from plant and animal tissues by decomposition reactions (Donald, 1952). These reactions are the life process reactions of soil organisms, and two of the principal end products, CO_2 and NO_3-N, are essential for the growth of higher plants (Dawson, 1952). The replacement of NO_3-N is largely from decomposition of SOM while that of CO_2 is also partly from this source. Donald (1952) submitted further that since, the amount of SOM is proportional to the amount of organic carbon (OC); the C/N ratio is proportional to the reciprocal of the amount of soil N expressed as a fraction of SOM.

Studies of variations in the C/N ratio have shown that these variations can be interpreted as follows: low ratios of C to N, 10 or smaller, in SOM tend to indicate an advanced stage of decomposition, resistance to further microbiological decomposition, and liberation of NO_3-N in any further decomposition that may occur; large ratios of C to N, 20 or larger, in SOM tend to indicate little decomposition, susceptibility to further and rapid decomposition by soil organisms, competition between organisms and higher plants for existing NO_3-N and little, if

any, liberation of NO_3-N by decomposition reactions until the C/N ratio is reduced to 15 or lower.

The oxidation of SOM liberates P and other inorganic ions as well as CO_2, NH_3 and NO_2. Watsman (1938) submitted that organic P contents of soils are related to their C contents; the amount and nature of SOM has considerable influence on the availability of P for the growth of higher plants; and some P compounds, phytin for example, are readily decomposed by soil organisms; others are more resistant to decomposition.

The amount of organic matter in a soil is a function of the amount of organic matter it received in the past and of the rate at which this input has decayed (Jenkinson, 1977a). The loss of organic matter from a soil is usually represented by a first order process in which the organic matter (or various fractions of it) decays exponentially. However, laboratory incubation studies have shown that high-quality residues (e.g., narrow C/N ratio, low lignin) supplied in conjunction with low-quality residues (e.g., wide C/N ratio and/or high lignin's) can provide a continous nutrient supply, with N being released from high-quality residues first (Snapp, 1995). Preliminary indications are that plants with high lignin's, polyphenolics, and other anti-quality factors may not release nutrients for many growing seasons, and thus these residues may be undesirable to use as organic soil amendments (Myers *et al*., 1994). Owing to the quantitative knowledge of the decomposition behaviour required for proper management of organic materials, an overview of decomposition studies shall be subsumed.

2.14 Decomposition Studies

Decomposition is a cascading process whereby primary dead organic matter experiences a succession of physical and chemical transformations in the soil, leading to mineralization of part

of the material, and the storage of resistant compounds such as 'humus' (Swift *et al*., 1979). It is mainly a biological process carried out by insects, worms, bacteria and fungi both on the soil surface and in the soil; being a biological process carried out primarily by bacteria and fungi, its speed is affected by temperature and soil moisture. Generally, decomposition increases exponentially with temperature (Sewanee and Simmons, 2003). Soil moisture effects are a little more complicated, since decomposition is inhibited in very dry soils because bacteria and fungi dry out; while in very wet soils, it is slow. This Sewanee and Simmons (2003) attributed to the anaerobic conditions developed in saturated soils.

Also, it can be described as an ecological process that recycles dead tissues, mainly from primary production, into nutrients in the soil (Berg and McClaugherty, 2008). This ecological process is a function of soil abiotic (moisture, temperature, O_2/CO redox potential, pH, N, P, etc), and biotic (microbial biomass, functional diversity) properties. Consequently, quantitative knowledge of the behaviour of these residues under the prevailing set of factors influencing the decomposition process (climate, soil properties – clay content, nutrient statues, etc.), substrate quality – N concentration, lignin content, and C: N ratio (Moorhead *et al*., 1999), macro organisms and microorganisms is panacea for proper soil management. The decomposition of organic materials in soil has been widely investigated using the containment systems such as the litterbag technique (Weider and Lang, 1982; Anderson and Ingram, 1993; Lehman *et* al., 1995; Thonnissen *et al*., 2000).

The litterbag technique is simple, convenient, easily replicable and non-destructive in character (Heal *et al*., 1997; Vanlauwe *et al*., 1997). It consists of enclosing plant material of known mass and chemical composition into a screened container. Initially, a large number of bags are buried in the field and at each sampling date, a randomly chosen set of bags are retrieved and analysed

for loss of mass and chemical composition of the litter (Weider and Lang, 1982). This technique enables recovery of residual experimental material without affecting variables that regulate the decomposition process (Anderson and Ingram, 1993; Lehman *et al*., 1995). Although, this technique may under estimate actual decomposition (Weider and Lang, 1982), the results of the technique however reflect trends characteristic of the unconfined organic inputs and as such, allow for relative comparisons of the decomposition of different organic materials (Vanlauwe *et al*., 1997).

Modeling of the dynamics of plant residue or soil organic matter decomposition in the field requires meaningful mathematical expressions for the biological, chemical and physical processes involved. Weider and Lang (1982) reported that two analytical approaches are commonly used to examine analytical data. One involves the comparison of treatment means by some parametric statistical procedure while the other involves fitting mathematical models to estimate constants that describe the loss of mass (or nutrient) over time. The sequence of the mass loss over time follows an initial rapid breakdown of plant amendments (small soluble C molecules, like starches and amino acids) then, the longer period of slow decomposition (breakdown of lignin) which results in a mass loss curve that resembles an exponential decay constant (Sewanee and Simmons, 2003).

Moorhead *et al*. (1996) distinguished three groups of decomposition models: (i) empirical models, which are mostly statistically based and are often useful for predictions, but are limited to the range of data from which they were developed; (ii) mechanistic models, which are often analytical in nature, using a system of equations to describe complex processes. These types of models have proven very useful for gaining insight into ecosystem behaviour, and for developing and testing general theories; and (iii) simulation models on the other hand, are

created to simulate the behaviour of a system, in a way that allows researchers to manipulate initial conditions, or other aspects of the model, to investigate outcomes. Simulation models may use a combination of empirical and mechanistic models to achieve its goal. One of the challenges facing those who model decomposition is the large number of factors that influence the rates and patterns of litter decomposition. Thus, a single model, or relatively simple approach would not likely give a generally applicable description of the decomposition process. Consequently, the review of a number of models shall be subsumed.

2.15 Decomposition models

The most frequently used model to describe decomposition is the single exponential decay function, first proposed by Jenny *et al*. (1949) and discussed in detail by Olson (1963). The appeal of this exponential model arises from the fact that a single constant, k_{se}, characterizes the loss of mass, thereby facilitating comparisons with other data sets and simplifying attempts to model the accumulation of organic carbon in soils (Olson, 1963; Oohara *et al*., 1971).

The single exponential model assumes that (1) the absolute decomposition decreases linearly as the amount of substrate remaining declines, or (2) the relative decomposition rate remains constant (Weider and Lang, 1982). This assumption corresponds with current knowledge and understanding of the biology of litter decomposition. However, because of the two-step nature of decomposition dynamics the single exponential decay model has been modified to the double exponential decay model.

- The double exponential model:

$$\frac{W_t}{W_o} = Ae^{-k1t} + (1 - A)\, e^{-k2t} \qquad \text{(Hunt, 1977).}$$

Where W_t is the amount of initial mass (W_o) remaining at time t; W_o is the mass at time zero; A and (1 – A) are the labile and recalcitrant fraction of the organic material while k1 and k2 are the decay constant at the 1st (labile fraction) and 2nd (recalcitrant fraction) compartment respectively. This model assumes that the biomass of organic materials can be divided into two components, a relatively easily decomposed or labile fraction (A), and a more recalcitrant fraction (1 - A). Each fraction decays exponentially at rates characterized by k_1 and k_2, respectively; total decomposition is represented by the losses from each fraction.

- The asymptotic exponential model:

$$\frac{W_t}{W_o} = C_a + (1 - C_a)\, e^{-kt} \qquad \text{(Weider } et\ al.\text{, 1983)}$$

Where C_a and (1 – C_a) represent the labile and the recalcitrant fractions respectively.The asymptotic model is a modification of both the single- and double exponential models, where the model tends towards a positive constant rather than zero as in the former, or the recalcitrant fraction is completely resistant to decay (i.e. $k_2 = 0$) as in the latter.

- The linear model:

$$\frac{W_t}{W_o} = C_1 - kt \qquad \text{(Grigal and McColl, 1977).}$$

The linear model assumes that the absolute decomposition is constant throughout the decomposition process, while the relative decomposition increases with time. These assumptions are difficult to justify biologically (Weider and Lang, 1982). Other less commonly used models are:

- Quadratic model (Pal and Broadbent, 1974)
- Power model (Howard and Howard, 1974) or modifications of the equations to permit more accurate estimates (Talpaz *et al*., 1981).

Weider and Lang (1982) consider the exponential models to be the most realistic in terms of both mathematical and biological behaviour. Several other workers have similarly found that the negative exponential is a useful descriptor to define the rate of decomposition (Budelman, 1989; Mugendi *et al*., 1994; Heal *et al*., 1997; Thonnissen *et al*., 2000). Thus, most studies report the decomposition constant *k* from the negative exponential function:

$$\frac{W_t}{W_o} = W_o e^{-kt}$$ (Jenny *et al*., 1949; Weider *et al*., 1983).

Where W_t is the amount of initial mass (W_o) remaining at time *t*, and *k* is the rate constant; or as the regression function:

$$\log_n (W_t / W_o) = \log_n W_o^{-kt}$$ (Anderson and Ingram, 1993).

The log transformation of the exponential model ($W_t / W_o = e^{-kt}$), allows for direct statistical comparisons of slopes, intercepts and residual variances using analysis of covariance techniques (Snedecor and Cochran, 1978). The value of the decomposition constant *k*, determines the rate of decomposition. Thus, the larger the value of k in the exponential model, the faster the rate of decomposition. However, during early decomposition, good quality litter is decomposed rapidly (Preston *et al*., 2000). Also, significant litter mass is lost through leaching of soluble compounds, which include some decomposition – retarding chemicals such as tannins, further enhancing decomposition (Trofymow *et al*., 2002).

Experiments both in the laboratory and field have shown that the decomposition rate constant *k* describing the decomposition of plant material is nearly always independent of the quantity added if the C addition does not exceed 1.5% of the soil dry weight. Higher addition rates can alter the soil characteristics and slow down decomposition. Decomposition has been found to

depend on organic material C, N, lignin, and carbohydrate composition. One method of expressing this dependence involves that used by Herman *et al*. (1977), where

$$CO_2 \text{ evolved} = \frac{\% \text{ carbohydrate}}{\text{C/ N residue} \times \% \text{ lignin.}}$$

It is pertinent to note however that only a portion of the actual decomposition is accounted for when determining the decomposition rate by measuring CO_2 output or the amount of C left in the soil.

The rate of decomposition of crop residue in soil is a function of the intrinsic quality of the substrate (the chemical constituents of the residue), extrinsic factors related to the environmental conditions in which decomposition occurs (temperature, moisture, soil properties) and the nature of the microbial communities involved (Swift *et al.*, 1979; Cadisch and Giller, 1997). On a global or broad regional scale, temperature and precipitation are largely responsible for determining the rate and extent of decomposition (Swift *et al*., 1979; Meentemeyer, 1978). Generally, warmer temperatures and higher precipitation result in higher rates of decomposition; faster litter turnover, and less organic matter accumulation (Terrell *et al*., 2001). At a local scale, the rate of decomposition and quantity of nutrients cycled through the decomposition mechanism are influenced primarily by:

1. the quality of the resource being decomposed (Lockaby *et al*., 1995; Belyea, 1996; Cornelissen, 1996; Hobbie, 1996; Heal *et al*., 1997),
2. Physicochemical properties (i.e. Temperature and moisture regime, pH, oxygen) that affect decomposer organisms *in situ* (Donnelly *et al*., 1990; Berg *et al*., 1993), and
3. The length of time the resource is in contact with the soil microenvironment (Lockaby and Walbridge, 1998).

Day (1982) submitted that litter quality was more important than site factors in determining the rate of decomposition, although litter mixtures decayed more rapidly on sites that experienced more flooding. Mitsch and Gosselink (1993), however, reported that hydroperiod (i.e. inundation frequency and duration) was the single most important factor governing ecological processes in wetland and floodplain environments; not only does hydrologic regime determine vegetation community type (Hardin and Wistendahl, 1983), but the frequency and duration of floodwater inundation determines the suitability of the soil environment for decomposer organisms to process organic materials (Groffman *et al*., 1996).

Brinson (1981) opined that decomposition is optimized at a point along the soil moisture continuum where cycles of wetting and drying prevail. Rates are lower where permanently flooded, permanently dry, or even alternating aerobic and anaerobic conditions prevail. Lockaby *et al*. (1996) suggested that brief flooding regimes, followed by moist but well aerated conditions, maximized mass and carbon (C) loss. Brinson (1981) suggested further that where decomposition is not limited by either oxygen availability or moisture, temperature is the "single most important variable" governing mass loss.

Accumulation of nutrients in decomposing organic materials may come from several exogenous sources or through immobilization by soil flora and fauna inhabiting the litter (Terrell *et al*., 2001). They observed that N was limiting to decomposition of mixed-species litter in the drier laurel oak community, whereas decomposition was P limited in the hydric sweetgum/ swamp tupelo community; and there were brief periods of N and P accumulation. These nutrients accumulation in decomposing litter, they suggested occurred at least briefly during the early to mid growing season. The accumulation of P coincided with floodwater recession and some fraction of the accumulation may be the result of P association with the sediment being

deposited on the decomposing litter. However, the bulk of both N and P recorded in their study, they submitted was probably attributable to immobilization by decomposers, particularly as this coincided with periods of peak biological activity and floodwater recession.

Okalebo *et al*. (1997) reported that the reduction in crop yield from organic materials after their incorporation into the soil is not uncommon, particularly when added in large quantities. In a guideline submitted by Giller (2000) and Palm *et al*. (2001), when the N content of the organic material is > 2.5%, as in leguminous green manure, the material should be applied directly without additional N input from inorganic fertilizer. However, most crop residue are of low quality (N < 2.5%, C: N ratio > 25); thus the need for a suitable combination with inorganic fertilizer to achieve their maximum effect. This approach requires that both the release of nutrients and the efficiency of nutrient availability to the plant be manipulated by controlling the quantity and quality of organic inputs, which sometimes facilitate the retention of added inorganic inputs, and timing of their input. The NSC has been reported to induce exchangeable acidity in laboratory studies, a review of the nitrification of this organic amendment as an acidifying process is therefore crucial in an effort to achieving sustainability.

2.16 NSC as Nitrification Inhibitor

Mishra *et al.* (1975) reported that NSC significantly inhibited nitrification of urea in soil. Also, Neem foundation (2005) submitted that the cake is a nitrification inhibitor and when mixed with urea it cuts down on the amount of urea converted to nitrate in the soil. Although, the transformation of NH_3 into nitric acid (HNO_3) must acidify the soil (Leeper, 1964), this is not the case in soil. This he attributed to the formation of the bases, calcium bicarbonate and magnesium bicarbonate which are washed out in the drainage, although the end products of microbial metabolism are organic acids, carbonic acid, and nitric acid. The reasons for this could

be subsumed as follows: firstly, although, certainly free organic acids are formed, but their calcium and magnesium salts are formed simultaneously and such salts tend to make the environment alkaline. Secondly, plants themselves modify the acidity of environment (Leeper, 1964).

Following the aforesaid, NSC-amended field study should not observe that much markedly increased exchange acidity and significantly decreased soil pH submitted by Agbenin *et al*. (2008) in their study which was limited to laboratory incubations. The above assumption could be attributed to protons generated from the nitrification of NH_4-N which can be neutralized by OH^- ions released by plant roots when NO_3-N is absorbed (Boumann *et al*., 1995) in the field. Adams (1984) showed that for each mole of NH_4-N nitrified or oxidized to NO_3-N, two moles of protons are generated through the reaction:

$NH_4^+ + 2O_2 = NO_3^- + 2H^+ + H_2O$.

Nitrification rates were low in the findings of Agbenin *et al*. (1999) even though some investigators used NO_3-N as an index of net N mineralization in soils (Cassman and Munns, 1980; Hadas *et al*., 1989; Weier and MacRae, 1993). Several reports indicated that NSC contain biologically active ingredients particularly azadirachtin, di- and triterpenoids, pentanotriterpenoids and small number of non terpenoidal ingredients which are not only inhibitory to nitrification (Mishra *et al*., 1975; Parashar *et al*., 1980; Kethar and Kethar, 1995) but also toxic to soil-borne pathogens (Schmutterer, 2002). Donaldson and Henderson (1990) attributed the low nitrification under laboratory incubation as against the relatively high amount of NO_3-N released under greenhouse cropping (Agbenin *et al*., 1999) as due to the effect of plants and their roots on soil microbial dynamics and composition with implications for mineralization and nitrification processes.

Mishra *et al*. (1972) have found that following application of NSC to soil it reduces the numbers of soil bacteria and actinomycetes. In India, NSC up to 0.05% had no effect on NO_3 formation, while, NO_2 was significantly delayed at 0.2% NSC and above. This implied that NSC checked conversion of NH_4 to NO_2; presumably by its selective effects on the NH_4-oxidizing bacteria (Mishra *et al*., 1975). They submitted further that the addition of NSC at the rate of 0.02% C which amounts to 8156 kg/ha may also assist to build up SOM which are low in these soils.

Prasad *et al*. (1999) also submitted that coating urea with neem oil, neem cake or neem oil micro emulsion improved rice growth and resulted in more grain and straw than did commercial prilled urea. Similarly, Santhi *et al*. (1986) observed that application of neem products like neem leaf and neem cake to wetland soil which they studied did not have any adverse effect on the population of heterotrophic microflora; nitrifying bacteria, on the other hand, decreased significantly due to addition of neem cake and fresh and dried neem leaf with urea. It was consequently opined that neem leaf could be used as an inhibitor of nitrification for enhanced NUE of fertilizers where neem leaf is available in plentiful supply.

2.17 Soil acidification

Soil acidification is a slow natural process that occurs during pedogenesis and can be either accelerated or slowed down by farming practices. The causes of soil acidification in agricultural systems have been attributed mainly to an imbalance in the carbon and nitrogen cycles (Haynes, 1983; Helyar and Porter, 1989). The major processes leading to soil acidification include:

1. net H^+ excretion by plant roots due to excess uptake of cations over anions;
2. removal of alkalinity in farm products such as grain, hay, meat, and wool;
3. accumulation of organic anions in the form of soil organic matter;

4. mineralization of organic matter, nitrification of ammonium, and subsequent leaching of nitrate, and
5. Input of acidifying substances such as NH_4^+- based fertilizers.

Rengel (2003) also reported that removals of plant residues carrying organic anions and excess cations as well as the accumulation of partially decomposed organic matter in soils are likely to accelerate soil acidification. However, short term incubation experiments have shown that the addition of organic residues with excess cations increases the pH of the soil (Ritchie and Dolling, 1985 and Tang *et al*., 1999). Accumulation of organic anions is the primary source of the potential alkalinity that causes an increase in soil pH if decomposed by soil micro-organisms. The change in soil pH with the addition of organic matter depends on the rate of release or consumption of H^+ by the organic matter added to the soil.

The degree of consumption or release of H^+ by organic matter is dependent on its initial content of anion charge balanced by basic cations relative to undissociated acid groups, the initial soil pH, the dissociation constant (pK_a) of the remaining undissociated organic acids, the extent of dissociation of the organic acids when they are released into soil, and finally the extent of decomposition of the organic matter in the soil (Rengel, 2003). If the soil pH is less than the pK_a value of the organic acid in the organic matter, there will be an increase in soil pH due to the association of H^+ ions from the soil with some of the organic anions (Dolling, 1995). Subsequent decomposition of highly reduced organic matter is likely to generate carboxylic acids as oxidation products. This is common during the decomposition of C-rich cereal straw, and some of these carboxylic acids may dissociate. If organic anions are decomposed (respired or decarboxylated), they generate HCO_3^- or OH^- ions (Rengel, 2003).

The incomplete cycling of C, N and to a lesser extent S in soils under agricultural management has been identified as a major cause of increasing soil acidity. In particular, accumulation of undecomposed soil organic matter rich in organates, losses of organates in products, and inputs of symbiotically fixed N and ammonium-based fertilizers with consequent nitrate leaching are involved in the accelerated acidification of agricultural soils (Rengel, 2003). Acidification of soils under managed ecosystems occurs mainly through uncoupling of the processes generating H^+ and OH^- in the C, N, and S cycles. To minimize the rate of acidification and negative impacts on agricultural production, three approaches were enumerated (Rengel, 2003): (1) reduce the amount of H^+ ions generated, (2) reduce the uncoupling of processes generating H^+ and OH^- ions, and (3) neutralize the acid produced.

The rate of acid generated can be altered by selecting the nutrient forms added to soil-plant systems that produce less acid and selecting plant species that do not accumulate cation excesses. Liming is most commonly practiced to overcome soil acidification. However, an integrated approach involving liming, management practices, and plant tolerance have been suggested (Rengel, 2003). Cregan *et al*. (1989) and Helyar (1991) identified a number of management practices to minimize soil acidification; these include: using less acidifying fertilizers, improving nutrient use efficiency, reducing nutrient leaching losses, and reducing product removal. Soil acidity is considered a special case with respect to mineralization-immobilization and synchrony. Alexander (1977) submitted the assumption that soil pH affects mineralization and immobilization differently because immobilizing organisms tend to utilize ammonia rather than nitrate.

2.18 Fertilizer Use Efficiency

Fertilizer/ nutrient use efficiency (FUE) may be defined as yield per unit input. In agriculture this is usually related to the input of fertilizer, whereas in scientific literature the FUE is often expressed as fresh weight or product yield per content of nutrient. Improvement of FUE is an essential pre-requisite for expansion of crop production into marginal lands with low nutrient availability. The nutrients most commonly limiting plant growth are N, P, K and S. FUE depends on the ability to efficiently take up the nutrient from the soil, and also on transport, storage, mobilization, usage within the plant, and even on the environment (Biswas and Mukherjee, 2005).

Fertilizer use efficiency (FUE) is a measure of the percentage of an applied fertilizer nutrient that is utilized by the crop/ crops/ cropping system. This can be estimated best by the crop, being the best judge, either by the percentage of added fertilizer nutrient recovered by the harvested portion of a crop or kilogram of economic produce per kilogram of nutrient applied. Regardless of the criterion used, all the factors that increase crop yield depend on the integrated effect of all edaphic factors. Crop management, among other things, deals with plant, soil, water, fertilizers, pesticides and environmental conditions. Thus, FUE is a multi-factored entity (Biswas and Mukherjee, 2005).

FUE is often low in tropical cropping systems due to the declining level of organic matter (Arihara, 2001). Addition of small amounts of high quality organic matter (a narrow C/N ratio and a low proportion of lignin) to tropical soils can substantially improve fertilizer efficiency (Snapp, 1995). Dennison (1961) about five decades ago reported that long-term cropping studies in Kenya and Nigeria indicated that organic and inorganic inputs sustain fertility at a higher level than the expected additive effects of either input by itself. Nutrient effects alone do not

explain the benefits derived from modest amounts of organic manure combined with inorganic fertilizers. Of the major plant nutrients, N and P have received the greatest attention (Dennison, 1961). Interestingly, the problems in regard to one are just opposite to those of the other. Hence, leaching and volatilization loss are the problems of N fertilizers, whereas fixation, immobility, and transformation are the problems related to P.

2.18.1 Nitrogen use efficiency

Quantification of NUE requires better understanding of soil N mineralization during the growing season in systems where organic and inorganic forms of N are applied (Dwyer *et al*., 1993). The higher the clay content of the soil and its exchange capacity, the better is the NUE. However, if the rate of nitrification is more than the rate of uptake by the crops, the surplus is lost through leaching (Biswas and Mukherjee, 2005). They opined further that the main factors that determine nutrient uptake by crops apart from the nature of the root system which varies from crop to crop are water, texture and pH of soil, management practices and agro-climatic conditions.

The recovery of applied N (by difference), as recorded from field experiments conducted in India, has been found to vary from 28 to 34 percent for rice and 40 to 60 percent for other crops. The low recovery is the result of losses caused by volatilization, denitrification, leaching and runoff. NUE depends not only on the source, rate, time and methods of fertilizer application, but also on a large number of soil and crop management factors, such as land preparation, choice of variety, timely sowing, optimum plant population, timely weed control, proper water management, plant protection and balanced supply of essential plant nutrients (Biswas and Mukherjee, 2005).

Attempts have been made to increase efficiency through the use of slow release nitrogenous fertilizers. They are mainly: (1) urea-aldehyde condensation products e.g. urea-form (urea formaldehyde compounds), oxamide, and isobutylidene diurea (IBDU) and (2) urea coated with sulphur (SCU) and lac (LCU), and neem and saal cakes (op cit). The coating is meant to form a temporary barrier between the urea granules and soil or soil-water, thus reducing the rate of urea hydrolysis. The other approach has been to blend N fertilizers with a nitrification inhibitor which retards the rate of transformation of NH_4^+ to NO_3^-, thereby making the fertilizer N gradually available to the crops.

Prasad *et al*. (1999) observed that coating urea with neem oil, neem cake or neem oil micro-emulsion improved rice growth and resulted in more grain and straw than did the commercial prilled urea. Similarly, Santhi *et al*. (1986) submitted that application of neem products like neem leaf and neem cake to wetland soil which they studied did not have any adverse effect on the population of heterotropic microflora, nitrifying bacteria. However, these decreased significantly due to addition of neem cake and fresh and dried neem leaf with urea. It was consequently opined that neem leaf could be used as an inhibitor of nitrification for enhanced NUE of fertilizers where neem leaf is available in plentiful supply.

Predicting optimum rates of nitrogen (N) fertilizer for maximum economic crop production has always been a challenge (Mengel et al., 1982; Touchton and Hargrove, 1982; Maddux et al., 1984; Lamond and Whitney, 1991; Rao and Dao, 1992, 1996; Scharf, 1993). In addition to the economic consequences, excess N fertilization causes contamination of ground and surface water (Feinerman et al., 1990). Potential contamination of groundwater from nitrates dictates that N fertilizer applications should be timed so that crop N use is high (Gravelle et al., 1988).

Current agronomic and environmental concerns emphasize the need for more accurate application of crop N fertilizer to increase N-use efficiency.

Nitrogen-use efficiency of crops grown under dry land conditions relates largely to plant-available-soil moisture that depends on rainfall. An erratic rainfall pattern during grain sorghum (Sorghum bicolor L. Moench) growing season greatly limits grain yields in many years. Observations during the grain sorghum growing season reveals that luxuriant crop growth can occur when the crop receives adequate to excessive rainfall in the early part of the growing season and has adequate to excessive N available. However, this luxury vegetative growth does not necessarily translate into higher grain yields because heavy rainfall during the early growing season may leach NO_3^--N from the sandy soils resulting in late-season N deficiency.

Also early season luxurious vegetative crop growth significantly increases the daily crop water use (Khosla and Persaud, 1997). Consequently, plants may experience severe water stress later in the growing season causing early leaf senescence, poor head development and grain filling, and resulting lower grain yields. Optimum grain yields therefore depend on whether there is an adequate supply of N and water stored in the soil to meet the plant N and water needs.

Typical soils used for grain sorghum production in Nigeria vary from low (125 mm water m^{-1} of soil) to very low (50 mm water m^{-1} of soil) in 39 plant-available-water holding capacity. These soils are deep and well drained and are susceptible to leaching of nitrates. Total crop N requirement therefore cannot be applied in a single dose before or after planting. The challenge with grain sorghum production in dry land of the Northern Guinea Savanna of Nigeria therefore is to synchronize N applications with crop N need and plant-available-water.

Fertilizer N applications when made prior to the period of rapid uptake and growth have increased N uptake and N-use efficiency (Johnston and Fowler, 1991). Matching fertilizer N applications to crop need can be achieved by partitioning total N application into several doses and applying each dose at the time of plant N need. Partitioning N application also offers opportunity to evaluate the available water supply before applying N, permitting increased rates of application under adequate available moisture conditions and reduced rates when soil moisture is low (Eckert, 1995). Vanderlip (1993) submitted that the period of rapid N uptake and growth in grain sorghum occurs at the eight-leaf and mid-bloom growth stages. It was observed in their studies that crop N and water needs at these growth stages (eight-leaf and mid-bloom) are very high and occur at about 35 and 65 days after emergence, respectively (Vanderlip, 1993, Khosla and Persaud, 1997).

Side-dress N applications at these stages with a high clearance applicator perhaps would improve crop production efficiency in several ways. First, it would moderate early season luxuriant vegetative crop growth that increases the daily crop water use and depletes the soil water reserves needed during the later part of the growing season. Second, the leaching potential of nitrates would be lowered by minimizing the time that the fertilizer N is exposed to leaching processes. Finally, the N-use efficiency would be enhanced because N applications are done immediately before the period of maximum N uptake (Vanderlip, 1993), thereby promoting proper head development, grain filling and increased grain yield.

2.18.2 Phosphorus use efficiency

In the case of P fertilization, fixation of phosphate (PO_4^{2-}) is the main problem. Water-soluble phosphatic fertilizers when added to the soil do not remain so, but in a short while interact, preferably with iron and aluminium, to form less or sparingly soluble products called the 'initial

PO_4^{2-} reaction products'. The efficiency of phosphatic fertilizers depends primarily upon the release of P from the products rather than the fertilizers per se.

One of the measures taken to improve P use efficiency is to have minimum contact of the fertilizers with the soil to restrict PO_4^{2-} fixation. Another measure to increase it is to raise the pH, preferably of acid soil, by liming. Liming, deep placement and combined use of superphosphate and organic manures are known to increase the PUE (Biswas and Mukherjee, 2005).

Biswas and Mukherjee (2005) observed that in India, the application of PO_4^{2-} fertilizers with organic manures is beneficial. This increases the crop response and minimizes P fixation. They submitted further that soil organisms immobilize PO_4^{2-} from labile pool and many remove as much P as the crop. In addition, there is a critical concentration of about 0.2 % P in the organic matter being decomposed, above and below which there will be net mineralization and immobilization. Thus, it is very important to note this point when using organic manure as a source of fertilizer.

The PO_4 mineralizing microorganisms are more active in the thermophilic range and natural range of soil reactions. PO_4 release is more rapid under conditions favouring ammonification. Thus, mineralization of P depends on the C: N: P ratio of the organic matter. The ratio of 100: 10: 1 has been suggested to be optimum. Insofar as P use efficiency is concerned, plants adopt at least four broad categories of mechanisms to increase their access to native or applied soil P (Arihara, 2001). These include: modification of soil exploration by roots (through increasing absorptive area), better symbiosis with soil microbes (like arbuscular mycorrhizal fungi), modification of rhizosphere to increase nutrient availability (through release of enzymes or other

compounds capable of liberating P from metal-P compound or organic complexes), and reduced tissue P requirements (Marschner, 1998).

2.19 Soil microbial biomass

Soil microbial biomass is the living portion of the soil organic matter, excluding plant roots and soil animals larger than 5 x 10^{-3} μm^3. The soil microbial biomass generally comprises approximately 2% of the total organic matter in soil and it may be easily dismissed as of minor importance in the soil (Jenkinson and Ladd, 1981; Dalal, 1998). Soil microbial biomass parameters give useful information about the restoration degree and quality of contaminated soils (Clemente *et al*., 2007). At present, microbial biomass is seen to exert a controlling influence on the dynamics of soil organic matter and the availability of many nutrients. The critical roles that microbial biomass performs in the soil system was summarized as follows by Dalal (1998): a labile source of C, N, P, and S; an immediate sink of C, N, P, and S; an agent of nutrient transformation and pesticide degradation; an agent of mineral weathering and soil formation; includes organisms, especially in association with plant roots, that form and stabilize soil aggregates; includes organisms that are antagonistic to plant pathogens and parasitic nematodes; produces plant growth regulators.

The challenges of using microbial indicators are to identify the best choice among the many techniques available to assess soil quality. Winding *et al*. (2005) proposed measures of microbial biomass, respiration (rate of aerobic catabolism of SOM by heterotrophs; Cotrufo *et al*., 1995), N mineralization, and community profiling as techniques to be considered. Brookes (1995) suggested that either the ratio of CO_2 production to biomass C (biomass specific respiration rate) or biomass C as a percentage of SOM might be better indicators of soil pollution than either microbial activity or biomass measurements alone (Barajas-Aceves *et al*.,

1999). The link between biomass C and total SOC may constitute a form of "internal control" in soils of similar type and under similar management (Barajas-Aceves, 2005).

However, in determining microbial activity both the turnover rate and the size of the microbial biomass are pertinent (Theng *et al*., 1989). Depending on climatic and other variables, turnover rates of microbial biomass C (C_{mic}) usually range from 0.5 to 5 years, as compared to >20 years for the bulk of SOC (Dalal, 1998). The size of the living community in the soil, the microbial biomass, is generally positively related to the SOM level; rarely is C_{mic} less than 1% or more than 5% of the total SOC (Carter, 2001; Dalal, 1998). Increases in SOM are usually associated with similar increases in microbial biomass, because the SOM provides the principal substrates for the microorganisms. But, the two parameters are only loosely linked, giving rise to the four- to fivefold variation commonly observed in the ratio C_{mic}: SOC. This microbial quotient, or the C_{mic} as a percentage of SOC, is considered by some to be an indicator of health or stress of the soil microbial community, a healthy, low-stress community being able to sustain a relatively high level of C_{mic} with a given level of SOC (Weil and Magdoff, 2004).

2.20 Particulate organic matter (POM)

Particulate organic matter (POM) fraction referred to all soil organic matter (SOM) particles less than 2 mm and greater than 0.053 mm in size (Cambardella and Elliot, 1992). POM is biologically and chemically active and is part of the labile (easily decomposable) pool of soil organic matter (SOM). Particulate organic matter can be defined as the proportion of organic matter that plays important biological and physical roles in soil (Wander, 2004). Though POM is most often used as an index of labile SOM, POM fractions include materials that are heterogenous in age and function. Size, density, and energy can be combined in a variety of ways to recover materials that can be associated with active, slow, and recalcitrant pools.

As perhaps the most easily decomposable fraction of nonliving SOM after microbial biomass, POM fulfills many soil functions mediated by OM. It is a source of food/energy for microorganisms and soil animals as well as nutrients for plant growth. Particulate organic matter enhances aggregate stability, water infiltration and soil aeration; it increases cation exchange capacity and buffering pH. It also binds environmental pollutants such as heavy metals and pesticides. Particulate organic matter may play an important role in the suppression of soil borne diseases (e.g. damping off of cucumber) by compost. This may be explained by the fact that POM is an important source of food/energy in the compost for microorganisms responsible for disease suppression.

In poorly managed soils, the transport by erosion of sediments rich in POM into rivers and other water bodies can result in alteration of water quality and aquatic life. Build up and mineralization of those organic materials lead to the eutrophication of lakes and rivers. Incomplete mineralization of POM carbon in very poorly drained soils can lead to the formation of methane, which escapes into the atmosphere and contributes to ozone depletion. Management that affects SOM accumulation also affects POM content in soil. More POM in the soil means that carbon and other nutrients are being stored in the intermediately available pool and are not subjected to losses (e.g., leaching) yet are available when needed. Wander and Bidert (2000) showed that potential N mineralization was better correlated with total POM than loose POM recovered after gentle shaking of the sieved soil. This again demonstrated that the concentration of POM most closely associated with residues does not provide valuable information about soil N supply.

Soil quality (SQ) is usually defined as the capacity of the soil to carry out ecological functions that support terrestrial communities (including agroecosystems and humans), resist erosion, and

reduce negative impacts on associated air and water resources (Karlen et al., 1997). The soil quality concept addresses the associations among soil management practices, observable soil characteristics, soil processes, and the performance of soil ecosystem functions (Lewandowski et al., 1999). Soil quality can be influenced by many properties inherent to a particular soil and reflective of the environmental factors affecting long-term soil formation, such as steepness of slope, depth of solum, and soil texture. Soil quality can also reflect the condition of a soil resulting from the alteration of certain soil properties by management practices. Aggregate stability, infiltration capacity, nitrogen mineralization potential, and biodiversity of soil organisms are among the soil properties that are substantially altered by management. High levels of SOM are associated with reduced erosion and runoff; enhanced soil aggregation and nutrient cycling; and improved infiltration, movement, and retention of water (Greenland and Szabolcs, 1994; Woomer and Swift, 1994). Organic-matter-related soil properties, such as total organic carbon, microbial biomass C, extractable carbohydrates, and macroaggregate stability, exhibited significantly higher values in the soils perceived by the farmers as being in better condition or in a state of higher SQ.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Site and Climate

The potentials of NSC were evaluated under laboratory, greenhouse and field conditions. The field study was conducted for two years (2009 and 2010) on an Alfisol at the Experimental Farm of the Institute for Agricultural Research (IAR) at Samaru (11^0 11' N, 7^0 38' E); latitude of 686m above sea level and an average rainfall of about 1060mm in the Northern Guinea Savanna of Nigeria (Owonubi *et al*., 1991; Odunze, 2011). The area is characterized by distinct two seasons: the dry season, comprising of a cold dry period (harmattan) between November and December, and a hot dry period between April and May/June as well as a warm rainy season in June to September. October and March constitute transitional months between rainy and cold dry season, and between hot dry period and rainy season. Warm conditions and high relative humidity prevail during the rainy season. July and August are the months with highest rainfall (Odunze, 2011). The site has a mono-modal rainfall of 950 – 1270 with a mean of 1100mm. It has a growing period varying between 150 – 180 days per year.

3.2 Pre-cropping site characterization

3.2.1. Soil sampling and analysis

The experimental site was plot C14 of the IAR Experimental Farm, Samaru, Zaria. Composite soil samples were collected in the rainy season, after land preparation, before any fertilizer was applied or seed sown. Subsamples taken were ground, sieved and analyzed for the following physico-chemical properties using standard procedures (Anderson and Ingram, 1993), while the remaining were stored until required at 2 - 3^0 C to reduce mineralization process.

(i) Particle size distribution using hydrometer method (Gee and Bauder, 1986).

(ii) Soil pH in water and $CaCl_2$ were determined in ratio 2.5: 1 water: soil by pH meter.

(iii) Total N by micro-kjeldahl procedure (Bremmer, 1996).

(iv) Soil available P using Bray No. 1 as described by Kuo (1996).

(v) Organic carbon by modified Walkley-Black method as described by Nelson and Sommers (1996).

(vi) Exchangeable bases extraction was done with 1 *N* ammonium acetate pH 7.0. K and Na were determined by flame photometry, while Mg and Ca were determined using Atomic Absorption Spectrophotometer (AAS) (Anderson and Ingram, 1993).

(vii) Exchangeable acidity was determined by the KCl extraction method and titrated with sodium hydroxide (NaOH) as laid out by Juo (1979).

(viii) Micronutrients (Zn, Cu, Fe, Mn) were determined using 1 % EDTA and the elements estimated by AAS.

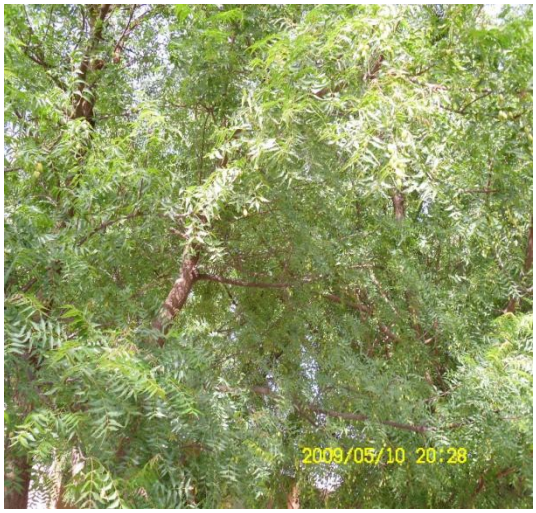
(ix) Electrical conductivity in dS m^{-1} was determined using the saturated paste extract as described by Okalebo *et al*. (2002) while categorization as saline or non-saline was done following Rhoades (1996) classification.

3.3 Characterization of neem seed cake (NSC)

Neem seed cake (NSC) was obtained from the National Research Institute for Chemical Technology (NARICT) at Basawa in Zaria. The seeds used were sourced locally from different locations with the bulk from the far north of the country. These seeds were processed as shown in Figure 1. The NSC flakes were ground and sieved to pass through 2mm sieve for homogenization. This was then analyzed before incorporation in the field.

3.3.1. Analytical method for the neem seed cake

I. Total N by micro-Kjeldahl procedure (Bremmer, 1996; Jones, 1991).



A matured neem tree



The neem ripe fruits



The air-dried neem seed



Wetting of the neem seed prior to extraction of oil



Pouring of the wetted neem seed into the grinding/ oil extraction machine



The neem seed cake (residue after oil extraction)

Figure 3.1: Pictures showing how the neem seed cake was obtained.
Source: National Research Institute for Chemical Technology, Basawa-Zaria.

II. Total P was analysed using wet digestion method and P determined by the ammonium molybdate/vanadate yellow colour method (Anderson and Ingram, 1993).

III. Total basic cations: K, Ca, Na and Mg using flame photometry and AAS as appropriate after wet digestion (Anderson and Ingram, 1993).

IV. Organic matter and ash content were determined using ash method as described by Okalebo *et al*. (2002).

V. Lignin and cellulose contents were determined by Acid Detergent Fibre test as described by Okalebo *et al*. (2002).

VI. Polyphenol was extracted with methanol and total soluble polyphenol analysed by the Folins-Denis method (Waterman and Mole, 1994).

3.4 Greenhouse Experiment

Greenhouse cropping was initiated to determine bio-available nutrients (N, P, K, Ca, and Mg) from NSC and estimate the soil biomass produced in response to applied treatments. Two series of pots were employed in the greenhouse. One series was sown with the test crop (cultivated) while the other, though given the same treatments as the former, was not sown with sorghum (uncultivated), as they serve as bench marks for studying soil microbial biomass in the cultivated pots (Jenkinson, 1981).

3.4.1. Soil sample collection and preparation

Soil was collected from 0 – 15cm depth in a fallow field at the boundary of the experimental plot for the field trials at the Institute for Agricultural Research, Zaria. The soil sample was air-dried, crushed and sieved through a 2mm mesh sieve.

3.4.2. Treatment and experimental design

The experiment was conducted as a completely randomized design (CRD) with three repetitions. The treatments consisted of factorial combinations of 4 levels of NSC and 4 rates of the recommended fertilizer rates of 64-32-32 kg N, P_2O_5, K_2O for sorghum. The treatment combinations were as shown in Table 3.1. The ratio of NSC and fertilizer were as used in the field trial.

3.4.3. Greenhouse techniques

Four kilogram of the sieved soil was weighed out and thoroughly mixed with appropriate amount of NSC. These were put into plastic pots of about 4 litre capacity and incubated for two weeks. The pots were placed on plastic receivers and watered to field capacity. Ten seeds of the test crop (sorghum, *Samsorg 17*) were planted and later thinned to two plants per pot seven days after planting (DAP). The soils were maintained at field capacity and any seepage collected on the plastic receivers was returned to the pot. Approximate amounts of muriate of potash (MOP) 23.810 mg , 47.619 mg and 95.238 mg, corresponding to ¼, ½ and full doses of K_2O as well as amounts of single super phosphate 79.365 mg, 158.730 mg and 317.460 mg, corresponding to ¼, ½ and full doses of P_2O_5 as recommended for sorghum were applied at planting. One-quarter of the recommended N rates of ¼, ½ and optimum rate, being 62.112 mg, 124.224 mg and 248.447 mg per pot were applied a week after planting (WAP) and the remaining three-quarter N was applied at 4 WAP.

3.4.4. Greenhouse observation and measurement

Plant height, numbers of leaves, stem girth measurements were taken for each plant at weekly intervals from two weeks after planting. The shoots were harvested at eight weeks by cutting the

Table 3.1: Treatment combinations of the greenhouse studies

Treatment number	NSC (t ha^{-1})	Fertilizer rate (kg ha^{-1})
1	0	0
2	0	¼
3	0	½
4	0	Full
5	1	0
6	1	¼
7	1	½
8	1	Full
9	2	0
10	2	¼
11	2	½
12	2	Full
13	4	0
14	4	¼
15	4	½
16	4	Full

¼, ½ and full = Proportion of optimum recommended fertilizer rate of 64 - 32 - 32 for sorghum

stems from soil surface in the pot, weighed and washed, dried at 65^0 C to constant weight, re-weighed, ground and stored for elemental analysis.

3.4.5. Analytical method for the plant materials

All cations and phosphorus analyses in the ground plant materials were done in triplicate. Cation concentrations in sorghum were determined by flame and phosphorus by spectrophotometric analysis following digestion with sulphuric acid + perchloric acid + nitric acid for P, K, Ca and Mg as appropriate; and complete oxidation of samples using micro-kjeldahl procedures followed by distillation for N. This was also employed for the uncultivated pots (Okalebo *et al*., 2002).

3.4.6. Determination of soil microbial biomass (Analytical method)

The soil microbial biomass in cultivated and uncultivated pots was determined using the chloroform fumigation extraction method (Brookes *et al*., 1985; Vance *et al*., 1987; Anderson and Ingram, 1993; Okalebo *et al*., 2002). The procedure entails the subjection of moist soil to chloroform fumigation which results in cell wall lyses thereby allowing the cellular content to become extractable in 0.5 M K_2SO_4. Two subsamples of 16 g of the potted soil were weighed into 50 ml beakers and uncovered plastic vials as unfumigated and fumigated samples respectively. The first samples in the beakers were extracted with 0.5 M K_2SO_4 for one hour after which they were filtered using Whatman No. 1 filter paper. The second sample was fumigated with 30 ml chloroform in a desiccator for 5 days at 25^0 C and later extracted with 0.5M K_2SO_4. The organic C and total N contents of the extracts were determined as described earlier. A k_{EC} of 0.45 and a k_{EN} of 0.54 were used for calculating the biomass C and N (Jörgensen, 1996; Jörgensen and Müller, 1996), where k_{EC} and k_{EN} are extractable part of the total amount of C and N fixed in the microbial biomass respectively.

3.4.7. Fractionation of organic matter by particle size method

The objective of this procedure was to determine the absolute amounts and relative proportions of particulate organic C in the soil. This is because the particulate fraction (fractions with diameters between 250-50μm usually captured using a wet sieving technique), is assumed to be the SOM most readily formed and decomposed in soils, and serves as an important substrate for soil mineralization processes, the decline of which, with respect to total SOM, is indicative of a loss in inherent soil fertility (Okalebo *et al*., 2002).

Soil from cultivated and uncultivated pots were separated into the following particle-size fractions (> 200μm, 50-200μm and <50μm) by stirring 100g dry soil in 300cm^3 of 0.5M K_2SO_4 (16 h, 20° C), isolated by sieving under water, oven-dried, and crushed with a mortar grinder. The organic C was determined by Walkey-Black method and the organic N in the plant materials, total soil and soil particle-size fractions determined using the Kjeldahl method.

The exchangeable bases (K, Ca, Mg and Na) of the soil were determined by shaking 1g of soil sample with 20mls 1*M* NH_4OAc pH 7.0 for 30 minutes and centrifuged after which supernatant was collected for the determination of K and Na using flame photometer and Ca and Mg by atomic absorption spectrophotometer. While those of the plant materials were done after acid digestion of the milled samples with the triple acid mixture HNO_3, H_2SO_4 and $HClO_4$.

Calculations:

1. The total particulate OC of the dispersed soil (POM_T) was:

$$POM_T = (\text{Dry weight}_{50-250}) \times (C\% / 100),$$

where $\text{Dry weight}_{50-250}$ = oven- dry weight of the dispersed soil retained in sieve between 50 and 250 μm, and C = corresponding organic carbon content of the dispersed soil retained in sieve between 50 and 250 μm.

2. The relative proportion of particulate OC (POM_R) was:

$$POM_R = POM_T / \text{Total soil C}.$$

3.4.8. Statistical analysis

The effect of NSC application rates on the soil chemical properties after 8 weeks of potted experiment was determined by ANOVA, and mean separation achieved by standard error (SE). To understand the underlying relationships among the soil chemical properties, factor analysis was used to group the soil properties according to their co-variances (Johnson, 1978). The relationships between total soil organic carbon and soil microbial biomass C, particulate organic matter C were determined by simple regression.

3.5. Incubation studies (Laboratory and field methods)

Incubation studies were done in the laboratory and the field simultaneously in the first year during the cropping period so as to take into consideration the conditions under which the crop is growing.

3.5.1. Laboratory incubation studies of NSC

Laboratory incubation studies were initiated to determine the rate of decomposition (mineralization) of the NSC which was used as the basis for assessing the rate of nutrient release. It has been reported that fitting kinetic equations to net N or P mineralization curves quantifies the amount of mineralizable substrates and the rate at which it is made available for plant uptake (Stanford and Smith, 1972). An incubation-leaching method was used to allow for determinations of mineralization rates at regular intervals for extended periods of time (Legg *et al*., 1971).

To 50 g soil samples (dry weight basis) 2.64 g kg^{-1} of NSC to give 1.635 mg N kg^{-1}soil was mixed thoroughly to homogenize the soil-NSC mixture. This was transferred to a sinter funnel whose bottom was lined with cotton wool, placed beneath very fine retentive nylon netting (<0.05mm/50 μm mesh size). The soil was moistened and brought to 80% field capacity at a moisture tension between -20 and -60kPa, which was reported to be optimum for N mineralization (Wong and Notcliff, 1995). The top of the sinter funnel was then covered with perforated fine nylon netting to allow for aerobic respiration. The incubated soil was weighed periodically to determine moisture loss and brought back to 80% field capacity with deionized water (Agbenin *et al*., 1999).

At weekly interval, 50 ml of 2*M* KCl solution was used to leach the soil slowly over a period of 4 – 5 h. Leachates were collected and analyzed for total inorganic N, NH_4-N and NO_3-N. To avoid any salt build-up in the system after each extraction, the soil was slowly leached with deionized water until the electrical conductivity of the leachate approaches the electrical conductivity of the soil solution at incubation. This according to Agbenin *et al*. (1999) was designed to maintain constant ionic strength during incubation while the 2*M* KCl was to remove mineralized N (Weier and MacRae, 1993). Inorganic N (NH_4^+-N + NO_3^--N) in the extracts and leachates were determined by steam distillation (Mulvaney, 1996). Inorganic N (NH_4^+-N + NO_3^--N) mineralized from NSC were taken to be the difference between the control and soil treatment. The laboratory incubation was replicated three times. Measurements of N mineralization under controlled laboratory conditions provide an estimate of the pools of mineralizable N present at the time of sample collection. These pools are replenishable under field conditions as a result of inputs of organic N from root and above-ground litter and the slow transformation of more resistant pools of soil organic N.

3.6. Field mineralization experiment (PVC tube experiment)

3.6.1. Sampling procedures for mineralization experiment

An in situ covered-core method (Knoepp and Swank, 1995; Raison *et al*., 1987) was employed to measure N mineralization in 2009 and 2010. Four open-ended PVC tubes (25cm long with a diameter of 10cm) were inserted 20cm into the ground midway between sorghum rows and capped. Soil samples were taken at 2-week intervals beginning in June and ending in October.

Soil samples were taken from within the tube (these were referred to as incubated samples) and also from outside the tube (these were referred to as ambient samples). Each year, there were 7 sampling dates (T1 to T7) plus a time *t* zero (T0). The initial soil sampling was conducted concurrently with the bulk sampling for estimating rainy season soil residual N, however, incubation tubes were not set up at that time for T1 so as to allow for the incubation of the NSC that was incorporated at this time until after two weeks when TB (1) samples were collected and tubes inserted for T2. When soil samples were taken from T1 to T7, a new set of incubation tubes were inserted adjacent to the previous ones midway between sorghum rows for the next sampling time. The time schedule for sampling was concurrent with field operations, with T1 sampling at the time of planting, T7 at harvest. The concentrations of NH_4^+-N and NO_3^- N in soil samples were determined by oxidation (Bremner and Keeney, 1965). Total mineral-N (NH_4^+ and NO_3^-) was determined through summation.

The rate of net N mineralization (N_{min}) during a specific period (t_i) was calculated as the difference between mineral N content measured from the ambient sample prior to incubation (t_{i-1}) divided by the number of days elapsed between the two periods:

$$N_{min} \text{ (kg ha}^{-1} \text{ d}^{-1}) = NT_i - NA_{i-1} / t_i - t_{i-1} \quad \text{.....(1)}$$

Where NT_i is mineral N (total of NH_4^+ and NO_3^-) in the tube at time t_i, NA_{i-1} is ambient mineral N at time t_{i-1}. If $N_{min} \leq 0$, N_{min} will be set to zero. Cumulative mineralized N (N_{cum}) was calculated as the summation of mineralized N from planting to time j:

N_{cum} (kg ha^{-1}) = $\sum N_{min\ j}$ ……. (2).

3.6.2. Mineralization model

The cumulative N mineralized at time t (N_{min}) was calculated from the first-order rate decomposition model (Stanford and Smith, 1972). Similarly, the decomposition and nutrient release rate constants, *k* were estimated from several other exponential equations (eq. ii to v). These are the kinetic expressions which consist of consecutive reaction models (eq. ii and iii); a Gompertz function (eq. iv) and a mixed-order rate model (eq. v). The results from eq.ii to iv were tested along with the conventional first-order rate decomposition model (eq.i).

$N_{min} = N_o (1 - e^{-kt}) + N_e$ …… (i)

Where N_o is potentially mineralizable N, *k* is the rate constant, N_{min} is cumulative N mineralized at time *t*, while N_e is an additional term introduced to accommodate the initial rapid N flush (Jones, 1984).

$N_{min} = N_o - N_o (ke^{-ht} - he^{-kt}) / (k - h)$ …… (ii) (Noggle, 1985)

$N_{min} = N_o - N_o e^{-kt} (kt + 1)$ …….. (iii)

$N_{min} = N_o - N_o e^{-he-kt} - N_o e^{-h}$ ……. (iv) (France and Thornley, 1984)

$N_{min} = N_o (1 - e^{-kt-0.5ht2})$ …… (v)

Where *h* is an additional coefficient in eq. ii and v. All other terms are as defined for eq. (i). The consecutive reaction models (eq. ii and iii) describe a decomposition reaction in which reactants pass through an intermediary to form the final products. The conversion of reactants to the intermediary and from the intermediary to the final products is assumed to follow first-order rate kinetics with rate constants h and k respectively. A special case of the model is to allocate equal

rates to the formation of intermediary and products ($h = k$), in which case N mineralization can be described by a single rate constant (eq.iii). Diaz-Firroz *et al*. (1988) applied a consecutive reaction model to describe the kinetics of N mineralization from cattle slurry incorporated into a soil.

A Gompertz function which is an asymmetric logistic growth model, was also applied to N mineralization (Ellert and Bettany, 1988; Agbenin *et al*., 1999). When applied to the growth of organisms, the model accounts for an exponential increase or decrease corrected by a coefficient which is related to the difference between microbial population size at time t and its asymptotic value (Vanderpitte *et al*., 1995). The mixed-order model (eq. v), recognizes a single mineralizable substrate pool conforming to both first- and second-order rate kinetics (Brunner and Focht, 1984).

3.6.3. Statistical analysis

SAS non-linear regression models was employed to compare rates of net N mineralization and nitrification for the covered core and laboratory incubations; Coefficient of multiple determinations (R^2), chi-square ($א^2$) and the root mean square error (RMSE) was computed to assess the goodness-of-fit statistics of the models used.

3.7. Field decomposition study

3.7.1. Treatments, design and experimental details

Decomposition study was conducted on the field in each of the years (2009 and 2010) to assess the contribution of microbiological, substrate and soil environmental conditions such as moisture and temperature on the rate of decomposition (mass loss) of NSC, and the concomitant effects on soil fertility improvement and management. The NSC was milled to fine mesh size

since large fragments have been observed to cause marked immobilization during incubation (Schimel and Parton, 1986). Litterbags were introduced into plots with inorganic fertilizer alone as well as control (zero NSC and NPK fertilizer) amended plots. Treatment combinations were as shown in Table 3.2.

Treatments were the four NSC levels and four rates of inorganic fertilizers with four harvest periods. The treatments were replicated thrice. Twenty grams of milled NSC samples were put into 10 × 18-cm litterbags of mesh size < 2 mm. The bags were sealed and the NSC spread evenly within the bags. Four plots of 8 ridges (6m × 6m) each were marked out and treatment allocated as appropriate to relevant plots. Sorghum seeds were planted on all plots at 20 cm within row spacing. After thinning, litterbags were randomly placed in the outer ridge of the gross plot (6 × 4.5m) at 5-litterbags/ outer ridge/ plot between stands of sorghum at 10cm depth, leaving the additional one ridge at the boundary of each plot, to prevent seepage of treatments (interference). Although the materials were not uniformly mixed with the soil, it was considered adequate for the study, because the traditional hoe ridging simply places the plant material applied on the soil surface.

3.7.2. Time-step retrieval of litterbags

Two litterbags from each treatment plots were randomly retrieved at 2, 4, 8, and 12 week from a total of 96 experimental units in 2009, however, in 2010, the sampling date was earlier. Two bags were retrieved from each treatment plots at 3, 7, 10 and 14 days after which the fortnight approach of the previous year was adopted. The retrieved samples were oven-dried at 65^0 C to a constant weight. The dry weights were expressed as percentage of sample weight remaining undecomposed at each of the sampling dates. Sub-sample (1 g) was weighed and ash in the muffle furnace to correct for sand particles in retrieved litterbags.

Table 3.2: Treatment combinations

Treatment	NSC (t ha^{-1})	Fertilizer rate (kg ha^{-1})
1	0	0
2	0	¼
3	0	½
4	0	Full

3.7.2.1 Determination of Ash free dry weight

Ash-free dry weights were determined and subtracted from the original sub sample dry weight to determine the amount of NSC in the sub sample. The amounts of nutrients remaining were then calculated as the weight of the NSC multiplied by nutrient concentration.

3.7.3. Data management / models

Litter decomposition data from the decomposition studies were fitted to several models (Weider and Lang, 1982) to identify the model that best fits the decomposition data. Decomposition rate were calculated for the NSC using the formula thus:

$$\text{Daily decomposition rate (\%)} = \frac{\text{\% mass loss } (105^0\text{ C})}{\text{Length of incubation (day)}}$$

(Sewanee and Simmons, 2003)

The following models were used to fit biomass and N loss data. The analysis was carried out on the proportion (X_t) of the initial mass (X_o) remaining at time *t*. The model parameters were:

t = time (day)

X_o = quantity (capacity factor) of the total biomass (or N) at time zero that is available for decomposition.

k_o, k_L, k_I, k_R = decomposition rate constant (day^{-1})

X_L, X_I and X_R = defined compartments based on their proportions in % of the initial biomass or N.

Y = proportion (X_t) of the initial mass (X_o) remaining at time $t = X_t / X_o$, defined on the interval $0 \leq X \leq 1$.

1. Single exponential decay model

$$Y = X_o e^{-k0t}$$ (Ibewiro *et al*., 2000)

2. Double exponential decay model

   $Y = X_L e^{-kLt} + X_R e^{-kRt}$ (Somda *et al*., 1993)

3. Asymptotic negative exponential model

   $Y = X_L e^{-kLt} + X_R$ (Couteax *et al*., 1998)

4. Triple negative exponential decay model

   $Y = X_L e^{-kLt} + X_I e^{-kIt} + X_R e^{-kRt}$ (Couteax *et al*., 1998).

Using decay coefficient (*k*) value, and assuming constant decay rate for the NSC, the half life ($t_{½}$) value, the time it takes for loss of 50% of the NSC to occur was estimated from the best fit model using the formula:

$$t_{½} = \frac{0.693}{k}$$

Correlation and multiple regressions between depleted mass and initial chemical indices of the NSC were performed on untransformed data for each period. The analysis was performed on the initial amount of X remaining at time t, where X was the dry mass (Weider and Lang, 1982; Gordillo and Canberra, 1997). The decay models were compared using coefficient of multiple determination (R^2) and residual mean squared errors (RMSEs).

3.8 Field Trials

Field trials were conducted for two years – 2009 and 2010 – to investigate the effect of NSC and NPK fertilizer on the growth, nutrition and yield of sorghum.

3.8.1 Treatments and Experimental design

The treatment consisted of factorial combinations of four levels of NSC (0, 1, 2 and 4 t ha^{-1}) and four rates of chemical fertilizer package (0, ¼, ½ and full recommended fertilizer rates of 64 kg

N, 32 kg P_2O_5, and 32 kg K_2O for sorghum), giving a total of sixteen (16) treatment combinations as shown in Table 3.3. Plot size was 6m × 4.5m giving a gross plot size of $27m^2$ with six (6) and four (4) rows in the gross and net plots respectively. The experiment was laid out in a randomized complete block design (RCBD) with three replications.

3.8.2 Cultural practices and application of treatments

The field was ploughed, harrowed and ridged using a tractor in the first year. The plots were then laid out and the NSC treatment applied at 1, 2 and 4 ton ha^{-1}. The amounts of NSC applied per plot for the various treatment levels were 2.7, 5.4 and 10.8kg on dry weight basis. These were incorporated along the middle of the ridge after all land preparation operations.

The incorporated NSC was allowed to incubate for two weeks on the field before planting. Ten seeds of sorghum (variety, *Samsorg 17 (SK-5912)*) was planted at ten seeds per hill and at a spacing of 25cm within row and 75cm inter-row. Phosphorus (SSP) and potassium (MOP) fertilizers were applied at planting at 0, ¼, ½ and full recommended rates. The specific amounts of SSP and MOP applied per plot were 0, 0.12kg (8 kg ha^{-1}), 0.24kg (16 kg ha^{-1}) and 0.48kg (32 kg ha^{-1}) of single superphosphate and 0, 0.036kg (8 kg ha^{-1}), 0.072kg (16 kg ha^{-1}) and 0.144kg (32 kg ha^{-1}) of muriate of potash corresponding to 0, ¼, ½ and full fertilization for both nutrients, respectively. After emergence, the seedlings were thinned to two plants per stand at three weeks after planting. Quarter nitrogen levels at 0, 0.023kg (4 kg ha^{-1}), 0.047kg (8 kg ha^{-1}) and 0.094kg (16 kg ha^{-1}) of urea being 0, ¼, ½ and full of the recommended rates first dose was applied after first weeding at three weeks after planting and first weeding in accordance to the factorial design. The remaining second split dose (three-quarter) of the N requirements were applied at six weeks after planting at 0, 0.070kg (12 kg ha^{-1}), 0.141kg (24 kg ha^{-1}) and 0.282kg (48 kg ha^{-1}) of urea as appropriate. Weeds were controlled with broad spectrum herbicide

Table 3.3: Treatment numbers and combinations used in the field study

Treatment number	NSC (t ha^{-1})	Fertilizer rate (kg ha^{-1})
1	0	0
2	0	¼
3	0	½
4	0	Full
5	1	0
6	1	¼
7	1	½
8	1	Full
9	2	0
10	2	¼
11	2	½
12	2	Full
13	4	0
14	4	¼
15	4	½
16	4	Full

¼, ½ and full = Proportion of optimum fertilizer rate of 64 – 32 - 32 for sorghum

(Round up) which was applied two weeks before land preparation and pre-emergence herbicide (Vestrazine) applied immediately after planting. However, during the season, hoe weeding and non-selective herbicide (Miazone) were used within the treatment plots and the alley/ discard. The ridges were re-moulded at six weeks after planting.

It was necessary to control stem borer attack in the second year, consequently, *Best action* - a systemic and contact insecticide was used. The study was conducted on the same site and the plots were maintained in both years of the study period. In the second year, the plots were prepared manually to maintain plot properties. The old ridges were scattered and re-moulded with hoe and the appropriate NSC level incorporated and thereafter incubated for two weeks. All other operations were carried out as in the first year.

3.8.3 Field observations and measurements

3.8.3.1. Dry matter estimation by destructive sampling

Plant samples were harvested systematically from the gross plots beginning at 3 WAP for dry matter assessment and subsequently at fourteen days intervals until heading. A whole plant from each treatment was cut at ground level and separated into leaves and stem. The cumulative data over the period was employed to evaluate sorghum performance (growth) over time in the field. A total of seven samplings were carried out over the period. Measured leaves and stems were oven dried at 60^0 C until constant weight was attained and weighed for dry matter estimation at the various stages of growth. Three replicate samples were taken on every sampling date per treatment.

3.8.3.2. Leaf area measurement

Leaf area measurement was obtained from the sampled plants (3.4.3.1) using a tape meter to measure the length and breadth at the widest portion of the leaves. Direct leaf area measurement was then calculated in cm^2 by the multiplication of the corresponding length and breadth for each leaf and then multiplied by the conversion factor for sorghum (0.73). Total leaf area given in cm^2 was the cumulative value recorded per whole plant stand.

3.8.3.3 Leaf area index (LAI)

The leaf area index was calculated for each sampling date as:

$$LAI = \frac{\text{Actual leaf area measured in } cm^2 \text{ per stand (1 plant)}}{\text{Area of land available for the plant (1875 } cm^2\text{)}}$$

Where the actual leaf area was obtained by multiplying the total leaf area by the constant (0.73) for sorghum and the area of land available per plant was estimated thus:

Area of land available per plant = 75 cm × 25 cm where 75 cm was the distance within ridge and 25 cm was the distance along ridge.

3.8.3.4. Stem girth, leaf number and plant height measurements

Stem girth was measured using five tagged plants in the net plots of each treatment. This was done by taking the circumference of the widest part of the stem using a thread and the dimension was read off on the meter rule.

Leaf number was obtained by counting the leaves of the tagged plants, while plant height was obtained by measuring the height to the top of the leaf of the tagged plants per treatment using

the metre rule. The measurement was initiated from the base (just at the surface of the ridge) to the apex or flag leaf.

3.8.3.5 Yield and yield components

During the cropping season of 2009 and 2010, designated sample areas within each plot were permanently marked to represent the harvest area. The harvest area (net plots) was 12 m^2 for both years. The harvest area (net plot) comprised of the four inner ridges with a length of 4 meters. Parameters considered before crop maturity and harvest were: plant stand per net plots at harvest (maturity), days to 50% panicle emergence and 50% flowering. At maturity, the net plots per treatment were harvested for both grain and stover yield. Harvesting was done by cutting panicles from each stand when all sorghum heads were properly dry enough for threshing.

The stover within the harvest area was cut at ground level to determine stover weight per net plot. A sub sample of the stover was taken and oven dried at 60^0C for 3 days, milled and stored for nutrient analysis. Similarly, at harvest, grain samples were taken from all the plots, oven-dried to constant weight at 70^0C, ground with Willey mill to pass through a 40-mesh screen, and subjected to chemical analysis for estimation of total N, P K, and tannin concentrations on a dry weight basis. Soil samples were also collected at harvest from which soil pH, exchangeable bases, exchangeable acidity, organic carbon, total N and P were also determined. The following parameters were calculated thus:

1. Relative yield at each fertilizer level, RY (%)

$$RY = \frac{\text{Yield}_{\text{treatment}}}{\text{Yield}_{\text{optimum chemical fertilizer}}} \times 100 \quad \text{(Chien } \textit{et al.}\text{, 1990)}$$

2. Relative yield increase, RYI (%)

$$RYI = \frac{\text{Yield}_{\text{treatment}} - \text{yield}_{\text{control}}}{\text{Yield}_{\text{optimum chemical fertilizer}} - \text{Yield}_{\text{control}}} \times 100$$ (Chien *et al*., 1990)

3. Agronomic nutrient use, ANU (%): This reflects the efficiency of applied nutrient applied as treatments.

$$ANU = \frac{\text{Yield}_{\text{treatment}} - \text{yield}_{\text{control}}}{\text{Nutrient applied}_{\text{treatment}}} \times 100$$ (Singh *et al*., 1999)

4. Fertilizer Equivalence: which is the amount of inorganic fertilizer N that is equivalent to a given amount of organic amendment (FE) was obtained from the best fit regression line exhibited by the response of grain yield to the inorganic fertilizer N alone (Jokela, 1992; Murwira *et al*., 2002). Fertilizer equivalencies (FE) of treatments were obtained using a quadratic function with the equation:

$y = c + bFE + aFE^2$ (Murwira *et al*., 2002).

The following formula for solving quadratic equations was used to solve the regression equation for FE:

$FE = -b \pm \sqrt{(b^2 - 4ac)}/2a$.

Where a, b, and c are constants obtained from the quadratic function, y is the yield from a particular treatment plot and FE is the fertilizer response obtained from the formula for solving quadratic equations above.

5. Percent fertilizer equivalence values: In order to compare the fertilizer responses of the treatments, the % fertilizer equivalence (FE) values were calculated according to the following method:

$$\text{FE (\%)} = \frac{\text{FE x 100}}{\text{N applied}}$$

Where FE = fertilizer response obtained from the formula for solving quadratic equations, and N applied = actual amount of N applied in each plot (Mugendi *et al*., 2009).

6. Harvest Index (HI): this is defined as the proportion of economic yield produced per total dry matter production (biomass) was calculated as:

$$\text{HI} = \frac{\text{Economic yield (grain yield)}}{\text{Total biomass}} \times 100$$

3.8.4 Nutrient concentration of the sorghum plant

3.8.4.1 Analytical methods for grain samples

The ground sub samples of the sorghum grains were subjected to proximate analysis for the determination of the crude protein and tannin contents. The crude protein (CP) was calculated using the conversion factor of 5.9 suggested for cereal proteins due to the variation in the CP in feeds (13 – 18 %) (Gilchrist, 1967) following the wet digestion for total N by the micro-Kjeldahl method. Tannin was determined as described by Allen (1989) and the soluble tannins calculated thus:

$$\text{Soluble tannins (\%)} = \frac{C \times V}{10 \times A \times W}$$

Where C = concentration (mg), V = extract volume (cm^3), A = Aliquot volume taken (cm^3) and W = sample weight (g)

3.8.4.2 Analytical methods for the plant samples

Sorghum stover, after separation into stem and leaves were analysed for total nitrogen (TN) using the micro-Kjeldahl wet digestion method. The plant materials were wet digested using tertiary acid (sulphuric + nitric + perchloric) method, and the P in the digest determined colorimetrically, while K was determined by flame photometer, and Ca and Mg were determined by atomic absorption spectrophotometry.

3.9. Statistical analysis

Data obtained in the two-year trial period were subjected to analysis of variance (ANOVA), using SAS, version 8.1 programme. The differences among the experimental treatments were compared using the standard error (SE) and the Duncan Multiple Range Test (DMRT) tests, for two or multiple comparisons of means at the $P < 0.05$ probability level. The Pearson correlation coefficients was used to correlate the sorghum performance (grain, stover, protein and tannin content) with the yield and growth (Leaf Area Index, Dry Matter Yield) parameters. To understand the underlying relationships among the soil chemical properties, factor analysis was used to group the soil properties according to their covariance (Johnson, 1978) using IBM SPSS version 20.0. The database contains information on the soil pH in water and calcium chloride, exchangeable acidity, organic carbon, exchangeable bases, available P, N and effective cation exchange capacity. Factor Analysis was performed with reference to the whole dataset and estimates of the initial factors obtained from principal component analysis. The number of factors to be retained was chosen on the basis of the relative proportions of the variance explained by the Eigenvalue (standardized variance associated with a particular factor). To simplify the interpretation of the results, VARIMAX rotation with Kaiser normalization was used. On the basis of the rotated component matrix, it was then possible to identify the most

significant variables within the group of components and the degree of inter-relationship between them.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Characterization of the study site

4.1.1 Soil characteristics and geology

Soils of the experimental site have been classified as Typic Haplustalf sub-order, an Alfisol in the USDA Soil Taxonomy system (Harpstead, 1973); or Orthic Acrisol in the FAO-UNESCO Legend (Valette and Ibanga, 1984). The soil is generally formed in underlain, at varying depths, by iron pan over rocks of Basement Complex. The contact zone between soil and the iron pan is made up of iron concretions, ironstone or other coarse fragments (Valette and Ibanga, 1984). Soil chemical and physical properties of the experimental soil prior to experimentation in 2009 are presented in Table 4.1. The soil was sandy loam in texture and low in clay content (160 g kg^{-1}). The soil was characteristically low in organic carbon content (4.41 g kg^{-1}) and CEC (5.20 cmol kg^{-1}) (Jones and Wild, 1975; Uyovbisere and Lombin, 1991). The low level of organic carbon coupled with the associated sandy texture (Table 4.1), would encourage rapid leaching of cations (Jones, 1973; Enwezor *et al*., 1989), and consequently the soil would be low in CEC.

The soil was slightly acidic, with pH-value in $CaCl_2$ solution (5.3) lower than that in water (6.0) indicating that the soil possesses a net negative charge in the colloidal complex (Daudu, 2004). The pH value in water was above 5.0 indicating that exchangeable Al toxicity may not be a problem in this soil (Kamprath, 1972). Exchangeable bases: calcium (2.20 cmol kg^{-1}), magnesium (0.65 cmol kg^{-1}), potassium (0.21 cmol kg^{-1}) and sodium (0.32 cmol kg^{-1}) contents were all low in the soil. Calcium and magnesium were however the dominant cations on the exchange sites of the soils. The effective cation exchange capacity of the soil was 3.58 cmol kg^{-1} calculated as the summation of exchangeable bases and acidity which was low. This makes the soil susceptible to soil acidification because the ability to hold on the basic cations is low. The

Table 4.1: Physico-chemical characteristics of soils of the field experimental site and Greenhouse

Soil property	Amount in soil
Particle sizes (g kg^{-1})	
Clay "	160
Silt "	240
Sand "	600
Textural class	Sandy loam
pH (H_2O; 1:2.5 w/v)	6.00
pH (0.01M $CaCl_2$; 2.5 w/v)	5.30
Bray-1 P (mg kg^{-1})	0.368
Organic Carbon (g kg^{-1})	4.41
Total N (g kg^{-1})	5.25
Exchangeable cations (cmol kg^{-1})	
K "	0.21
Ca "	2.20
Mg "	0.65
Na "	0.32
Cation exchange capacity "	5.20
Effective cation exchange capacity "	3.58
Exchangeable Acidity (cmol kg^{-1} soil)	0.20
Extractable micronutrients (mg kg^{-1})	
Zn "	5.00
Fe "	24.29
Cu "	1.50
Mn "	3.06

*ECEC = TEB + EA

generally low content of soil nutrients implies that there would be the possibility of a good response to applied nutrients, which is an important criterion in the selection of experimental site (Stevenson, 1982; Palm, 1995).

4.1.2 Climatic conditions of the study years

The daily weather data of the Institute for Agricultural Research Farm site used in this study are given in Appendix 1, while the climatic features in the trial years described in comparison with its short and long term data are summarized in Table 4.2 for 2009 and 2010, respectively. The first rainfall in 2009 and 2010 was recorded on the 19th of April. Although, there was no long dry spell, the rainfall pattern was erratic in both years (Appendices 1 and 2) with the equations: $y = 0.0238x + 9.5283$; r (correlation coefficient) = 0.0714 and $y = 0.0313x + 7.6252$; r = 0.1233, respectively; where y is the quantity of rainfall in millimeters and x is time in days. Consequently, the timing and duration affected crop growth and development adversely, since rainfall amount was equally low throughout June compared to same period in previous years. However, rainfall distribution in the months of July and August were better for crop growth in 2009.

The months of July and August of year 2010 experienced about 35% decrease in total quantity of rainfall when compared with that of the previous year. Although, higher rainfall amounts were recorded throughout year 2009, 2010 was found to be warmer than the immediate past year (2009) that recorded mean temperatures in the range of 23.2°C to 30.7 °C. Also, except in the month of June which had an equal number of days of rainfall as in 2009, other months had a decrease. Thus, the planting months of the year experienced inadequate amount of rainfall, while much heavier rainfall was experienced later in the season (at harvest), almost destroying the matured crops (Table 4.2). The average rainfall and temperature for the two years combined were 1203mm and 22.8 ºC respectively.

Table 4.2 Monthly summary of weather conditions at Samaru-Zaria for two years of the study

	Tmean (ºC)		Rain (mm)		Days of rainfall	
Month	2009	2010	2009	2010	2009	2010
January	23.2	23.6	0	0	0	0
February	26.6	27.3	0	0	0	0
March	28.7	29.2	0	0	0	0
April	30.7	30.7	20.3	23.7	4	3
May	29.0	29.1	85.1	104.7	6	8
June	27.8	26.6	89.5	165.4	11	11
July	25.7	24.9	285	188	14	12
August	25.9	25.0	439.7	287.7	20	18
September	26.4	26.1	206.7	241.4	14	17
October	26.6	26.7	151.7	98.9	7	10
November	23.8	25.0	0	0	0	0
Total/ average	26.8	26.7	1278	1128.5	76	79

Source: IAR meteorological station

4.2 Characteristics of the neem seed cake (NSC) used for the study

The chemical properties of the organic material showed that there was much variation in the nutrient contents of the NSC used in the study (Table 4.3). Processed seed were picked from different locations. The compositions reflected differences in the sources, as neem seed from different geographical locations vary widely in their chemical compositions (Radwanski, 1969; Mengel and Kirkby, 2001). Also, the quality of NSC is determined by the amount of oil left in it, as well as the process by which the extraction was done (Espanol, 2009). Although, all the nutrients in the NSC may not be available to a crop, the information can provide a qualitative estimation of the organic material (Palm *et al.*, 1997). Both N (3.85 % in 2009 and 5.34 % in 2010) and P (0.37 % in 2009 and 0.18 % in 2010) values of the NSC used in the study for the two years (Table 4.3) have above the critical levels of 2.5% and 0.2% for N and P respectively, and would be expected to result in net release of these nutrients on application to the soil (Palm *et al*., 1997; Giller, 2000; Benton, *et* al., 2001).

Also, the low lignin content (< 15%) coupled with the narrow C: N ratio (5.99 and 5.62 in 2009 and 2010 samples, respectively) would result in fast decomposition and release of nutrients (Okalebo and Woomer, 1994; Microsoft Student Encarta Premium, 2008). Consequently, incorporation directly into soil with annual crops at planting would be expected to give better results in terms of improving the synchronization of nutrients release and subsequent uptake by the crop (Murwira and Kirchmann, 1993; Giller, 2000; Palm *et al*., 2001). On the contrary, K and Ca values were below critical or standard concentrations of 1.9% and 1.0% respectively while Mg was approximately equal to the standard value of 0.2% (Benton, *et al*., 2001). This corroborates earlier submissions that organic materials do not contain all the essential nutrients that are required by a particular crop in the appropriate amount (Palm *et al*., 2001).

Table 4.3: Selected chemical characteristics of the neem seed cake used in the study for the two years

Parameter	Unit	2009	2010
N	%	3.85	5.34
P	%	0.37	0.18
K	%	1.47	1.00
Ca	%	0.014	0.014
Mg	%	0.02	0.02
OC	%	23.05	30.02
Lignin	g kg^{-1} DM	30.10	44.67
Cellulose	g kg^{-1} DM	303.97	316.33
Polyphenol	g kg^{-1}	13.30	8.00
C: N		5.99 : 1	5.62: 1
N: P		4.53 : 1	12.71: 1
C: P		27.12: 1	71.48: 1

4.3 Greenhouse experiment

4.3.1 Main effect of treatment factors

4.3.1.1 Response of Agronomic parameters to NPK fertilizer levels

Number of leaves

Non-significant ($P \leq 0.05$) difference in the number of leaves was observed between each of the treated pots and the control (Table 4.4). In the sole CF treatments, the control and the full recommended rates (RR) recorded same number of leaves (8.59) on the average statistically while the ¼ RR recorded least number of leaves (8.36) (Table 4.4).

Stem girth

Statistically, there were no significant differences on sorghum stem girth with respect to treatment in the greenhouse.

Plant height

The treatments had no significant effect on plant height ($P \leq 0.05$). However, the full recommended rate (FRR) treatment produced plants with the tallest plants (56.59 cm) at the end of the experiment (eight (8) weeks after planting) as shown in Table 4.4.

Dry matter yield (DMY)

There was no significant difference in DMY with respect to mineral fertilizer in the greenhouse. However, sorghum DMY increased with increasing rate of CF (Table 4.4).

4.3.1.2 Response of agronomic parameters to NSC levels

Number of leaves

In the sole NSC treatments, highest number of leaves (8.64) was obtained from the 4 t ha^{-1} NSC while the control recorded the least (8.39). However, there was significant difference in number of leaves at both the 1% and 5% level of significance (Table 4.4).

Table 4.4: Main effects of neem seed cake and chemical fertilizer on sorghum performance in the greenhouse.

Treatment	Number of leaves	Stem girth (cm)	Plant height(cm)	Dry matter yield (g pot^{-1})
NPK kg ha^{-1} (N)				
0	8.59	0.98	54.79	6.26
¼ RR	8.36	0.97	55.24	6.18
½ RR	8.46	1.08	55.19	6.21
FRR	8.59	1.01	56.59	7.60
SE ±	0.0512	0.0076	5.883	1.025
NSC t ha^{-1} (S)				
0 TC	8.39	1.00	55.41	6.15
1 TC	8.50	1.08	56.36	6.93
2 TC	8.47	0.95	54.08	6.16
4 TC	8.64	1.02	55.97	7.01
SE ±	0.0512	0.0076	5.883	1.025
Interaction (N x S)				
N x S	NS	NS	NS	NS

NS = Not Significant; RR = recommended rate; FRR=Full recommended rate; TC = ton ha^{-1} NSC

Stem girth

Sole NSC generally had higher stem girth on the average at eight (8) weeks after planting than the CF (Table 4.4)

Plant height

There was no significant difference in plant height in sole NSC treatments. However, 1 TC recorded the highest plant height (56.36 cm) (Table 4.4).

Dry matter yield

There was no significant difference in DMY in the sole NSC pots. However, sole CF pots gave better results on the average than the sole NSC (Table 4.4). This shows that the initial soil nutrients level could not sustain sorghum growth and yield. Also suggested the inability of organic materials to release nutrients fast enough to meet crop needs at periods of high demand especially when crops are not grown to maturity (Allen *et* al., 1989). The Increase in rates of NSC to 4 tonne ha^{-1} led to marginal and non-significant dry matter increase (Table 4.4) in the sole NSC pots. This indicates that it was not the amount of nutrients added by the NSC but the availability and/ or the time frame under which the crop was grown that were the major factors limiting sorghum yield.

4.3.1.3 Interaction of NPK and NSC levels on agronomic parameters

Number of leaves

Interaction effect was not significant but the highest number of leaves (9.42) was obtained from the 4 TC + FRR (Table 4.5). This would imply that combined application of NSC and CF led to the production of more leaves than their sole applications.

Table 4.5: Interaction of neem seed cake and inorganic fertilizers on sorghum performance in the greenhouse

Treatment	Dry matter yield (g pot^{-1})	Plant height (cm)	Stem girth (cm)	Number of leaves
Control	6.46	57.6	1.02	8.72
¼ RR	8.69	59.82	1.08	8.67
½ RR	5.36	51.78	0.93	8.67
FFR	4.52	49.94	0.89	8.31
1 TC	5.48	53.68	0.95	8.42
1 TC + ¼ RR	6.66	55.3	1.01	8.44
1 TC + ½ RR	5.61	53.35	0.92	8.25
1 TC + FRR	6.99	58.62	1.01	8.33
2 TC	6.47	55.52	1.09	8.39
2 TC + ¼ RR	4.69	52.04	1.23	8.33
2 TC + ½ RR	6.9	57.59	0.99	8.61
2 TC + FRR	6.77	55.61	1.02	8.5
4 TC	6.21	54.84	0.93	8.03
4 TC + ¼ RR	7.68	58.25	1.01	8.56
4 TC + ½ RR	6.77	53.58	0.96	8.36
4 TC + F RR	9.75	59.69	1.15	9.42
Mean	6.56	55.45	1.01	8.5
CV (%)	28.71	8.14	16.1	4.96
SE ±	0.47	1.13	0.04	0.11

RR= recommended rate
FRR=Full fertilizer recommendation rate
TC = ton ha^{-1} NSC

Stem girth

Combination of NSC and CF at 4 TC + FRR gave the highest stem girth (1.15 cm) (Table 4.5) an index to the importance of complementary use of the two nutrient sources on growth of sorghum (Ayoola and Makinde, 2009).

Plant height

There was no significant difference in plant height in the interaction of NPK and NSC. In spite of the insignificant difference recorded from the combined NSC and CF treatments (Table 4.5), adequate nutrient required for early growth could be supplied from organic fertilization, by enrichment with inorganic nutrients. This was contrary to the findings of Garba (2010) in a greenhouse experiment using maize as test crop with significant effect. Perhaps, variations in the soil characteristics as well as the ability of sorghum (the test crop) used in the present experiment could account for better response to nutrient application.

Dry matter yield

Dry matter yield (DMY) was highest in pots where NSC was applied in combination with CF (Table 4.5). This shows that complementary use of NSC with CF enhanced sorghum growth and yield. Readily available nutrients would have been supplied by the CF for initial plant root absorption and the immediate requirement of micro-organisms for organic matter decomposition and subsequent nutrient release by the NSC would have been met.

In the sole NSC pots, the highest dry matter yield, plant height and stem girth were obtained from the 2 ton ha^{-1} treatment pots while the highest number of leaves was obtained from the 1 ton ha^{-1}, although the value was less than 8.72 obtained from the control treatment pots (Table 4.5). The interaction of NPK and NSC recorded increase for some treatment pots as well as a decrease in others. For dry matter yield, seven out of the nine interaction treatment pots recorded increase higher than the control pots. Three of the nine interactions recorded plant height that

were higher than the control while two of the treatments had values that were higher than the control for stem girth. Only the 4 TC treatment + FRR (9.42) had leaf number that was higher than the control treatment (Table 4.5).

However, none of the treatments – sole NPK or NSC and the interaction – were statistically significant at both the 0.01 and 0.05 level of probability for the four growth parameters studied in the greenhouse (Table 4.4). Greenhouse study would give a clue of what could be obtainable in the field as other environmental factors play substantial roles in the mineralization/immobilization process. Also, soil sample used for greenhouse experiment would only give results based on what was contained in them at sampling (Harmsen and Van Shreven, 1955; Raison *et al*., 1987).

4.3.2 Nutrient uptake studies

4.3.2.1 Effect of NSC and chemical fertilizer (CF) treatments on nutrients concentration of sorghum tissue.

Main effects of treatments on N, P and K concentrations in sorghum tissue in the greenhouse are shown in Table 4.6 and the interaction in Table 4.7.

Nitrogen

Higher N concentration (10.79 g kg^{-1}) in sorghum tissue was recorded with 4 t NSC ha^{-1} (TC) + FRR while ½ RR recorded the least (7.00 g kg^{-1}) (Table 4.7). This indicated the positive interaction of NSC and CF on the improvement of soil fertility which enhanced sorghum plant mineral composition (Garba, 2010). Although, there was no significant influence of treatment on N concentration in sorghum tissue, the concentration of N increased with increasing level as shown by the response from 0 – 2 t NSC ha^{-1}. However, N content was depressed at 4 TC. The control recorded the least N concentration in both cases which indicated the need for N for

Table 4.6: Main effects of NSC and CF on nutrient concentrations of sorghum tissue in the greenhouse

Treatment	Concentration (g kg^{-1})		
	N	P	K
NPK kg ha^{-1} (N)			
0	8.17	1.21a	10.45
¼ RR	8.61	1.02b	2.64
½ RR	8.90	1.10ab	0.75
FRR	9.04	1.17ab	8.11
SE ±	0.52	0.06	3.18
NSC t ha^{-1} (S)			
0 TC	8.02	1.21	2.61
1 TC	8.24	1.15	6.25
2 TC	9.26	1.06	6.10
4 TC	9.19	1.08	7.00
SE ±	0.52	0.06	3.18
Interaction (N × S)			
N × S	NS	NS	NS

N. B. Means followed by the same letter(s) are not statistically significant using DMRT
NS = Not significant at 0.05 level of probability
RR= recommended rate
FRR=Full fertilizer recommendation rate
TC = ton ha^{-1} NSC

Table 4.7: Interaction of NSC and CF on nutrient concentrations of sorghum tissue in the greenhouse

Treatment	Concentration (g kg^{-1})		
	N	P	K
Control	8.17	1.22	8.21
¼ RR	7.88	1.22	0.74
½ RR	7.00	1.14	0.74
FRR	9.04	1.25	0.74
1 TC	7.59	1.17	7.80
1 TC + ¼ RR	9.04	1.08	0.78
1 TC + ½ RR	9.63	1.29	0.72
1 TC + FRR	6.71	1.05	15.69
2 TC	7.88	1.04	7.48
2 TC + ¼ RR	9.34	0.90	0.77
2 TC + ½ RR	10.21	1.00	0.75
2 TC + FRR	9.63	1.30	15.39
4 TC	9.04	1.39	18.31
4 TC + ¼ RR	8.17	0.90	8.28
4 TC + ½ RR	8.75	0.96	0.80
4 TC + FRR	10.79	1.08	0.62
SE ±	0.07	0.07	0.21
	NS	*	NS

*=Significant at 5% level of probability
TC= ton ha^{-1} neem seed cake
FRR= Full fertilizer recommendation rate
RR= recommended rate

sorghum production in the soil. There was no significant difference in the interaction of NSC and NPK on the concentration of N in sorghum tissue. However, the 4 TC + FRR (10.79 g kg^{-1}) recorded the highest N concentration in sorghum tissue (Table 4.7). Though not significant, the highest N concentration from the combined use of NSC and NPK fertilizers corroborates the report of Murwira and Kirchmann (1993) that combination of organic-inorganic nutrient sources could improve the synchronization of nutrient release and subsequent uptake by crop.

Phosphorus

Differences in nutrient concentration values were statistically significant ($P \leq 0.05$) for P in the sole NPK treatments (Table 4.6). Phosphorus concentration in sorghum decreased with increasing NPK with control (1.22 g kg^{-1}) performing better than any of the sole CF treatments (Table 4.6). Similarly in the sole NSC treatments, phosphorus concentration was decreased with increase in levels of NSC with control (1.21 g kg^{-1}) also performing better than any of the other treatments (Table 4.6), but was not statistically significant ($P \leq 0.05$). However, in the NSC plus CF treatments, the 4 TC recorded the highest P concentration (1.39 g kg^{-1}) in the sorghum tissue while 2 TC + ¼ RR and 4 TC + ½ RR, recorded the least P concentration (0.90 g kg^{-1}) (Table 4.7).

Potassium

There was no significant influence of treatments on K concentration in the sorghum tissue. Potassium concentration of sorghum tissue was erratic with increase in levels of treatments (Table 4.7). The rationale behind the trend observed in the greenhouse K concentration in this study was not known. But, the inconsistency in the K concentration with increase in the levels may suggest that K may have been well supplied in the soil and may not need K fertilization. However, the 4 TC (sole NSC) recorded the highest concentration (18.31 g kg^{-1}) while the 4 TC + FRR gave the least (0.62 g kg^{-1}) value (Table 4.7). The level of K was observed to be higher in the control (10.45 g kg^{-1}) plot than in any of the sole NPK treatments.

4.3.2.2 Effect of NSC and CF on nutrient uptake by sorghum in the greenhouse

Data on the main effects of treatments on nutrient uptake by sorghum in the greenhouse are presented in Table 4.8 and the interaction in Table 4.9.

N uptake

There was no significant difference on N uptake with treatment in the greenhouse in sole NPK and NSC treatments. In sole NPK pots, ½ RR recorded the least (5.19 g pot^{-1}) N uptake while ¼ RR gave the highest (5.95 g pot^{-1}) which were not statistically different from other treatments. There was no significant difference in N uptake in sole NSC pots with treatments in the greenhouse. 1 TC recorded the least N uptake (5.31 g pot^{-1}) while 2 TC gave the highest (5.73 g pot^{-1}) (Table 4.8). Effect of NPK and NSC interaction was not significant in the greenhouse. However, ¼ RR recorded the highest N uptake (8.34 g pot^{-1}) (Table 4.9).

P uptake

P uptake was significantly different ($p < 0.05$) with treatment effect in sole NPK pots. Control recorded the least P uptake (0.65 mg pot^{-1}) which was statistically at par with ½ RR (Table 4.8). ¼ RR also recorded the highest P uptake (0.86 mg pot^{-1}) which was statistically different from the control and ½ RR but similar to FRR (0.72 mg pot^{-1}). There was no significant difference in P uptake in sole NSC pots with treatments in the greenhouse. 2 TC recorded the least P uptake (0.66 mg pot-1) while control gave the highest (0.78 mg pot^{-1}). Effect of NPK and NSC interaction was not significant in the greenhouse. However, ¼ RR recorded the highest P uptake (1.15 mg pot^{-1}) (Table 4.9).

K uptake

There was significant difference in K uptake with treatments in sole NPK pots. ½ RR recorded the least K uptake (1.31 g pot^{-1}) while control gave the highest (5.09 g pot^{-1}) which was not statistically different from other treatments. There was however no discernible pattern of nutrient uptake in the greenhouse. 4 TC recorded the least K uptake (0.55 g pot^{-1}) while 1 TC

Table 4.8: Main effects of NSC and NPK levels on nutrient uptake in the greenhouse

Treatment	N uptake (g kg^{-1})	P uptake (g kg^{-1})	K uptake (g kg^{-1})
NPK (kg ha^{-1})			
Control	5.41	0.65b	5.09
¼ RR	5.95	0.86a	3.50
½ RR	5.19	0.65b	1.31
FRR	5.70	0.72ab	3.04
SE ±	0.50	0.06	2.01
NSC (t ha^{-1})			
Control	5.62	0.78	1.92
1 TC	5.31	0.74	5.91
2 TC	5.73	0.66	4.57
4 TC	5.59	0.70	0.55
SE ±	0.50	0.06	2.01
Interaction (N × S)			
N × S	NS	NS	NS

Means followed by the same letter (s) within the same column are not significantly different at $P < 0.05$
NS= Not significant
RR= recommended rate
FRR= Full recommended rate
TC= ton ha^{-1} neem seed cake

Table 4.9: Interaction of NSC and NPK levels on nutrient uptake in the greenhouse

Treatment	N uptake (g kg^{-1})	P uptake(g kg^{-1})	K uptake(g kg^{-1})
Control	5.29	0.74	6.14
¼ RR	8.34	1.15	0.71
½ RR	4.87	0.64	0.42
FRR	3.99	0.58	0.39
1 TC	5.71	0.67	8.72
1 TC + ¼ RR	5.12	0.91	0.48
1 TC + ½ RR	4.55	0.63	12.2
1 TC + FRR	5.80	0.77	0.62
2 TC	6.45	0.53	5.03
2 TC + ¼ RR	4.31	0.64	3.79
2 TC + ½ RR	6.24	0.67	0.52
2 TC + FRR	5.33	0.64	0.52
4 TC	4.18	0.65	0.46
4 TC + ¼ RR	6.10	0.72	10.66
4 TC + ½ RR	5.67	0.81	0.51
4 TC + FRR	7.02	0.75	0.61
SE ±	0.19	0.06	0.38

RR= recommended rate
FRR= Full recommended rate
TC= ton ha^{-1} neem seed cake

gave the highest (5.91 g pot^{-1}). K uptake in sole NSC treatments decreased with increase in quantity of organic amendment. Effect of NPK and NSC interaction was not significant in the greenhouse. However, highest K uptake was recorded from 1 TC + ¼ RR (12.20) (Table 4.9). It is known that inorganic fertilizers release their nutrients rather fast for plants to utilize. This accounts for the observed high value of the N content of crops fertilized with NPK fertilizer. N leaching and gaseous emissions have been reported to be least with reduced N application (Guo *et al*., 2007). This perhaps accounts for the low N applied in the sole NPK treatment having the highest N content. Plant from control pot had a K uptake of 6.14 g, which is an indication of additional contribution from the weathering of the base rock complex. Generally, uptake of nutrients was better with sole NPK treatments. Sole NSC gave values similar with observed from unfertilized plant. It even reduced N and P uptake (Table 4.8). The reduced N uptake in sole NSC plant could be as a result of nitrogen chelation. This is a characteristics nature of organic fertilizers (Ravankar *et al*., 2001). The applied N was, therefore, not made totally available to the crops and so plants fertilized with NSC had even lower values than observed from the control. However, a combined use of NPK and NSC fertilizers gave a higher N and K value (Table 4.9).

4.3.3 Effect of NSC and chemical fertilizer (CF) on selected soil properties of cropped greenhouse soils.

The study was to elicit information on the effect of NPK and NSC on soil physical and chemical properties after cropping pots in the greenhouse using sixteen treatments. Data obtained was subjected to Anova and results presented in Table 4.10 for main treatment effects and Table 4.11 for the interaction.

Table 4.10: Main effects of NSC and CF on selected soil properties in the greenhouse after cropping.

Treatments	pH_{water}	pH_{CaCl2}	EA	OC	N	P	K	Ca	Mg	Na
NPK g kg^{-1} (N)			cmol kg^{-1}	g kg^{-1}	g kg^{-1}	mg kg^{-1}	←	cmol kg^{-1} →	cmol kg^{-1}	cmol kg^{-1}
0	6.0417a	5.2417	0.22ab	9.272	0.935ab	10.5	0.28ab	3.4167	0.5784	0.47
¼ RR	5.9917ab	5.2833	0.23a	9.065	0.744c	11.23	0.3217a	3.6667	0.5783	0.4567
½ RR	5.9333bc	5.2917	0.18b	8.453	0.847bc	11.67	0.2633b	3.0833	0.5738	0.4725
FRR	5.9025c	5.2333	0.18b	8.217	0.993a	11.67	0.2867ab	3.1667	0.5945	0.475
SE ±	0.02	0.03	0.05	0.01	0.005	0.66	0.02	0.29	0.02	0.03
NSC ton ha^{-1}										
0 TC	6.2025a	5.1667b	0.2083ab	7.973	0.760c	10.21b	0.2975ab	2.9000b	0.606	0.4475
1 TC	5.9500b	5.3417a	0.2417a	9.368	0.921ab	12.40a	0.3042a	3.2500b	0.5923	0.4692
2 TC	5.8833c	5.3083a	0.1917b	9.176	1.022a	10.65ab	0.2525b	4.2000a	0.5448	0.4475
4 TC	5.8333c	5.2333b	0.1750b	8.489	0.817bc	11.81ab	0.2975ab	2.9833b	0.5818	0.51
SE ±	0.02	0.03	0.05	0.01	0.005	0.66	0.02	0.29	0.02	0.03
Interaction (N × S)										
N × S	NS	S	NS	NS	NS	NS	NS	NS	NS	NS

N. B.: Means followed by the same letter (s) within the same column are not significantly different at $p < 0.05$ using DMRT
NS = Not significant at 0.05 level of probability; S= Significant at 0.05 level of probability
TC = ton ha^{-1} NSC
RR= recommended rate
FRR=Full fertilizer recommendation rate

Table 4.11: Interaction of NSC and CF on selected soil properties in the greenhouse after cropping

Treatment	pH_{water}	pH_{CaCl2}	OC	EA	Ca	Mg	K	Na	Av. P	TKN
			g kg^{-1}	←		cmol kg^{-1}		→	mg kg^{-1}	g kg^{-1}
Control	6.37	5.07	8.57	0.20	3.60	0.63	0.29	0.46	8.75	0.59
¼ RR	6.23	5.17	8.70	0.23	2.80	0.56	0.35	0.38	9.92	0.70
½ RR	6.10	5.23	8.06	0.20	2.67	0.53	0.28	0.47	10.50	0.82
FRR	6.11	5.20	6.57	0.20	2.53	0.70	0.26	0.48	11.67	0.94
1 TC	5.97	5.27	9.53	0.30	3.73	0.60	0.33	0.44	12.25	0.99
1 TC + ¼ RR	5.97	5.40	9.53	0.23	3.53	0.61	0.35	0.51	12.83	0.76
1 TC + ½ RR	5.87	5.30	9.91	0.20	4.87	0.54	0.24	0.46	9.92	0.82
1 TC + FRR	5.90	5.27	8.12	0.27	3.47	0.60	0.35	0.47	12.25	0.70
2 TC	5.90	5.30	9.78	0.17	3.87	0.52	0.23	0.44	11.08	1.23
2 TC + ¼ RR	5.97	5.40	8.70	0.20	2.80	0.60	0.22	0.50	12.25	0.94
2 TC + ½ RR	5.87	5.27	7.74	0.20	3.93	0.59	0.27	0.43	11.67	0.93
2 TC + FRR	5.80	5.27	8.38	0.13	2.93	0.58	0.29	0.49	12.25	0.70
4 TC	5.93	5.33	9.21	0.20	2.47	0.57	0.27	0.55	9.92	0.93
4 TC + ¼ RR	5.90	5.30	9.72	0.23	2.93	0.56	0.32	0.43	12.25	0.99
4 TC + ½ RR	5.90	5.37	9.27	0.2	4.13	0.53	0.27	0.46	9.92	1.11
4 TC + FRR	5.70	5.07	8.25	0.1	3.07	0.58	0.29	0.53	12.83	0.93
SE ±	0.02	0.02	0.05	0.01	0.25	0.02	0.01	0.02	0.57	0.04

TC= ton ha^{-1} neem seed cake
RR = recommended rate
FRR=Full fertilizer recommendation rate

4.3.3.1 pH in water

Sole application of CF and NSC slightly reduced soil pH in water. The magnitude of decrease increased with the increase in level of either of the soil amendments. The same trend was also observed in the sole CF and NSC for exchangeable acidity except the ¼ RR (0.23) and the 1 TC (0.24). This conforms to the findings of Agbenin *et* al. (1999) and Garba (2010) where maize was used as the bioindicator in which the ability of NSC to increase H^+ and Al^{3+} were reported. Also, the decrease in rhizosphere pH as plants receive ammonium ions are caused by hydrogen ions exuded by the root to maintain electro-neutrality or charge balance inside the plant (Tisdale *et al*., 2003). Thus, NSC with ammonium ions been the form of which substantial quantity of the available N was released into the soil, evident from the laboratory incubation study (Table 4.14) was able to decrease the soil rhizosphere pH by the hydrogen ions concentration released from every conversion to nitrate, while exudate by the sorghum plant roots ensured the maintenance of the electro-neutrality of the crop.

4.3.3.2 Exchangeable Acidity (EA)

There was significant difference in EA with treatments in sole NPK treatments. ¼ RR (0.23) recorded the highest value (0.23 cmol kg^{-1}) of EA than any of the other treatments (Table 4.10), including the control (0.22) which was statistically similar to the ½ RR and FRR (0.18). In the sole NSC treatments, the 1 TC (0.24) recorded the highest exchangeable acidity which was not statistically different from the control (0.21) but was different from the 2 TC (0.19) and the 4 TC (0.18) which were statistically the same (Table 4.10). The treatment interaction was not significant ($P < 0.05$). The 4 TC + FRR (0.10) gave the least exchangeable acidity while the 1 TC (0.30) recorded the highest value which was higher than the control (0.20) (Table 4.11).

4.3.3.3 Organic carbon (OC)

Main effects of CF seemed to decrease the OC content of the soils from 9.27 g kg^{-1} for the control (0 RR) to 8.22 g kg^{-1} for FRR. Reasons for this observation though not significant, can be attributed to higher microbial activity of the soils with higher levels of fertility as a result of the treatments. Also, OC values seemed to decrease with increasing levels of NSC of the NSC treated soils. However, the control value was lower (7.97 g kg^{-1}). Though, this may be contrary to expectation, the higher level of microbial activity can only be suggested here for this observation. It also depicts strong interaction of NSC and CF on soil reactivity.

4.3.3.4 Nitrogen (N)

Main effects of CF and NSC significantly increased the N concentration in the soil after cropping (Table 4.10). FRR (0.99 g kg^{-1}) gave the highest N concentration in the sole NPK treatment which was not statistically different from the control (0.94 g kg^{-1}) while the ¼ RR (0.74 g kg^{-1}) recorded the least N content which was statistically different from the control but similar to the ½ RR (0.85 g kg^{-1}) (Table 4.10). In the sole NSC treatment, the 2 TC (1.02 g kg^{-1}) gave the highest N concentration after cropping while the control (0.76 g kg^{-1}) recorded the least N concentration. Effect of NSC and CF was not significant on total N. However, the 4 TC + ½ RR (1.10 g kg^{-1}) gave the highest N concentration among the NSC and CF treatments, while the 2 TC (1.23 g kg^{-1}) recorded the highest concentration when treatment interaction were compared (Table 4.11). This showed that combined applications of organic and inorganic fertilizers increased total soil N values more than sole application of inorganic fertilizer. The combined application of organic materials and inorganic fertilizers enhanced soil N mineralization rate, which resulted in a larger size of available N pool.

4.3.3.5 Phosphorus

Main effects of treatments on soil available phosphorus after cropping were not significant in sole NPK (Table 4.10). The available P increased with increasing CF with the ½ RR and FRR being at par with the highest concentration (11.67 mg kg^{-1}) and the control (10.50 mg kg^{-1}) gave the least P concentration after cropping. In the sole NSC treatments, the 1 TC (12.40 mg kg^{-1}) gave the highest P concentration which was statistically similar to the 2 TC (10.65 mg kg^{-1}) and the 4 TC (11.81 mg kg^{-1}) while the control (10.21 mg kg^{-1}) recorded the least P concentration which was statistically different from any of the other treatments (Table 4.10). The significant difference in the sole NSC treatments could be attributed to the more gradual and presumably more in synchrony with crop nutrient demand of nutrient release from organic inputs than with inorganic fertilizers (Kayuki and Wortmann, 2001). However, when the treatments were combined, 1 TC + ¼ RR and 4 TC + FRR (12.83 mg kg^{-1}) recorded the highest P concentration after cropping. This trend in the interaction could be attributed to inadequate P content of NSC when used alone, thus, the better response when used in combination with inorganic P.

4.3.3.6 Exchangeable bases (K, Ca, Mg and Na)

Effect of sole NPK treatments was not significant ($P \leq 0.05$) on soil exchangeable bases except for K (Table 4.10). The higher content of exchangeable K (0.35 cmol kg^{-1} in the ¼ RR) in sole NPK fertilizer amended pots (Table 4.10) compared with the NSC treated pots at the end of the cropping might be attributed to the quick release of nutrients from the fertilizer, since nutrients are slowly released from organic sources. There were significant ($P \leq 0.05$) increase in exchangeable K and Ca in the sole NSC pots. This significant difference could be attributed to improved soil organic matter status of NSC amended pots, since soil organic matter is a natural source of nutrients and CEC.

4.3.4 Inter-relationships of selected soil properties after cropping (Greenhouse experiment).

Factor analysis was used to investigate the role of different commonly measured soil properties in the determination of the effect of treatments on soil properties. These analyses were performed to identify the parameters which play a role in soil physico-chemical properties as influenced by treatments. On the basis of the rotated component matrix it was then possible to identify the most significant variables within the group of components and the degree of inter-relationship between these presented in Tables 4.12 and 4.13.

4.3.4.1 Principal component analysis of selected soil properties

The factor components (FCs) with eigenvalues > 1 were retained, since Eigenvalues < 1 indicated that the factor could explain less variance than an individual soil property. Eigenvalues from the correlation analysis indicated that the first five factor components accounted for 74 % of the variance of soil properties raw data (Table 4.12). The first factor component (FC 1) explained 26% of the total variance followed by the second factor component (FC 2), the third factor component (FC 3), the fourth factor component (FC 4) and the fifth factor component (FC 5) which explained 15%, 12%, 11% and 9% of the total variance respectively (Table 4.12).

A high communality estimate suggests that high portion of the variance was explained by the factor components; therefore, it would get higher preference over a low communality estimate (Garson, 2007; Dunteman, 1989). Magnitudes of the eigenvalues were used as a criterion for interpreting the relationship between measured soil properties and factor components. The FC 1

Table 4.12: Eigenvalue, proportion and cummulative variance explained by factor analysis using correlation matrix of 11 soil properties in the greenhouse.

Component	←	%	→
	Eigenvalue	Proportion	Cummulative
1	2.903	24.190	24.190
2	1.887	15.724	39.914
3	1.44	12.000	51.914
4	1.342	11.186	63.101
5	1.332	11.103	74.204

Table 4.13: Proportion of variance using varimax rotation and kaiser normalized, and communality estimates for 11 soil properties (principal component method) in the greenhouse.

Soil properties	FC 1	FC 2	FC 3	FC 4	FC 5	Communality estimates
pH_{water}	-0.194	**-0.733**	0.062	0.362	-0.045	0.712
pH_{CaCl2}	0.108	**0.503**	-0.22	0.291	-0.056	0.401
Exchangeable acidity	0.096	-0.014	0.029	**0.906**	-0.016	0.832
Organic carbon	-0.033	**0.362**	-0.521	0.329	-0.069	0.516
Calcium	**0.98**	0.001	-0.059	0.077	-0.106	0.981
Magnesium	-0.082	-0.162	0.249	0.171	**0.832**	0.816
Potassium	-0.091	-0.136	**0.754**	0.125	-0.084	0.617
Sodium	-0.014	0.08	-0.339	-0.349	**0.732**	0.779
Available phosphorus	-0.06	0.541	**0.599**	-0.033	0.252	0.72
Nitrogen	0.011	**0.741**	-0.051	0.041	-0.108	0.565
Effective Cation Exchange Capacity	**0.984**	-0.014	-0.014	0.119	0.014	0.982

The rotation convergent in 12 iterations. Factor scores of variables in bold letters indicate the major contributors in the group. FC – factor component

explained 26% of total variance (Table 4.13) which included exchangeable calcium and effective cation exchange capacity (communality estimate > 0.90 for each variable) as the major contributing variables, was directly related to 'soil potential exchange capacity properties' with a positive loading of exchangeable Ca and ECEC. The FC 2, named 'soil highly potential nutrient properties' explained 16% of variance with positive loading from pH_{CaCl2}, organic carbon and nitrogen; and a negative loading from pH_{water} (Table 4.13) (communality estimates varied between 0.40 and 0.71 for different variables) as the major contributing variables. The 'soil highly potential nutrients' included soil organic carbon and nitrogen which played crucial role for nutrient holding in soil pool and responsible for plant vegetative growth as well, respectively.

The NSC acidified the soil in agreement with reports of decreased pH of red sandy soil under neem vegetation in the Sudan Savanna of Nigeria due to accumulation and mineralization of neem leaf litter (Agbenin *et* al., 2008). This is one problem that may arise from NSC application. However, the increasing exchange acidity and decreasing pH caused by NSC incorporation into this soil were probably a consequence of increasing nitrification of NH_4-N released from mineralization of the NSC. This present finding was consistent with that of Adams (1984) who explained that for each mole of NH_4-N nitrified or oxidized to NO_3-N, two moles of proton (H^+) are generated through the reaction: $NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$. However, it is unlikely that NSC would acidify the soil to the same degree under field conditions as it did in the laboratory closed-system incubation, because protons generated from nitrification of NH_4-N can be neutralized by OH^- ions released by plant roots when NO_3-N is absorbed (Mohammed, 2009; Boumann *et al*., 1995). Declining pH would also have contributed to loss of pH-dependent charges consistent with decreased ECEC at the end of eighth (8^{th}) week after NSC application.

This seems supported by negative loading of pH on factor 1 (Table 4.13) in contrast to the positive ECEC loading on the same factor.

Similarly, FC 3, called the 'soil moderately potential nutrients' explained 12% of the variance had positive loading for exchangeable K and available P (communality estimate for exchangeable K = 0.62 and for available P = 0.72) (Table 4.13) as the major contributing variables. FC 4, termed the 'soil acidifying properties' explained 11% of variance had positive loading from exchangeable acidity (communality estimate for exchangeable acidity = 0.83) while FC 5, called the 'soil additional properties' also explained 11% of variance which included exchangeable magnesium and sodium (communality estimate of 0.78 and 0.82 for sodium and magnesium respectively) as the major contributing variables (Table 4.13). The decrease in exchangeable K evident from the negative loading in FC 5 could have engendered by its displacement from the exchange sites by Ca and Mg. This could be predicted by cation exchange theory of preferential adsorption of divalent to monovalent cations in soil colloids (Marshall, 1964). Thus, it had the associate influence with 'soil moderately potential nutrients'. Consequently, in the study of soil chemical properties following incorporation of NSC in the greenhouse, 'soil potential exchange capacity', 'soil highly potential nutrients', and 'soil moderately potential nutrients' were the three most important factors that influenced the nutrient components and caused influences on sorghum production in the greenhouse.

4.3.5 Soil organic carbon dynamics in cultivated and uncultivated greenhouse pots.

In this experiment, the soil was separated into four fractions as described: greater than 250 µm; greater than 125 µm to less than 250 µm, 125 µm and less than 50 µm - after wet-sieving of both cultivated and uncultivated pots are presented in Table 4.14. The highest OC content (2.765 g kg^{-1}) associated with macro-aggregate (> 250 µm) was obtained from 4 TC while the least

Table 4.14: Organic carbon dynamics (g kg^{-1}) of cultivated and uncultivated greenhouse pots after wet-sieving into four fractions.

Treatment	Cultivated > 250µm	Cultivated > 250µm <125 µm	Cultivated 125 µm	Cultivated <50 µm
	←	g kg^{-1}		→
Control	2.217	12.197	3.627	2.418
¼ RR	1.612	3.224	2.015	2.015
½ RR	1.411	2.418	2.418	4.030
FRR	1.612	2.519	3.224	2.217
1 TC	2.015	2.144	3.023	1.209
1 TC + ¼ RR	1.209	0.504	2.015	1.612
1 TC + ½ RR	0.806	2.418	2.821	1.612
1 TC + FRR	2.217	1.791	1.814	1.411
2 TC	1.411	1.511	2.217	1.814
2 TC + ¼ RR	0.198	1.580	1.185	0.988
2 TC + ½ RR	1.580	0.933	2.173	0.988
2 TC + FRR	1.383	0.506	1.185	0.988
4 TC	2.765	0.790	1.383	0.593
4 TC + ¼ RR	0.395	0.420	1.383	1.778
4 TC + ½ RR	1.778	1.317	1.383	0.790
4 TC + FRR	0.988	0.790	1.383	1.383
	Uncultivated > 250µm	**Uncultivated > 250µm <125 µm**	**Uncultivated 125 µm**	**Uncultivated <50 µm**
Control	0.004	1.425	1.425	2.195
¼ RR	2.036	1.629	1.221	1.197
½ RR	2.036	2.036	1.221	0.798
FRR	1.221	2.239	0.204	1.197
1 TC	0.407	2.239	0.814	1.397
1 TC + ¼ RR	0.407	1.832	1.018	1.397
1 TC + ½ RR	1.221	0.204	1.425	0.399
1 TC + FRR	1.629	2.239	1.629	0.798
2 TC	1.629	2.036	1.018	1.197
2 TC + ¼ RR	1.629	1.629	1.425	1.796
2 TC + ½ RR	4.071	1.629	2.646	3.294
2 TC + FRR	4.479	1.832	2.443	0.798
4 TC	4.071	1.629	2.239	0.200
4 TC + ¼ RR	4.071	1.018	2.239	1.197
4 TC + ½ RR	3.664	1.425	3.257	1.596
4 TC + FRR	5.293	1.425	2.036	0.399

RR= recommended rate
FRR= Full recommended rate
TC= ton ha^{-1} neem seed cake

content (0.988 g kg^{-1}) was recorded from the 4 TC plus FRR for the uncultivated pots (Table 4.14). For the uncultivated pots, microaggregate (> 125 µm to < 250 µm) fractions, the control recorded the highest OC content (Table 4.14).

However, in the cultivated pots, the highest OC content associated with macro-aggregates was obtained from the 4 TC + FRR (5.29 g kg^{-1}) while the control recorded the least concentration (0.004 g kg^{-1}). For the micro-aggregate fractions on the other hand, FRR, 1 TC and 1 TC (2.24 g kg^{-1}) recorded the highest OC content while 1 TC + ½ RR (0.20 g kg^{-1}) gave the least OC for the > 125 µm to < 250 µm. Similarly, 4 TC + ½ RR (3.26 g kg^{-1}) recorded the highest OC content while FRR (0.20 g kg^{-1}) had the least for the 125 µm soil fraction. Also, 2 TC + ½ RR (3.29 g kg^{-1}) and 4 TC (0.2 g kg-1) had the highest and least OC content respectively in the 50 µm soil fraction (Table 4.14).

Analysis was not replicated for test of significant effects by treatments, as alterations in soil structure and increased soil organic matter losses could only be evident in long term cultivations (Dalal and Mayer, 1986). However, it could be inferred from the data of the cultivated and uncultivated pots that complementary use of high quantities of NSC (4 TC) and chemical fertilizer (FRR) did not enhance macroaggregate OC fractions which are less stable than microaggregates (Edwards and Bremmer, 1967; Oades, 1984; Beare *et al*., 1994). 4 TC + FRR recorded the least OC macroaggregate content (0.988 g kg^{-1}) in the uncultivated pots while on cultivation gave the highest macroaggregate OC content (5.29 g kg^{-1}). This probably implied that cultivation of the pot with high quantities of both NSC and CF did not disrupt soil aggregates by exposing more organic matter to microbial attack as microaggregates were formed on cultivation (Edwards and Bremner, 1967; Gregorich *et al*., 1989), aside the physical protection of OC within stable macroaggregates (Elliot, 1986; Gupta and Germida, 1988).

Control with higher macroaggregates in the uncultivated pots had the least macroaggregates in the cultivated pots as much of the SOM was lost due to mineralization of SOM binding microaggregates to macroaggregates. This is because macroaggregates are more susceptible to the disruptive forces of cultivation and to the dispersion that results from rapid wetting of the uncultivated pots (Tisdall and Oades, 1980, 1982).

4.3.6 Comparison of total soil carbon and selected soil quality parameters

Studies on the turnover of microbial biomass carbon (C) in soils had been reported to provide useful information regarding the quality of organic matter in soils (Chaussod *et al*., 1988; Chen *et al*). Particulate Organic Matter Carbon (POMC) was calculated as the summation of the OC from each of the four fractions - greater than 250 µm; macroaggregates, greater than 125 µm to less than 250 µm, 125 µm and less than 50 µm - (Section 4.3.4) as one of the two measures of soil quality parameters in the greenhouse and the result presented in Table 4.15.

In the uncultivated pots, 4 TC + ½ RR recorded the highest total particulate OC (0.59 and relative proportion of particulate OC (0.51) while control gave the least total particulate OC (0.13), 1 TC + ½ RR and 2 TC + FRR (13) both gave the lowest relative proportion of particulate OC (Table 4.13). In the cultivated pots, 2 TC + FRR recorded the highest POM_T (0.41) and POM_R (0.52) while 4 TC + ¼ RR gave the least POM_T (0.14) and POM_R (0.16) values (Table 4.15). The relatively low fractions obtained in the cultivated pots compared to the uncultivated pots could be attributed to nutrient release and corresponding uptake by sorghum plants thereby destroying the organic matter in the cultivated pots. The relatively higher POM_T and POM_R recorded in the 2 TC + FRR of the cultivated pots would imply that at that complementary rates of NSC and NPK fertilizer, the sorghum plants had enough nutrient uptake

Table 4.15: Particulate organic matters(POM) statuses of active or labile SOM for cultivated and uncultivated pots receiving different treatments of NSC and/ or inorganic fertilizers

	Cultivated pots				Uncultivated pots			
Treatment	Organic carbon (%) particulate fraction	Total soil organic carbon (%)	POM_T	POM_R	Organic carbon (%) particulate fraction	Total soil organic carbon (%)	POM_T	POM_R
Initial soil sample	0.69	0.44	0.19	0.42				
Control	1.14	0.93	0.34	0.37	0.59	0.44	0.13	0.29
¼ RR	0.73	0.99	0.22	0.22	0.55	1.00	0.14	0.14
½ RR	0.75	0.97	0.23	0.24	0.93	0.95	0.24	0.25
FRR	0.67	0.95	0.25	0.26	1.00	1.09	0.26	0.24
1 TC	0.73	0.98	0.21	0.22	0.89	1.04	0.21	0.2
1 TC + ¼ RR	1.00	0.92	0.3	0.33	0.73	0.93	0.20	0.22
1 TC + ½ RR	1.00	0.81	0.28	0.34	0.62	1.06	0.14	0.13
1 TC + FRR	0.65	0.49	0.25	0.52	1.10	1.04	0.32	0.31
2 TC	0.63	0.81	0.25	0.3	1.31	0.95	0.44	0.46
2 TC + ¼ RR	0.75	0.87	0.30	0.34	1.21	1.11	0.38	0.34
2 TC + ½ RR	0.67	0.95	0.20	0.21	0.79	1.06	0.20	0.19
2 TC + FRR	1.35	0.77	0.41	0.52	0.81	1.37	0.18	0.13
4 TC	1.20	0.84	0.36	0.42	0.75	1.06	0.15	0.15
4 TC + ¼ RR	0.47	0.87	0.14	0.16	0.95	1.06	0.32	0.30
4 TC + ½ RR	0.51	0.86	0.19	0.23	2.31	1.15	0.59	0.51
4 TC + FRR	1.08	0.82	0.32	0.39	0.69	1.06	0.20	0.19

POM_T = Total particulate organic carbon ; POM_R = Relative proportion of particulate organic carbon; 0-, 1-, 2- and 4 NSC = 0, 1, 2 and 4 ton inclusion level per hectare of neem seed cake; 0-, ¼-, ½- and full NPK = 0, ¼, ½ and full optimum recommended NPK rate for sorghum in the region; TC = ton ha^{-1} NSC; RR = recommended rate; FRR= full recommended rate.

from the inorganic fertilizer while the organic amendment helped in stabilizing the soil as soil aggregates were not exposed to microbial attack.

To affirm relationship between the total soil C and selected soil quality parameters, regression analysis was employed. Particulate organic matters (POM) statuses of active or labile SOM were estimated, and are presented in Table 4.15. For the uncultivated and cultivated pots, the following equations were obtained respectively:

$Y = 0.1664X + 0.0854$; $r = 0.2452$ (i)

$Y = -0.1282X + 0.3754$; $r = 0.2258$ (ii).

Where, Y is the soil total organic carbon, X is the particulate organic carbon and r is the regression coefficient.

The disparity in the r-values of the uncultivated (i) and cultivated (ii) pots could be attributed to the interaction between the sorghum plant roots and the soil in the latter which according to Six *et al*. (2000) was attributed to a less physical perturbation, resulting in macro aggregates under no tillage that are enriched in fine POM, which is more resistant to decomposition. Also, from the theorized hierarchical approach to aggregate formation, Tisdall and Oades (1982) submitted that macro aggregates (>0.25 mm) form as a result of root entanglement and polysaccharides produced by heterotrophic micro organisms decomposing POM that glue together micro aggregates (0.05 to 0.25 mm). Furthermore, the two main objectives of organic matter management in agricultural systems are to (1) restore or maintain SOM to benefit soil quality and (2) supply crops with nutrients contained within or associated with SOM (Bruce *et al*., 1990). These two objectives are not always compatible (Bouldin, 1987) because mineralization that releases nutrients also destroys SOM. Thus, a decrease in the r-value of the cultivated (r = 0.2258) and uncultivated (r = 0.2452) pots due to nutrient release for sorghum top uptake.

Total soil C data were also fitted in a linear regression analysis against selected soil quality parameters - Particulate Organic Matter Carbon (POMC) and Soil Microbial Biomass Carbon (SMBC) - to test the correlations for significance and are presented in Table 4.15. Soil Microbial Biomass Carbon correlated with Soil Total Organic Carbon (TOC) (r = 1) in accordance with Leita *et al*. (1999) submission that biomass C increases when organic wastes are added to soil, showing long-term effects. Also, the size of the living community in the soil, the microbial biomass, was generally positively related to the SOM level; rarely was rate of microbial carbon (C_{mic}) less than 1% or more than 5% of the total SOC (Carter, 2001; Dalal, 1998). Additionally, increases in SOM are usually associated with similar increases in microbial biomass, because SOM provides the principal substrates for microorganisms (Weil and Magdoff, 2004).

Similarly, Johnson (1992) and Wardle (1992) submitted that microbial growth in soils typically was resource limited and growth increased rapidly in response to added carbon sources. The availability and composition of organic matter are key factors affecting microbial biomass, and also community composition (Facelliand and Pickett, 1991; Boehm, *et al*., 1997). NSC, just like manure, contains high concentrations of labile, easily degradable compounds, leading to a rapid increase in microbial biomass in soils shortly after application. It also helped to reduce the stress symptoms enabling soil microbial biomass to increase quickly (Clemente *et al*., 2007).

4.3.7 Derivations from the greenhouse works

The following observations were made from the greenhouse experiment:

- Highest number of leaves (9), dry matter yield (9.75 g pot^{-1}) and plant height (56.69 cm) were obtained from the 4 TC + FRR treatments while 2 TC + ¼ RR gave the widest stem girth of 1.23 cm;

- Highest P (1.39 g kg^{-1}) and K (18.31 g kg^{-1}) contents were obtained from sorghum tissue that received 4 t NSC ha^{-1} while 4TC + FRR gave sorghum tissue with the highest N content (10.79 g kg^{-1});
- Highest N uptake (7.02 g kg^{-1}) was obtained from 4 TC + FRR; P uptake (1.15 g kg^{-1}) from ¼ RR and K uptake (12.20 g kg^{-1}) from 1 TC + ½ RR;
- Soil physico-chemical properties was better enhanced with complementary use of NSC and NPK fertilizer with 1 TC + ½ RR with the highest OC content of 9.91 g kg^{-1}, 4 TC + FRR with the highest available P (12.83 mg kg^{-1}) while sole NSC application at 2t ha^{-1} gave the highest N content (1.23 g kg^{-1}) after cropping soils in the greenhouse;
- Result of the factor analysis explained that 'soil potential exchange capacity', soil highly potential nutrients' and 'soil moderately potential nutrients' were the three most important factors that influenced the nutrient components and characteristics of NSC which influenced sorghum production in the greenhouse;
- However, it could be inferred from the data of the cultivated and uncultivated pots that complementary use of high quantities of NSC (4 TC) and chemical fertilizer (FRR) did not enhance macroaggregate OC fractions which are less stable than microaggregates, 4 TC + FRR recorded the least OC macroaggregate content (0.988 g kg^{-1}) in the uncultivated pots while on cultivation gave the highest macroaggregate OC content (5.29 g kg^{-1});
- 2 TC + FRR gave the highest total and relative particulate organic matter content (0.41 and 0.52 respectively) in the cultivated pots which implied that complementary use of NSC and NPK fertilizer ensured that the sorghum plants had enough nutrient uptake from the inorganic fertilizer while the organic amendment helped in stabilizing the soil as soil aggregates were not exposed to microbial attack.

4.4 Decomposition and Mineralization Experiments

4.4.1 Laboratory incubation studies using sintered funnel

N mineralization pattern was studied using 2.64g of NSC mixed thoroughly with 50g of soil in the laboratory. Seven sampling periods were used to determine the rate of N released from collected leacheate by distillation. The data collected from the study were subjected to five decomposition models to determine the best model for predicting N release from NSC and ascertain if the model could be employed for future predictions in the field. Result of the laboratory nitrogen mineralization studies of NSC using sintered funnel is presented in Table 4.16. The data showed an increase in the ammonium-N, nitrate-N and mineral-N with time. The cumulative N mineralization showed initial rapid rate in the first 21 days followed by slower release with time (Figure 4.1). At 98 days, cumulative N mineralization represented 50% of total N applied as neem seed cake. The N mineralization pattern showed that ammonium-N fraction in the soil far exceeded nitrate-N fraction (Figure 4.1), accounting for 91.5 % of N mineralized from the organic material. This was in agreement with findings of Agbenin *et al*. (1999) where 94% of N mineralized was from the ammonium fraction.

The goodness-of-fit of the models were determined by the R^2, χ^2 and RMSE values. The best models were by the highest R^2 value and least χ^2 and RMSE values. N mineralization pattern from neem seed cake was best described by a consecutive (h=k) model ($R^2 = 1$; RMSE = 0.01). Although, the Gompertz and mixed order rate models also modeled the mineralization fairly well (Table 4.17) judging from the R^2 and RMSE values, the negative rate constant (-0.0002) and potentially mineralized N obtained from the former, and coefficient of variation (-4E-6) of the latter do not make either of the two models superior to the consecutive (h=k) rate order model. The relatively high χ^2 value (4.65E+8) obtained with the consecutive model (h=k)

Table 4.16: Ammonium-N, nitrate-N and Mineral-N mineralized during laboratory incubation of NSC using sintered funnel.

Time in days	Ammonium-N	Nitrate-N	Mineral-N
	←	$mg\ kg^{-1}$	→
0	0.000000	0.000000	0.0000000
7	0.001190	0.000163	0.001353
14	0.002007	0.000117	0.002123
21	0.002077	0.000163	0.002240
28	0.002007	0.000163	0.002123
42	0.002147	0.000233	0.002333
56	0.002217	0.000303	0.002473
98	0.002322	0.000338	0.002613
Total	0.013965	0.001481	0.015260

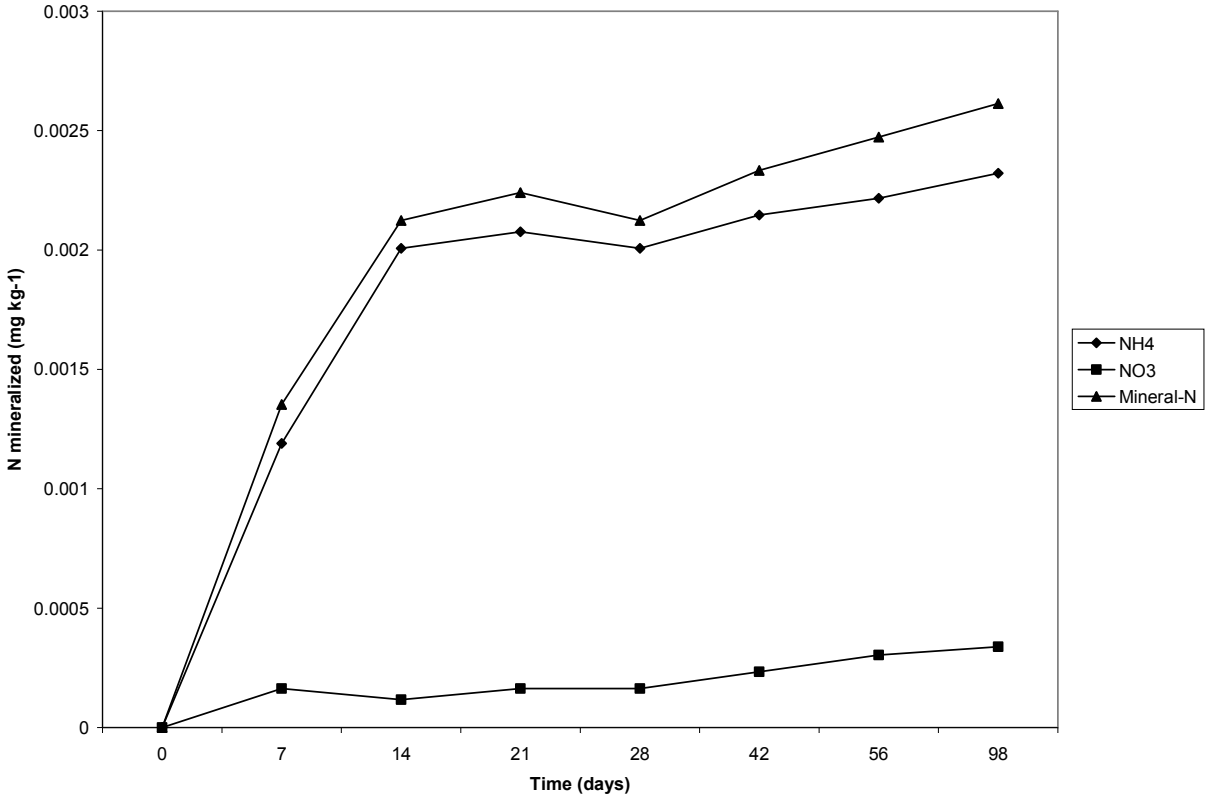


Figure 4.1: Cumulative total mineral-N, NH_4^+-N and NO_3^--N released during laboratory incubation

Table 4.17: Goodness-of-fit statistics, and parameter estimates of five mathematical models fitted to inorganic N mineralized from neem seed cake decomposition in the laboratory

Model	R^2	א ^{2}	CV	RMSE	N_0	N_e	k	h
First-order rate	0.31	-97.36	22.75	1.77	123.6	2.09	4560.2	3.7
consecutive (h≠k)	1	-3099.41	1.4	0.02	-1.13E-07		-0.0066	2.2
Consecutive (h=k)	1	465110518	0	0.01	67.26		42.806	
Gompertz	1	1.12	0	0.01	-1.56E-04		-0.0002	3.7
Mixed-order	1	372.41	-4.00E-06	0.01	4665.5		-4.00E+19	20

LEGEND: CV = Coefficient of Variation; R^2 = Coefficient of Determination; RMSE = Root Mean Square Error; N_0 = potentially mineralized N at time 0 in mg kg^{-1}; N_e = Additional term to accommodate the initial rapid N flush in mg kg^{-1}; h and k are constants.

shows the inefficiency of laboratory incubation studies to simulate field conditions. The consecutive reaction model with an additional parameter h was not superior to its simpler form with a single rate constant (h≠k). The N mineralization pattern was not adequately described by a first order rate equation compared to other mineralization models probably because N mineralization from neem seed cake was not simply a function of substrate N concentration in the residue, a fundamental assumption of a first order rate decomposition model (Stanford and Smith, 1972; Jones, 1984; Agbenin *et* al., 1999).

Result of this study would suggest that consecutive reaction model with a single rate constant (h=k) gave the best N mineralization pattern description from neem seed cake in the laboratory. This could be attributed to the fact that neem seed cake passed through an intermediary and from the intermediary to products following the first order rate kinetics with equal rates to the formation of intermediary and products (h=k). This finding was contrary to that of Agbenin *et al*., (1999) where a Gompertz function and mixed order rate were adequate, but, corroborate the submission of Diaz-Firros *et al*. (1988) where a consecutive reaction model described the kinetics of N mineralization from cattle slurry incorporated into a soil. The assumption of a single rate constant for a consecutive reaction model (h=k) did not decrease the fit of the model to the mineralization pattern.

The mineralization rate constant estimated by the simple first order rate model was 4560.2 mg kg^{-1} day^{-1} while that of a consecutive reaction was k = -6.6E-3 mg kg^{-1} day^{-1} and h = 2.2 mg kg^{-1} day^{-1}. When k = h, the overall rate constant k was 42.806 mg kg^{-1} day^{-1}. The overall rate constant obtained in this laboratory study could not be used to predict the amounts of mineralization with time as it depicts a relatively slow (T_{50} of 0.016 day^{-1}) N mineralization which might not be feasible in the field. However, the cumulative N released at the end of the

experiment was 0.015 mg kg^{-1} N from 2.64g NSC. Therefore, the estimated N released per hectare from 1t NSC and its equivalent will be 5.68 kg N ha^{-1}. This value is however relatively lower than the N requirement for sorghum growth or mineralized under field condition.

4.4.2 Field incubation studies using PVC tubes

4.4.2.1 Cummulative N mineralized

The mean inorganic N mineralized (mg kg^{-1}) from NSC as influenced by NPK levels over a period of thirty-two weeks of sorghum growth in the field was measured using covered PVC tubes and the results presented in Tables 4.18 and 4.19 respectively for the two years. In the sole NPK plots, an inconsistent mineralization pattern was observed across the sampling periods (Tables 4.18 and 4.19). In 2009, the highest mean inorganic N (69.56 mg kg^{-1}) across the sampling period was obtained from ½ recommended rates (RR) while the ¼ RR (66.38 mg kg^{-1}) gave the least mean inorganic N. However, there was no significant difference in measured inorganic N with respect to treatment across the seven sampling dates in the sole NPK plots.

There was no significant difference in the inorganic N mineralized for six out of the seven sampling periods in the sole NSC plots in 2009 (Table 4.18). There was significant difference ($P < 0.05$) in inorganic N mineralized during the fourth week. 4 TC (69.65 mg kg^{-1}) recorded the highest concentration while the control (49.09 mg kg^{-1}) gave the least which was statistically different from 4 TC but similar to 1 TC (62.35 mg kg^{-1}) and 2 TC (61.03 mg kg^{-1}) (Table 4.18). The eighth week of sampling recorded an increase in the inorganic N mineralized in the sole NSC plots with the highest concentration from the control (102.82 mg kg^{-1}) and the least from 4 TC (78.94 mg kg^{-1}). The rationale behind this sudden flush was however not understood. There was uniform inorganic N (31.84 mg kg^{-1}) concentration in the twelfth week from the sole NPK and NSC plots (Table 4.18). This corroborates the submission of Jenkinson (1981) who reported

Table 4.18: Pattern of Inorganic N Mineralization (mg kg^{-1}) of NSC as influenced by NPK treatment over a period of 32 weeks of sorghum growth in the field in 2009

	Inorganic N mineralized (mg kg^{-1})							
Treatment	←		**WEEKS OF SAMPLING**				→	
NPK kg ha^{-1}(N)	2	4	6	8	12	19	32	**Mean Total**
0	72.04	59.7	100.16	56.38	31.84	62.69	39.8	68.95
¼ RR	82.38	58.37	86.9	53.07	31.84	53.07	36.48	66.38
½ RR	65.67	66.33	92.2	72.3	31.84	56.72	42.45	69.56
FRR	82.38	57.71	95.52	55.72	31.84	46.77	39.8	67.34
SE ±	12.42	4.85	9.35	6.64	0	6.02	5.15	2.29
NSC t ha^{-1}(S)								
0 TC	54.92	49.09b	102.82	54.39	31.84	59.04	36.48	64.69
1 TC	79.2	62.35ab	90.88	58.37	31.84	53.4	37.81	67.85
2 TC	77.21	61.03ab	102.15	62.35	31.84	55.06	43.12	70.21
4 TC	91.14	69.65a	78.94	62.35	31.84	51.74	41.13	69.47
SE ±	12.42	4.85	9.35	6.64	0	6.02	5.15	2.29
Interaction (N x S)								
N x S	NS	NS	NS	NS	NS	NS	NS	NS

*=5% level of significance; TC = ton ha^{-1} NSC
0-, 1-, 2- and 4 NSC = 0, 1, 2 and 4 tonne inclusion level per hectare of neem seed cake;
0-, ¼-, ½- and full NPK = 0, ¼, ½ and full optimum recommended NPK rate for sorghum in the region.

that although a small addition of N-poor OM will decompose more quickly than a larger addition, larger additions tend to catch up with smaller additions as decomposition proceeds.

In 2010, there was no significance difference in inorganic N mineralized across the seven sampling periods in the sole NPK plots. However, ½ RR (62.73 mg kg^{-1}) recorded the highest mean concentration while ¼ RR (56.76 mg kg^{-1}) gave the least. Sole NSC plots recorded significance difference ($P < 0.05$) only during the sixth week of sampling. 4 TC (72.97 mg kg^{-1}) gave the highest inorganic N while control (52.40 mg kg^{-1}) recorded the least concentration which was statistically different from 4 TC but similar to N mineralized from 1 TC (60.03 mg kg^{-1}) and 2 TC (66.33 mg kg^{-1}) (Table 4.19). A consistent decrease was however observed from eighth week to thirty-second week in the sole NSC plots (Table 4.19). The highest cumulative mean inorganic N (63.87 mg kg^{-1}) was obtained from 4 TC while control recorded the least concentration (57.95 mg kg^{-1}).

The cumulative N mineralized after 32 weeks of incubation using PVC tubes in the field in the year 2009 and 2010 are presented in Figures 4.2 and 4.3 respectively. The cumulative N mineralization with time showed initial rapid rate in the first six (6) weeks after incubation followed by slower release in both years. The N mineralization pattern showed that the NH_4^+-N fraction in the soil slightly exceeded the NO_3^--N fraction in 2009, accounting for about 52% of N mineralized from neem residue. However, in 2010, the N mineralization pattern showed that the NO_3^- -N fraction in the soil far exceeded the NH_4^+-N fraction, accounting for 64% of the N mineralized from neem seed cake. Generally, the highest concentration of the ammonium (NH_4^+) was observed during the first twenty-eight (28) days of incubation. This was mainly due to the fact that during this period, the intense organic matter degradation assisted NH_4^+ production via the mineralization of organic N; subsequently, NH_4^+ level gradually reduced. The

Table 4.19: Pattern of Inorganic N Mineralization (mg kg^{-1}) of NSC and NPK treatment over a period of 32 weeks of sorghum growth in the field in 2010

Treatment	Inorganic N mineralized (mg kg^{-1}) ← WEEKS OF SAMPLING →							
NPK kg ha^{-1}(N)	2	4	6	8	12	19	32	**Mean Total**
0	92.88	66.67	64.01	62.69	56.72	54.73	31.18	61.27
¼ RR	85.57	61.03	59.70	59.04	55.72	49.75	26.53	56.76
½ RR	97.51	67.66	65.34	64.34	59.04	52.74	32.50	62.73
FRR	90.88	68.66	62.69	65.01	63.02	54.06	34.49	62.69
SE ±	8.08	3.18	6.26	3.36	3.83	2.99	3.69	1.95
NSC t ha^{-1}(S)								
0 TC	84.91	61.03	52.40b	58.37	63.35	51.74	33.83	57.95
1 TC	84.92	65.34	60.03ab	66.33	57.38	53.07	33.83	60.13
2 TC	100.83	69.65	66.33ab	60.36	55.39	50.75	27.20	61.50
4 TC	96.18	67.99	72.97a	66.00	58.37	55.72	29.85	63.87
SE ±	8.08	3.18	6.26	3.36	3.83	2.99	3.69	1.95
Interaction (N x S)								
N x S	NS	NS	NS	NS	NS	NS	NS	NS

*=5% level of significance; TC = ton ha^{-1} NSC
0-, 1-, 2- and 4 NSC = 0, 1, 2 and 4 tonne inclusion level per hectare of neem seed cake;
0-, ¼-, ½- and full NPK = 0, ¼, ½ and full optimum recommended NPK rate for sorghum in the region.

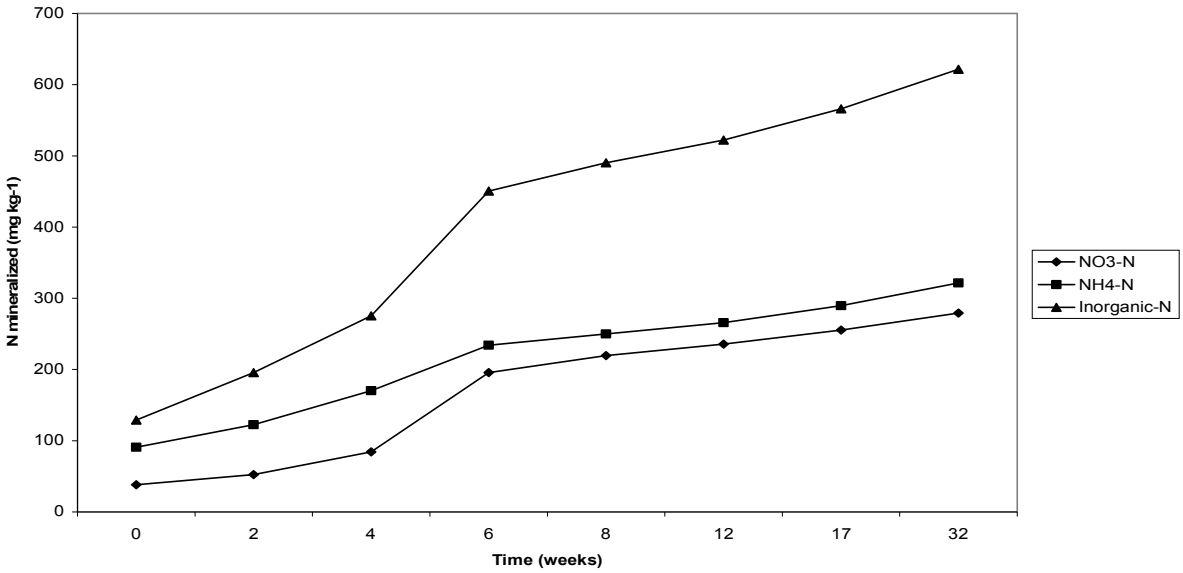


Figure 4.2: Cummulative total inorganic N, ammonium-N and nitrate-N from field incubation studies using PVC tubes in 2009

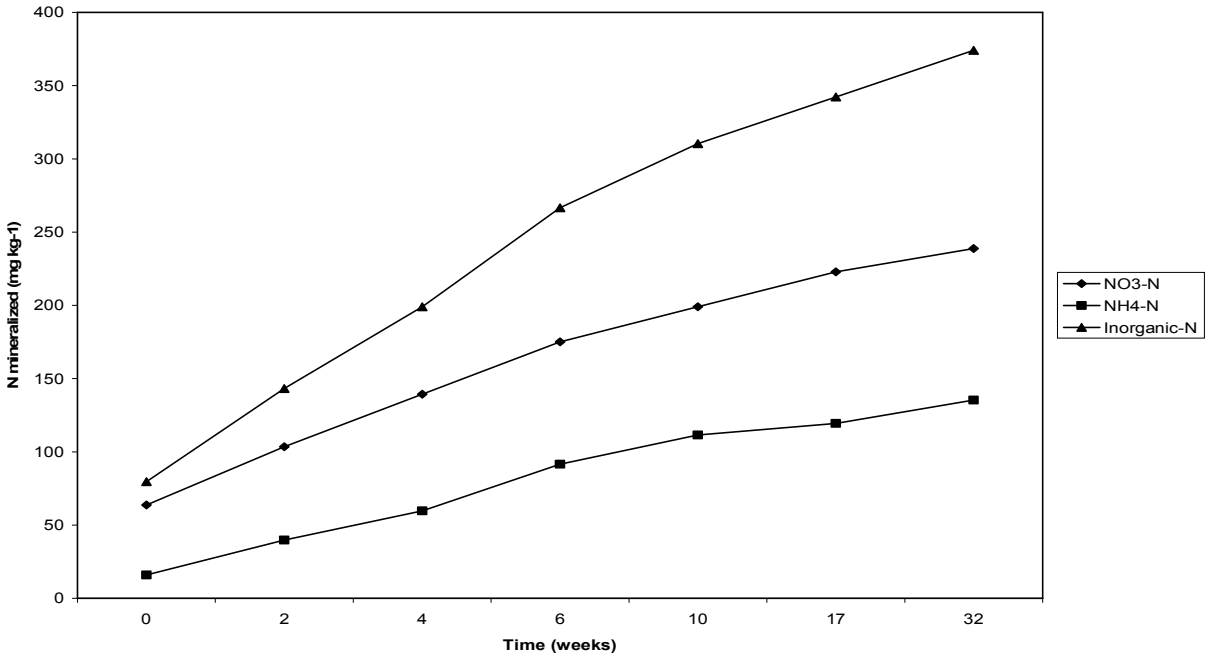


Figure 4.3: Cummulative total inorganic N, ammonium-N and nitrate-N from field incubation studies using PVC tubes in 2010

results of this study in 2009 would suggest that though neem seed contains nitrification-inhibiting compounds (Schmutterer, 2002), the low nitrification under field incubation in the first year could be attributed to the high residual mineral-N as well as the high rainfall intensity in three – four months of the entire growing season (Kowal and Kassam, 1978). However, the high nitrification rates recorded in the second year could be attributed to the retardation effect of neem residues on nitrification which maybe due to their active ingredient azadirachtin and other di- and triterpenoidal compounds which are toxic to nitrifying bacteria which agrees with the findings of Singh *et al*. (1991b).

Also, the amounts generally increased throughout the period indicating progressive mineralization with time. The mean amounts of inorganic N mineralized were not significantly different ($P < 0.05$) in the control which recorded the highest quantity for the sole NPK treatment plots than in the other treatments in 2009 (Table 4.18). However in 2010, the amounts of N mineralized though not significantly different ($P < 0.05$) was lower in the control than in the other treatments except in the ¼ recommended rates (RR) of NPK fertilizer for sorghum with a mean total inorganic N of 56.76 mg kg^{-1} (Table 4.19). In 2009 and 2010 for the NSC treatments alone, the mean inorganic N mineralized were not significantly different ($P < 0.05$) in the control which recorded the lowest quantity in both years than in the other treatments (Tables 4.18 and 4.19). There were no significant differences between the interactions in both years (Tables 4.18 and 4.19). This was in accordance with the findings of Adegbite and Olayinka (2010) that attributed the no significant difference between the NPK and the organic amended treatments to N immobilization.

4.4.2.2 N mineralization kinetic model and mineralization rates for the field studies

Net nitrogen mineralization data was fitted into five mathematical models and the results from each model presented in Table 4.20 for 2009 and 2010. The cumulative N mineralized from 0 to 34 week displayed the best fit with the mixed order rate constant (Eq. v) (R^2 = 0.91 and 0.99; RMSE = 18.9 and 28.4 for 2009 and 2010 respectively) and the Gompertz function (Eq. iv) (R^2 = 0.99 and 1.00; RMSE = 22.8 and 52.5 in 2009 and 2010 respectively) than with the first-order model equation (Eq. i) (R^2 = 0.92 and 0.98; RMSE = 237.4 and 397 in 2009 and 2010 respectively) advocated by Stanford and Smith (1972) or the consecutive models (Eqs. ii and iii) from the goodness-of-fit statistics (Table 4.20). This corroborates the findings of Agbenin *et al*. (1999) in the laboratory, where a mixed order rate constant described N mineralization pattern from the same organic material just as the Gompertz model.

$N_{min} = N_o (1 - e^{-kt}) + N_e$ ..... (i)

$N_{min} = N_o - N_o (ke^{-ht} - he^{-kt}) / (k - h)$ ..... (ii) (Noggle, 1985)

$N_{min} = N_o - N_o e^{-kt} (kt + 1)$ ..... (iii)

$N_{min} = N_o - N_o e^{-he-kt} - N_o e^{-h}$ ..... (iv) (France and Thornley, 1984)

$N_{min} = N_o (1 - e^{-kt-0.5ht2})$ ..... (v)

Where N_o is potentially mineralizable N content (mg kg^{-1}), *k* and *h* are rate constants ($week^{-1}$), N_{min} is cumulative N mineralized at time *t* (mg kg^{-1}), while N_e is an additional term introduced to accommodate the initial rapid N flush (mg kg^{-1}) (Jones, 1984). The N mineralization pattern was not adequately described by the first order rate equation compared to other models probably because N mineralization from neem seed cake was not just a function of substrate N concentration in the residue, a fundamental assumption of the first order rate model (Stanford and Smith, 1972; Jones, 1984).

Table 4.20: Goodness-of-fit statistics and parameter estimates of five mathematical models fitted to inorganic N mineralized from neem seed cake incorporation

	CV		R^2		χ^2		RMSE		N_0		N_e		h		k	
Model	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
1st order rate	-89.3	-36.3	0.9156	0.9827	-5.49 E+22	-2.30 E+24	237.4	397	-447 E-20	-927 E-22	6 E+20	2 E+22			-1 E+20	-5 E+21
Consecutive (h≠k)	-92.3	-5.58	0.9104	0.9879	1.27 E+5	4.90 E+5	104.5	165	291.1	430.9			19.61	-0.6	4 E+19	0.227
Consecutive (h=k)	89.3	36.3	0.9156	0.9827	2.44 E+24	1.13 E+26	272.5	398	1.07 E-19	1.9 E-21					0.11	2 E+23
Gompertz	3.23	0.535	0.9913	0.9988	1.08 E+5	4.63 E+5	22.8	52.5	386.4	568.4			-12.11	-1.0	9 E-13	0.095
Mixed order rate	-89.3	7.36	0.9156	0.9915	1.46 E+5	3.29 E+5	18.9	28.4	289.5	427.2			3.07	-0.1	1169.9	0.812

CV = Coefficient of Variation; R^2 = Coefficient of Determination; RMSE = Root Mean Square Error; N_0 = potentially mineralized N at time 0 in mg kg^{-1}; N_e = Additional term to accommodate the initial rapid N flush in mg kg^{-1}; h and k are constants.

The goodness-of-fit statistics and kinetic parameters for N mineralization that were calculated using the five equations are shown in Table 4.20. The N_0 values were interpreted as an estimate of the N content that would be mineralized in an infinite time period under optimal conditions of temperature and moisture (Stanford and Epstein, 1974). Results obtained showed that the estimated N_0 values were lower in the first order (-447E-20 and -927E-22 in 2009 and 2010 respectively) and consecutive (h=k) (1.07E-19 and 1.9E-21 in 2009 and 2010 respectively) models than the mixed order (289.5 and 427.2), consecutive (h≠k) (291.1 and 430.9) and the Gompertz (386.4 and 568.4) for 2009 and 2010 respectively. The negative N_0 values (Table 4.20) indicated a lag in N mineralization arising from immobilization by microbial biomass early in the decomposition or mineralization process (Agbenin *et al*., 1999).

The mineralization rate constant (*k*) of the five mathematical models displayed a wide range from -1E-20 to 4E+19 $week^{-1}$ in 2009 and -5E+21 to 2E+23 $week^{-1}$ in 2010 and this may be attributed to the ability of the model to account for early N mineralization. Agbenin *et al.* (1999) reported comparatively lower *k* values for neem seed residue N mineralization in a laboratory incubation study (0.046, 0.204, 0.076, 0.094 and -0.002 for the five models respectively). However, the *k* value of the Gompertz model (0.095) in 2010 was almost at par with that reported by Agbenin *et al.* (1999) in their laboratory study (Table 4.20).

The mineralization rates obtained in the present study were not in the order of mineralization rates determined for neem seed cake in literature. This could be due to the fact that N released during laboratory incubation is derived from rather ill-defined and variable organic N sources as evidenced above. As a result of field temperature fluctuations, greater rate of net N mineralization was obtained in laboratory incubated soil samples than for in-situ samples. These

pools are however, replenishable under field conditions as a result of inputs of organic N from root and above-ground litter and the slow transformation of the more resistant pools of soil organic N. Thus, laboratory measures of mineralization especially on undisturbed soils can be an unreliable index of field rates, as measurements of N mineralization under controlled laboratory conditions provide an estimate of pools of mineralizable N present at the time of sample collection.

4.4.3 Field Decomposition Studies Using Litterbags

4.4.3.1 Dry matter loss

Field decomposition was carried out using 20g NSC in a litterbag introduced into four (4) inorganic fertilizer treatments (0, ¼, ½ and full NPK recommended rate) to determine mass loss and decomposition rate. The data collected at each sampling period were subjected to five (5) models to determine the effect of inorganic fertilizer on the rate of mass loss. Effect of time and inorganic fertilizer levels on dry matter loss of NSC for the two years (2009 and 2010) is shown in Table 4.21. The rates of decomposition of the NSC were significantly different over the whole decomposition period and at individual sampling periods for the study years. Weight loss of NSC due to decomposition was rapid within the first 28 days; within the period about 70% of the soil organic amendment had been lost in 2009 (Figure 4.4). A further 5 to 13% weight loss of the NSC from the litterbag was recorded over the next 28 days. Litterbag sampling was stopped at 56 days after application (DAA) in 2009 because the amount of NSC left was too small (about 4g) to allow for analysis after two weeks. The remaining higher ash free dry mass obtained in 2010 as compared to 2009 for all the treatments could be attributed to the high residual mineral N in 2009 (Table 4.21) which resulted in reduced activity of bacteria and fungi necessary for decomposition reaction during the year.

Table 4.21: Effect of inorganic fertilizer levels on dry matter loss of neem seed cake in 2009 and 2010

	← Days of decomposition →													
	3		7		10		14		28		56		84	
	← year →													
Treatment description	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
0 NSC/ 0 NPK	nd	14.68	Nd	13.51	nd	11.5	10.39	11.26	6.12	5.97	4.86	4.22	nd	2.53
0 NSC/ ¼ NPK	nd	15.28	Nd	13.74	nd	11.8	10.59	10.98	5.31	4.69	4.23	3.83	nd	2.51
0 NSC/ ½ NPK	nd	15.11	Nd	13.71	nd	11.4	10.87	11.07	5.88	5.43	3.21	3.15	nd	1.44
0 NSC/ FULL NPK	nd	15.31	Nd	13.89	nd	11.8	11.32	11.09	5.61	7.02	3.94	2.86	nd	2.17

0 NSC = 0 ton of neem seed cake per hectare; 0-, ¼-, ½-, and Full optimum recommended NPK rate for sorghum in the region
nd = not determined

In 2010, the numbers of sampling date were increased to include the first ten days of decomposition owing to the rapid loss recorded within the first sampling period (fourteen days) in 2009 (Table 4.21). Also, mosquito netting were employed alongside the calico materials during the second year to offset the difficulty encountered during the late sampling periods in 2009. A significant ($P < 0.05$) decrease in dry mass (Ash free) was observed for the seven sampling periods in 2010 (Table 4.21). Dry mass loss of neem seed cake was rapid during the first fourteen (14) days of decomposition relative to later periods. This would imply that weight loss at the initial stage of decomposition was due to leaching of nutrients. This conforms to the findings of Berg and Staaf (1981) and McClaugherty and Berg (1987) that in the initial stages of leaf breakdown small soluble carbon molecules, like starches and amino acids, are lost first leaving behind the more recalcitrant molecules like lignin. Consequently, decomposition during the first phase (two weeks) was rapid because the small soluble carbon molecules of NSC were easy to breakdown and were energy rich (Sewanee and Simmons, 2003).

Dry matter losses were generally in the order 0 NSC/0 NPK > 0 NSC/ ½ NPK > 0 NSC/ ¼ NPK >0 NSC/ Full NPK. The corresponding dry matter loss for the organic residue under zero NPK after ten days was 42.45, 41.25, 43.00 and 41% respectively. At the end of the eighty-four (84) days decomposition, only 2.53, 2.51, 1.44 and 2.17g of the buried 20g samples of neem seed cake were remaining from the 0 NSC/0 NPK, 0 NSC/ ¼ NPK, 0 NSC/ ½ NPK and 0 NSC/ Full NPK treatment respectively. Addition of NPK significantly ($P < 0.05$) reduced the rate of dry mass loss of neem seed cake as a result of reduced activity of bacteria and fungi under fertilization. Okalebo and Woomer (1994) reported that decomposition and residual effects were enhanced when low quality organic materials were incorporated with a small amount of mineral N and then ploughed into the seedbed, preferably before the successive crop was planted.

The negative effect of this low quality organic material, Giller and Wilson (1991) explained in terms of nutrient immobilization because the microorganisms active in organic matter decomposition (e.g. bacteria, fungi) also obtain their nutrient requirements from the decomposing organic materials. Varying the NPK level did not affect dry mass loss of NSC significantly during the whole period of decomposition. At the end of the decomposition study, 17.47, 17.49, 18.56 and 17.83g of the initial weight (20g) of NSC were lost. This represents about 90% of the initial weight applied and suggests that incorporation of NSC about two weeks (10 – 14 days) before sowing could synchronize with period of high nutrient demand (Heading) of the short variety sorghum used.

4.4.3.2. Exponential decomposition kinetic model and decomposition rates

The data for dry mass remaining from retrieved litterbags at seven different sampling periods in 2010 were plotted against days of decomposition. The decomposition rates obtained from slope of the graphs along with the proportion of dry mass remaining were analysed using the SAS statistical package for non-linear regression model analysis. The results gave the parameter estimates for each of the four models and are presented in Tables 4.22 to 4.25 for the single exponential, double exponential, asymptotic negative and triple negative exponential models respectively.

The best fit was described by the Asymptotic negative exponential model (iii) (R^2 = 1.0, 1.0, 0.97 and 0.99; χ^2 = 3.89, 0.38, 0.60 and 0.37 for the zero, ¼-, ½-, and optimum recommended NPK fertilizer rates for sorghum in the Northern Guinea Savanna of Nigeria, respectively) when the goodness-of-fit statistics was employed than with the double exponential model (Eq. ii) (R^2 = 0.97, 0.74, 0.88 and 0.57; χ^2 = 1.22, 3.34, 1.37 and 0.27 for the four fertilizer rates respectively) or the triple negative exponential model (Table 4.24). Although, the single

Table 4.22: Goodness-of-fit statistics and parameter estimates of the four mathematical models fitted to cumulative dry mass loss (Ash free)

Single Exponential Model

Treatment description	Model	R^2	ϰ ^{2}	RMSE	X_0	K	T_{50}
0NSC/0NPK	$Y = X_0e^{k0t}$	0.93	18.19	0.2963	0.5627	0.0229	30.26
0NSC/¼NPK		0.87	3.23	0.3133	0.5564	0.0243	28.76
0NSC/½NPK		0.93	3.85	0.3249	0.5462	0.0302	22.95
0NSC/Full NPK		0.93	3.39	0.3132	0.5657	0.0271	25.57

R^2 = Coefficient of Determination; RMSE = Root Mean Square Error; X_0 = mass remaining at time 0; K = rate constant; T_{50} = time for 50% mass loss in days

Table 4.23: Goodness-of-fit statistics and parameter estimates of the four mathematical models fitted to cumulative dry mass loss (Ash free)

Double Exponential Decay Model

Treatment	Model	R^2	χ^2	RMSE	X_L	X_R	K_l	K_r	K	T_{50}
0NSC/0NPK	$Y = X_L e^{-Klt} + X_R e^{-Krt}$	0.97	1.22	0.06	0.6838	0.1857	0.0484	0.019	0.0674	10.28
0NSC/¼NPK		0.74	3.34	0.1142	0.6838	0.0691	0.0484	0.0165	0.0649	10.68
0NSC/½NPK		0.88	1.37	0.2884	0.6863	0.126	0.045	0.0288	0.0738	9.39
0NSC/Full NPK		0.57	0.27	0.2504	0.7082	0.2287	0.0322	0.0093	0.0425	16.31

R^2 = Coefficient of Determination; RMSE = Root Mean Square Error; X_L = Proportion of initial NSC for the labile fraction; X_R = Proportion of initial NSC for the Recalcitrant fraction; K_l = Rate constant for the labile fraction; K_r = Rate constant for the labile fraction; K = Cumulative rate constant; T_{50} = time for 50% mass loss in days

Table 4.24: Goodness-of-fit statistics and parameter estimates of the four mathematical models fitted to cumulative dry mass loss (Ash free)

Asymptotic Negative Exponential Decay Model

Treatment	Model	R^2	א ^{2}	RMSE	X_L	X_R	K_l	T_{50}
0NSC/0NPK	$Y = X_L e^{-Klt} + X_R$	1.00	3.89	0.2914	0.6838	0.5692	0.0484	14.32
0NSC/¼NPK		1.00	0.38	0.2963	0.6838	0.1742	0.0484	14.32
0NSC/½NPK		0.97	0.60	0.2884	0.6863	0.1260	0.0450	15.40
0NSC/Full NPK		0.99	0.37	0.2504	0.7082	0.1382	0.0332	20.87

R^2 = Coefficient of Determination; RMSE = Root Mean Square Error; X_L = Proportion of initial NSC for the labile fraction; X_R = Proportion of initial NSC for the Recalcitrant fraction; K_l = Rate constant for the labile fraction; T_{50} = Time for 50% mass loss in days

Table 4.25: Goodness-of-fit statistics and parameter estimates of the four mathematical models fitted to cumulative dry mass loss (Ash free)

Triple Negative Exponential Model

Treatment	Model	R^2	χ^2	RMSE	X_L	X_I	X_R	K_l	K_i	K_r	K	T_{50}
0NSC/0NPK	$Y = X_L e^{-Klt} + X_I e^{-Kit} + X_R e^{-Krt}$	0.88	5.74	0.3658	0.7957	0.9248	0.1857	0.0389	0.0478	0.019	0.1057	6.56
0NSC/¼NPK		0.76	1.12	0.3899	0.8104	0.1859	0.0691	0.0414	0.0634	0.0165	0.1213	5.71
0NSC/½NPK		0.79	9.81	0.1634	0.9712	1.2226	0.258	0.0437	0.0575	0.0288	0.1312	5.28
0NSC/Full NPK		0.64	4.19	0.316	0.8135	0.7946	0.0835	0.0407	0.0334	0.0093	0.0834	8.31

R^2 = Coefficient of Determination; RMSE = Root Mean Square Error; X_L = Proportion of initial NSC for first (initial flush) compartment; X_I = Proportion of initial NSC for the second (labile fraction) compartment; X_R = Proportion of initial NSC for the third (Recalcitrant fraction) compartment; K_l , K_i, K_r = Rate constant for the first, second and third compartment respectively; K = Cumulative rate constant; T_{50} = time for 50% mass loss in days

exponential model (Eq. i) proposed by Jenny *et al*. (1949) recorded close R^2 (0.93, 0.87, 0.93 and 0.93 for the four fertilizer rates respectively), the relatively low initial mass of neem seed cake (0.5627g) and high ϰ ^{2} (18.19, 3.23, 3.85 and 3.39) values estimated by the model did not make it compete favourably with the Asymptotic negative exponential model.

The neem seed cake decomposition pattern was not adequately described by the single exponential decay function compared to the asymptotic negative exponential model probablybecause mass loss from neem residue followed a two-step nature of decomposition dynamics which was not subsumed in the assumption of the single exponential model (Weider and Lang, 1982).

The higher the k value, the faster the rate of decomposition. High decay rates (K_l) in the first pool were indicative of soluble, non-structural carbohydrates and low C: N ratio compounds. This corroborates with the findings of Howard and Howard (1974) in the context of examining the decomposition of leaf litter when fauna were completely excluded. Thus, in the present study of neem seed cake decomposition using mosquito netting litterbag, excluded soil fauna necessary to enhance decomposition beyond a certain point (Weider *et al*., 1983; Tarfa *et al*., 2001; Daudu, 2004). Since, enclosing of the cake in mosquito net would probably have excluded or reduced the activity of the decomposer organisms, making the recalcitrant fraction of neem seed cake effectively indecomposable by biotic process.

This probably explains why the double exponential model was not able to properly describe the decomposition processes either. The recalcitrant fraction (K_r) was probably completely resistant to decay. The triple negative exponential model was unable to describe neem seed cake decomposition best because its regression failed to predict that at time = 0, all the initial neem

seed cake was present (Table 4.25). Consequently, inferences from this model would be meaningless and interpretation of comparisons among *k* values becomes questionable (Weider and Lang, 1982).

4.4.4. Derivations from the mineralization and decomposition experiments

The asymptotic model predicted a two weeks half life for 50% mass loss of incorporated NSC which implied that the two weeks incubation period used in the present study was adequate to synchronize with the nutrient release for optimum crop use. Although, this decomposition rate constant (k = 0.05) gave an half life that was higher than the one week from the mineralization study, this could be attributed to the patterns of nutrient release from decomposing litter (NSC) which did not follow that for mass loss as N was retained in the NSC during the initial stages of decay. Marked mass loss and decomposition rate per day was observed with lower inorganic fertilizer rate (¼ recommended rates for sorghum). This would imply that suitable combination of NSC with NPK fertilizer for optimum growth and yield would be at an inclusion level of ¼ recommended NPK rates for sorghum in the Northern Guinea Savanna of Nigeria.

4.5 Field Agronomic Experiments

4.5.1 Main effect of treatment factors

4.5.1.1 Response of agronomy parameters to NPK fertilizers

Main growth performance of sorghum as influenced by soil amendments in the study is shown in Table 4.26 and the interaction in Table 4.27.

Table 4.26: Main effects of sorghum growth parameters as affected by neem seed cake and inorganic fertilizer application

	2009	2010	combined	2009	2010	combined	2009	2010	combined	2009	2010	combined	2009	2010	combined
Treatment	Number of leaves			Dry matter yield (g plant^{-1})			Leaf area index			Stem girth (cm)			Plant height (cm)		
NPK kg ha^{-1} (N)															
0	11.65b	9.76b	10.79b	47.52b	31.18b	38.04b	3.83	2.52c	2.96b	2.48a	2.09c	2.27c	119.10b	103.50b	111.14c
¼RR	12.17ab	10.25b	11.01ab	50.26b	33.64b	40.86b	3.82	2.82cb	3.12b	2.53a	2.24b	2.38bc	121.84b	109.20b	115.26bc
½RR	12.31a	10.29b	11.43ab	54.40ab	36.98b	48.46a	3.62	2.97b	3.52a	2.58a	2.45a	2.47b	123.96ab	119.28a	120.63b
FRR	12.33a	11.07a	11.69a	58.54a	44.78a	51.29a	3.41	3.53a	3.66a	2.66a	2.51a	2.66a	130.28a	124.69a	128.90a
SE ±	0.18	0.18	0.26	2.51	2.24	2.42	0.17	0.14	0.14	0.07	0.05	0.05	2.75	2.45	2.18
NSC ton ha^{-1} (S)															
0 TC	11.83b	9.92b	10.80b	51.09b	28.56b	41.14b	3.53	2.50b	3.02b	2.48a	2.06d	2.28c	119.95b	103.18c	111.73b
1 TC	11.88b	9.86b	11.07b	49.00b	31.46b	41.32b	3.49	2.62b	3.16b	2.53a	2.22c	2.39bc	121.28ab	108.68	115.24b
2 TC	12.08a	10.56ab	11.19ab	51.84ab	42.52a	44.41b	3.67	3.23a	3.32b	2.61a	2.36b	2.53ab	124.84ab	117.29b	122.06a
4 TC	12.67a	11.04a	11.87a	58.79a	44.05a	51.78a	3.98	3.49a	3.76a	2.64a	2.66a	2.57a	129.11a	127.51a	126.90a
SE ±	0.18	0.18	0.26	2.51	2.24	2.42	0.17	0.14	0.14	0.07	0.05	0.05	2.75	2.45	2.18
Interaction (N × S)															
N × S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by the same letter (s) within the same column are not significantly different at P < 0.05 using DMRT
NS = Not significant at 0.05 level of probability; S= Significant at 0.05 level of probability
TC = ton ha^{-1} NSC
RR= recommended rate
FRR=Full fertilizer recommendation rate

Table 4.27: Interaction of NSC and CF on sorghum growth

Treatment	2009	2010	combined	2009	2010	combined	2009	2010	Combined	2009	2010	combined	2009	2010	combined
	Leaf number			Dry matter yield (g plant-1)			Leaf area index			Stem girth (cm)			Plant height (cm)		
Control	11.62	9.11	10.37	54.65	5.06	29.86	3.55	1.89	2.72	2.4	1.74	2.07	116.05	89.24	102.65
¼ RR	11.48	9.06	10.27	41.8	8.06	24.93	3.13	2.02	2.575	2.36	1.96	2.16	114.72	96.45	105.59
½ RR	11.62	10.22	10.92	49.21	11.06	30.14	3.54	2.9	3.22	2.39	2.15	2.27	119.52	104.96	112.24
FRR	12.62	10.67	11.65	58.71	14.06	36.39	3.9	3.26	3.58	2.75	2.51	2.63	129.51	123.35	126.43
1 TC	11.48	9.94	10.71	40.74	17.06	28.90	3.14	2.44	2.79	2.41	2.00	2.21	118.78	100.01	109.40
1 TC + ¼ RR	12.05	9.78	10.92	46.49	20.06	33.28	3.55	2.45	3.00	2.43	2.15	2.29	118.21	102.41	110.31
1 TC + ½ RR	12.14	10.89	11.52	50.64	23.06	36.85	3.47	3.32	3.40	2.71	2.25	2.48	117.15	114.77	115.96
1 TC + FRR	11.86	10.39	11.13	58.13	26.06	42.10	3.79	3.08	3.44	2.57	2.56	2.57	130.98	119.60	125.29
2 TC	11.43	10.11	10.77	43.01	29.06	36.04	3.19	2.58	2.89	2.59	2.18	2.39	117.18	110.27	113.73
2 TC + ¼ RR	12.43	10	11.22	56.01	32.06	44.04	3.71	2.83	3.27	2.69	2.39	2.54	127.00	115.84	121.42
2 TC + ½ RR	12.57	9.89	11.23	56.09	35.06	45.58	4.16	2.99	3.58	2.54	2.49	2.52	126.17	123.32	124.75
2 TC + FRR	11.9	11.17	11.54	52.25	38.06	45.16	3.64	3.5	3.57	2.64	2.75	2.70	128.99	127.69	128.34
4 TC	12.1	10.5	11.30	51.69	41.06	46.38	3.76	3.1	3.43	2.53	2.32	2.43	124.36	113.20	118.78
4 TC + ¼ RR	12.71	10.61	11.66	56.74	44.06	50.40	4.08	3.17	3.63	2.65	2.38	2.52	127.44	120.02	123.73
4 TC + ½ RR	12.9	11.22	12.06	61.66	47.06	54.36	4.09	3.73	3.91	2.66	2.56	2.61	133.00	126.12	129.56
4 TC + FRR	12.95	11.94	12.45	65.06	50.06	57.56	3.98	4.11	4.05	2.70	2.77	2.74	131.64	139.40	135.52
SE ±	0.16	0.23	0.20	2.17	1.94	2.06	0.15	0.12	0.14	0.06	0.04	0.05	2.38	2.12	2.25

TC= ton ha^{-1} neem seed cake
RR = recommended rate
FRR=full recommendation rate

Number of leaves

In the NPK amended plots, number of leaves increased with increasing nutrient content of fertilizer material with the Full Recommended Rate (FRR) performing better than the other rates (Table 4.26). This implied that the plant growth increased with increasing NPK fertilizer. The two years combined also showed similar trend as number of leaves increased with increasing nutrient concentration. This trend depicts a larger source/ sink ratio during grain filling period owing to nutrient release and thus yield improvement.

Dry matter yield

The dry matter assessment in the field was by destructive sampling at two weeks interval, the cumulative mean values across the period are presented in Table 4.26. FRR recorded the highest dry matter yield (58.54 and 44.78 g plant^{-1} in 2009 and 2010 respectively) while the control gave the least dry matter yield (47.52 and 31.18 g plant^{-1} in 2009 and 2010 respectively) (Table 4.26) in the sole NPK treatment. The two years combined had the FRR (51.29 g plant^{-1}) recording the highest dry matter yield for the sole NPK treatments. This value was statistically different the ½ RR and the control in the sole NPK treatments (Table 4.26). This would imply that dry matter yield increased with increasing nutrient contents in the NPK treatment plots indicative of enormous forage yield whose proportion of accumulation and partitioning into grain determine the grain yield.

Leaf Area Index

Leaf area index (LAI) was not significantly ($P < 0.05$) affected by treatment in the sole NPK plots in 2009 (Table 4.26). However in 2010, LAI was significantly affected by the sole application of NPK fertilizer. FRR produced the highest (3.53) while control had the least (2.52) which was statistically similar to the ¼ RR (2.82), but differed from the ½ RR (2.97) which were not the same as the FRR (Table 4.26). Significant differences in NPK treatments implied

that nutrients were readily available for the development of leaf area early in the season which consequently resulted in an appropriate LAI that contributed to total biomass.

Stem girth

The treatment significantly ($P < 0.05$) increased stem girth in 2010 and combined (Table 4.26). In sole NPK treatments in 2010, the FRR gave highest stem girth (2.51 cm), while the control recorded least (2.09 cm) which was statistically different from the other treatments.

Plant height

Plant heights were better enhanced with NPK treatments. Statistically, the FRR enhanced better plant height in the sole NPK treatments than any of the other treatments in both years (Table 4.26).

Days to 50% panicle emergence

In the sole NPK treatments, the highest number of days to 50% panicle emergence was recorded from ¼ RR (107) and control (104) while FRR had the least (106 and 101) in 2009 and 2010 respectively (Table 4.28).

Days to 50% flowering

Days to 50% flowering in the sole NPK treatments decreased with increase in treatments. ½ RR and control treatments recorded the highest (110 and 109 days) in 2009 and 2010 respectively. The least number of days to 50% flowering was obtained from FRR (Table 4.28).

4.5.1.2 Response of agronomy parameters to NSC levels

Number of leaves

4 TC enhanced better growth parameter compared to the 1 and 2 TC levels in the NSC amended plots alone. This implied that the plant growth increased with increasing nutrient supply from the NSC. The two years combined also showed similar trend as number of leaves increased with increasing nutrient concentration.

Dry matter yield

The two years combined had the 4 TC (51.78 g plant^{-1}) recording the highest dry matter yield for the sole NSC treatments. This value was statistically different from the control in the sole NSC treatments (Table 4.26). This would imply that dry matter yield increased with increasing nutrient contents in the NSC treatment plots.

Leaf Area Index

Leaf area index (LAI) was not significantly ($P < 0.05$) affected by treatment in the sole NSC plots in 2009 (Table 4.26). However in 2010, LAI was significantly affected by the sole application of NSC. Significant differences observed between the levels of sole NSC treatments, indicated a higher soil organic matter content which led to more nutrient release for sorghum.

The significant difference in the second year indicated that the soil was depleted following the continous cropping with sorghum and demonstrated the potential of sorghum crop to respond to organic fertilization organic.

Stem girth

4 TC had plant with the highest stem girth (2.66 cm), while the control had least (2.06 cm). NSC must have enhanced appropriate release, availability and uptake of nutrient by the sorghum plants compared to control.

Plant height

Plant heights were better enhanced with NSC treatments. 4 TC gave plant with the tallest plant height in the two years which was significantly different from the other treatments in 2010 but was similar to 2 TC in 2009. Similar trend was also observed in the combined.

Days to 50% panicle emergence

Sole application of NSC recorded the highest days to 50% panicle emergence from 1 TC (107 days) and control (104 days), and the least (105 and 100 days) from 4 TC in 2009 and 2010 respectively (Table 4.28).

Days to 50% flowering

In the sole application of NSC, highest number of days to 50% flowering was obtained from the control in both years while 4 TC recorded the least (Table 4.28).

4.5.1.3 Effect of interaction between NPK and NSC on agronomy parameters

Number of leaves

The treatment significantly ($P < 0.05$) increased number of leaves; highest number of leaves (12.95 and 11.94) were recorded in plots with 4 TC + FRR in 2009 and 2010 respectively while those treated with 2 TC (11.43 in 2009) and ¼ RR had the least in 2009 and 2010 respectively (Table 4.27). This implied that the plant growth increased with increasing nutrient supply from both organic and inorganic sources in line with the benefits of integrated soil fertility management as also reported by Okalebo and Woomer (1994). The two years combined also showed similar trend as number of leaves increased with increasing nutrient concentration.

Dry matter yield

The mean interactive dry matter assessment of sorghum in the field is presented in Table 4.27. In 2009 and 2010, the plot with 4 TC + FRR had the highest dry matter yield (65.06 and 50.06 g plant^{-1}).

Leaf area index

Leaf area index (LAI) was not significantly ($P < 0.05$) affected by treatment in the sole NPK and NSC plots in 2009 (Table 4.26). Although interaction effects were not significant at 0.05 level of probability in the two years and the combined, 2 TC + ½ RR (4.16) and 4 TC + FRR (4.11) (Table 4.27) recorded the highest leaf area index in 2009 and 2010 respectively. This finding buttressed the synergistic effect of complementary use of organic and inorganic fertilizers on growth parameters of sorghum.

Stem girth

Interaction was not significant but 4 TC + FRR recorded highest stem girth (2.77 cm) when treatments were compared (Table 4.27) in 2010. The slow release of nutrients by NSC coupled with the long period sorghum plants took to reach maturity made it easy for enhanced nutrient uptake by sorghum plants from the interaction of NPK and NSC soil amendments as compared to NPK that released its nutrients very fast or get leached out even before the plant could absorb it.

Plant height

Plant heights were also better enhanced in the combination. In 2009, the tallest plant (133.00 cm) was recorded from 4 TC + ½ RR treatments while in 2010 and the two years combined, 4 TC + FRR had the highest (139.40 cm in 2010 and 135.52 cm for combined) (Table 4.27). Plant height is associated with the growth and biomass of the crop, consequently, the taller the plant, the higher the dry biomass yield and potentially, soluble sugar yield.

Days to 50% panicle emergence

Interactions of the two soil amendments were not significant at both 0.01 and 0.05 level of probability in both years (Table 4.29). The least number of days to 50% panicle emergence (105 days) was obtained from three interaction treatments: 2 TC + FRR, 4 TC + ½ RR and 4 TC + FRR aside ½ RR (Table 4.29).

Days to 50% flowering

However, there was no interaction with NPK and NSC on days to 50% flowering in both years of this study (Table 4.29).

Table 4.28: Main effects of NSC and NPK on days to 50% panicle emergence and flowering of sorghum

Treatment	2009	2010	Combined	2009	2010	combined
	Days to 50% panicle emergence			Days to 50% flowering		
NPK kg ha^{-1} (N)						
0	106.67ab	104.42a	105.83a	109.75ab	109.42a	110.13a
¼RR	107.25a	104.17a	105.75a	110.25a	109.33a	109.88a
½RR	105.92bc	102.25b	104.08b	108.92bc	107.50b	108.08b
FRR	105.58c	101.08b	103b	108.67c	105.83b	106.75c
SE ±	0.33	0.6	0.53	0.32	0.63	0.44
NSC ton ha^{-1} (S)						
0 TC	106.83a	105a	105.63a	110.00a	110.50a	109.71a
1 TC	106.92a	104.25a	105.54a	109.92a	109.50a	109.63a
2 TC	106.17ab	102.25b	104.21ab	109.08ab	107.25b	108.29b
4 TC	105.50b	100.42c	103.29b	108.58b	104.83b	107.21b
SE ±	0.33	0.6	0.53	0.32	0.63	0.44
Interaction (N × S)						
N × S	NS	NS	NS	NS	NS	NS

Means followed by the same letter (s) within the same column are not significantly different at 0.05 level of probability using DMRT
RR= recommended rate
FRR= Full recommended rate
TC= ton ha^{-1} NSC
NS= Not Significant

Table 4.29: Interaction of NSC and NPK fertilizer on days to 50% panicle emergence and flowering of sorghum

Treatment	2009	2010	combined	2009	2010	Combined
	Days to 50% panicle emergence			Days to 50% flowering		
Control	107	107	107	111	111	111
¼ RR	109	109	109	112	112	112
½ RR	105	105	105	108	108	108
FRR	106	106	106	109	109	109
1 TC	107	107	107	110	110	110
1 TC + ¼ RR	108	108	108	111	111	111
1 TC + ½ RR	107	107	107	110	110	110
1 TC + FRR	107	107	107	110	110	110
2 TC	107	107	107	110	110	110
2 TC + ¼ RR	106	106	106	109	109	109
2 TC + ½ RR	106	106	106	109	109	109
2 TC + FRR	105	105	105	108	108	108
4 TC	106	106	106	109	109	109
4 TC + ¼ RR	106	106	106	109	109	109
4 TC + ½ RR	105	105	105	109	109	109
4 TC + FRR	105	105	105	108	108	108
SE ±	0.28	0.52	0.4	0.28	0.55	0.415

RR= recommended rate
FRR= Full recommended rate
TC= ton ha^{-1} NSC

4.5.2.1 Effects of NPK fertilizer levels on yield parameters

Grain yield

There was significant difference in grain yield in 2010. However, trend was erratic with increasing NPK across treatments. FRR (2,251.90 kg ha^{-1}) gave the highest grain yield in the two years combined. The present trend with FRR having the highest grain yield further signifies the low fertility and corresponding low yield except with addition of external input. The highest grain yield (3346.81 kg ha^{-1}) was recorded from FRR (optimum NPK recommended rate) which gave increase of 22.15% above the control in 2009 while the least (2362.30 kg ha^{-1}) grain yield was recorded in the ¼ RR for sorghum in the region (Table 4.30).

Stover yield

Increase in stover yield was recorded with increasing chemical fertilizer (CF) input in 2009, 2010 and the combined (Table 4.30). The yield obtained in the study was a reflection of the contribution of the treatments to the soil nutrient status. The combined followed the same trend with mean yield between 11,111 kg ha^{-1} in the control and 14,306 kg ha^{-1} for FRR.

Grain weight per panicle

Effect of the treatments on sorghum grain weight per panicle was significant in 2009 and 2010 (Table 4.28). Application of treatments did not show a discernable pattern on grain weight per panicle in the sole CF treatments in both years. However, grain weight was not significant in 2009 (Table 4.28). In 2010, ¼ RR recorded the highest grain weight per panicle (0.0250 g) which was statistically the same with the other two treatments while the control (0.0181 g) had the least and was statistically different from any of the CF treatments (Table 4.28).

1000 grain weight

Sorghum 1000 grain weight did not significantly increase with increasing rates of NPK in 2009. The marked increase in 1000-seed weight in 2010 over the control (Table 4.28) could be due to increased nutrient additions through the amendments (Iwuafor, 1986).

Table 4.30: Main effects of NSC and NPK fertilizer on yield and yield components

Treatment	2009	2010	combined	2009	2010	combined	2009	2010	combined	2009	2010	combined
	Grain yield (kg ha^{-1})			Stover yield (kg ha^{-1})			Grain weight per panicle (g)			1000 grain weight (g)		
NPK kg ha^{-1} (N)												
0	2845.8	959.94b	2002.5	15625b	28.83	11111	0.0538	0.0181b	0.0378	34.8	28.83	31.63
¼RR	2755.3	1330.90a	1939.9	16250ab	30.04	11354	0.0521	0.0250a	0.0366	35.33	30.04	32.48
½RR	2639.6	1176.02a	1867.3	16667ab	30.52	12604	0.0499	0.0220a	0.0353	33.98	30.52	32.52
FRR	3166	1249.85a	2251.9	18611a	30.45	14306	0.0597	0.0236a	0.0424	35.36	30.45	33.05
SE ±	186.58	62.51	210	873.04	0.56	1113.7	0.0035	0.0012	0.004	0.55	0.56	0.68
NSC ton ha^{-1} (S)												
0	2713	1159.19ab	1836.5	15208b	6597.2c	11233	0.0513	0.0218b	0.0347	34.8	28.47a	31.84
1	2922.3	1124.59b	2126.6	16042ab	6458.3c	11684	0.0522	0.0211b	0.0401	34.96	29.63ab	32.5
2	2782.6	1095.01b	1979.3	17500ab	8541.7b	12865	0.0526	0.0207b	0.0373	35.12	31.05a	32.82
4	2988.8	1337.91a	2119.3	18403a	10000a	13594	0.0565	0.0252a	0.04	34.58	30.74a	32.52
SE ±	186.58	62.51	210	873.04	478.13	1113.7	0.0035	0.0012	0.004	0.55	0.56	0.68
Interaction (N × S)												
N × S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

TC= ton ha^{-1} neem seed cake
FRR=full fertilizer recommendation rate
RR= recommended rate

4.5.2.2 Effect of NSC levels on yield parameters

Grain yield

There was significant difference in the sole NSC ($p<0.05$) in 2010. However, there was an erratic pattern was followed with increase in NSC levels. 4 TC gave the highest grain yield of 2,988.8 kg ha^{-1} in 2009 and 1,337.9 kg ha^{-1} in 2010 while the combined recorded the highest mean grain yield of 2,126.60 kg ha^{-1} in 1 TC treatment (Table 4.30). This signifies that optimum level for NSC treatment is 1 TC.

Stover yield

There was significant increase in stover yield with increasing NSC levels in 2009 and 2010. The yield obtained in the study was a reflection of the contribution of the treatments to the soil nutrient status. The combined followed the same trend with mean yield between 11,233 kg ha^{-1} in the control and 13,594 kg ha^{-1} for 4TC (Table 4.30).

Grain weight per panicle

In the sole NSC treatments, 4 TC recorded highest grain weight per panicle (0.0252 g) while 2 TC gave the least which was statistically similar with 1 TC (0.0211 g) and the control (0.0218 g) (Table 4.28).

1000 grain weight

Sorghum 1000 grain weight did not significantly increase with increasing rates of NSC in 2009. The marked increase in 1000-seed weight in 2010 over the control (Table 4.28) could be due to increased nutrient additions through the amendments (Iwuafor, 1986).

4.5.2.3 Effect of treatment interaction factors on yield parameters

Stover yield

Stover yield was not significant in the interactive effect in 2009, 2010 and two years combined. But, highest stover yield of 15,277.76 kg ha^{-1} was recorded from the 4 TC + FRR in the

combined (Table 4.31). This further signifies the importance of the complementary use of NPK and NSC on the yield of sorghum.

Grain yield

In 2010, the highest grain yield (1524.04 kg ha^{-1}) was recorded from treatments that received 1 TC + FRR which gave an increase of 44 % above the control (Table 4.31). However, no significant difference was observed between NSC and CF treatment, highest grain yield (2,321.56 kg ha^{-1}) was recorded from 2 TC+ FRR with the combined use of NPK and NSC in the two years combined (Table 4.31). The relatively higher grain yield with the combined use of NPK and NSC inputs at the 1 TC + FRR in 2010 and 2 TC + FRR corroborates the submission of Sanchez (1994) that combining mineral and organic inputs result in greater benefits than either inputs alone through positive interactions on soil biological, chemical and physical properties.

Also, organic resources are seen as complementary inputs to mineral fertilizers and their potential role has consequently been broadened from a short term source of nitrogen to a wide array of benefits both in the short and long term (Vanlauwe *et al*., 2002). Murwira and Kirchmann (1993) reported that a combination of organic-inorganic nutrient sources is thought to improve the synchronization of nutrient release and subsequent uptake by crops. Synchronization which was achieved by incorporating NSC two weeks before planting the sorghum conforms to Okalebo and Woomer (1994) reports that decomposition and residual effects are enhanced when low organic materials are incorporated with a small amount of mineral nitrogen and ploughed into the seed bed, preferably before the successive crop is planted. Neem seed cake, being a high quality organics (N > 2.5%, lignin > 15% and polyphenol > 4%) (Giller, 2000; Palm *et al*., 2001) was incorporated without mineral-N two weeks before sowing of sorghum seeds.

Table 4.31: Interaction of NSC and CF on sorghum yield parameters

Treatment	2009	2010	combined	2009	2010	combined	2009	2010	combined
	Stover yield (kg ha^{-1})			Grain yield (kg ha^{-1})			Grain yield increase (%)		
Control	15000	5138.89	10069.45	2605.45	850.71	1728.08	-	-	-
¼ RR	13611.11	5833.33	9722.22	2362.3	781.2	1571.75	-9.33	-8.17	-8.75
½ RR	15277.78	7916.67	11597.23	2537.6	1042.75	1790.18	-2.6	22.57	9.99
FRR	16944.45	10138.89	13541.67	3346.81	1165.1	2256	28.45	36.96	32.71
1 TC	16388.89	6250	11319.45	3144.67	1367.1	2255.89	20.7	60.7	40.7
1 TC + ¼ RR	17777.78	5833.33	11805.56	2775.34	1301	2115.37	12.45	52.93	32.69
1 TC + ½ RR	15000	8611.11	11805.56	2839.29	1131.44	1796.27	-5.54	33	13.73
1 TC + FRR	17500	8611.11	13055.56	2929.73	1524.04	2179.91	8.84	79.15	44
2 TC	15277.78	7500	11388.89	2461.09	1088.57	1931.96	6.52	27.96	17.24
2 TC + ¼ RR	17500	6805.56	12152.78	2835.77	1055.5	1821.72	-0.67	24.07	11.7
2 TC + ½ RR	20000	8194.45	14097.23	2587.93	1088.98	2167.21	24.56	31.29	27.93
2 TC + FRR	16111.11	10416.67	13263.89	3245.43	1471.04	2321.56	21.75	72.92	47.34
4 TC	14722.22	7500	11111.11	3172.08	1330.38	2084.84	8.97	56.38	32.68
4 TC + ¼ RR	18611.11	7361.11	12986.11	3047.64	1360.67	2204.16	16.97	59.95	38.46
4 TC + ½ RR	19166.67	9444.44	14305.56	2593.66	1116.87	1855.27	-0.45	31.29	15.42
4 TC + FRR	19722.22	10833.33	15277.76	3141.99	1191.45	2166.72	20.59	40.05	30.32
SE ±	756.08	414.07	585.075	161.58	54.13	107.855			

TC= ton ha^{-1} NSC
RR= recommended rate
FRR= Full recommended rate
NS= Not Significant

Yield obtained in this study was a reflection of contribution of the treatments to the soil nutrient status. Higher yield obtained in CF amended plots could be attributed to quick release of nutrients from inorganic fertilizer to soil and their uptake by the sorghum plants. Improved yield obtained in neem seed cake (NSC) amended plots in the second cropping season might be due to the cumulative effect of nutrients released by the organic material to soil. NSC used in the study compared favourably with CF in some of the parameters measured. It therefore implied that NSC investigated was as effective as CF in increasing soil nutrients and consequently, the yield of sorghum.

1000 grain weight

The non significant increase in 1000-seed weight as a result of application of both amendments shows that sorghum seed weight was not controlled by just improved levels of nutrients in the soil alone. Other factors such as adequate soil moisture regime which significantly affect photosynthate production and translocation from source (leaves) to the sink (seed) may have to be considered (Oikeh, 1997).

4.5.3 Nutrient uptake studies

4.5.3.1 Effect of NSC and CF on nutrient concentration of sorghum tissue.

Main effects of NSC and CF on concentration of N, P, and K in sorghum tissue in the field are shown in Table 4.32 and the interactive effect in Table 4.33.

Nitrogen

N concentration decreased with increasing sole NPK in 2009 while an indiscernible pattern was followed in 2010. In 2010, the sole NSC treatment recorded plant tissue whose N contents decreased with increasing NSC while in 2009, the reverse situation was obtained with the control (10.65 g kg^{-1}) recording the least (Table 4.32). Interaction effect of treatments was not significant on sorghum plant tissue N in both 2009 and 2010 (Table 4.33). However, plants

Table 4.32: Main effects of NSC and CF on nutrient concentration of sorghum tissue in the field

Treatment	N (g kg^{-1})		P (g kg^{-1})		K (g kg^{-1})	
	2009	2010	2009	2010	2009	2010
NPK kg ha^{-1} (N)						
0	14.08	7.44b	2.66	0.25	1.51	7.41
¼ RR	13.57	7.54b	3.32	0.41	12.27	13.68
½ RR	11.67	10.13a	2.89	0.35	14.62	10.18
FRR	11.31	7.76b	3.80	0.25	0.66	7.96
SE ±	1.22	0.80	0.73	0.08	7.84	2.80
NSC t ha^{-1} (S)						
0 TC	10.65b	7.33	2.48	0.38	24.8	7.79
1 TC	11.67ab	9.18	4.12	0.34	2.03	8.55
2 TC	13.71ab	8.25	3.56	0.27	1.57	12.6
4 TC	14.59a	8.13	2.52	0.27	0.66	10.28
SE ±	1.22	0.80	0.73	0.08	7.84	2.80
Interaction (N × S)						
N × S	NS	NS	NS	NS	NS	NS

Means followed by the same letter (s) within the same column are not significantly different at $P < 0.05$
NS= Not significant
RR= recommended rate
FRR= Full recommended rate
TC= ton ha^{-1} NSC

Table 4.33: Interaction of NSC and CF on N, P and K concentration in sorghum tissue
NS= Not significant

Treatment	N		P		K	
	←		g kg^{-1}			→
	2009	2010	2009	2010	2009	2010
Control	12.54	6.71	2.41	0.36	4.31	8.30
¼ RR	13.71	4.09	2.8	0.42	44.06	8.03
½ RR	6.71	9.92	2.41	0.26	50.15	6.30
FRR	9.63	8.58	2.29	0.49	0.68	8.53
1 TC	9.34	7.88	2.59	0.13	0.61	7.30
1 TC + ¼ RR	11.96	7.00	2.83	0.49	3.69	8.07
1 TC + ½ RR	14.88	8.17	5.3	0.29	0.66	29.07
1 TC + FRR	13.71	10.91	2.35	0.42	0.65	9.53
2 TC	14.88	7.88	2.89	0.39	0.48	8.50
2 TC + ¼ RR	15.17	13.07	4.02	0.42	3.22	9.57
2 TC + ½ RR	12.84	9.63	3.16	0.29	4.50	7.07
2 TC + FRR	11.96	7.88	1.96	0.42	0.62	17.80
4 TC	19.55	7.3	2.77	0.13	0.65	5.53
4 TC + ¼ RR	10.21	8.76	7.03	0.33	0.62	9.27
4 TC + ½ RR	12.26	7.29	2.89	0.10	0.63	5.77
4 TC + FRR	13.13	6.42	2.98	0.10	6.70	8.27
SE ±	1.06	0.69	0.63	0.07	6.79	2.43
	NS	NS	NS	NS	NS	NS

TC = ton ha^{-1} NSC
RR= recommended rate
FRR= Full recommended rate

treated with 4 TC (19.55 g kg^{-1}) and 2 TC + ½ RR (13.07 g kg^{-1}) had the highest value of N concentration while ½ RR (6.71 g kg^{-1}) and ¼ RR (4.09 g kg^{-1}) had the least in 2009 and 2010 respectively.

In 2010, analysis showed that N concentrations were lower in the control than all the other treatments. The data also showed that plant N contents decreased with years of cropping in the control and treatment plots; it signifies low soil fertility. This could be inferred from the shortcomings of monocropping since crops would be susceptible to the same pests and diseases as was experienced in the second cropping season when stem borer infestation was on the increase. Also, the soil would be mined of the same mineral constituents whose replacement with either organic or inorganic amendments might not be commensurate with plant uptake. However, since the combined analysis showed that lower rate of CF were superior to higher rates (Tables 4.32 and 4.33), it indicates that for short term sorghum production programmes, the combined use of lower rates CF and NSC would be superior to either of the amendments used alone.

NSC which released a higher percentage of its initial nutrients slowly had higher plant nutrient contents in 2009. This is consistent with reports in literature (Palmer, 1995). Application of NSC significantly ($P < 0.05$) improved sorghum N concentration compared with the absolute control. 4 TC (14.59 g kg^{-1}) had plants with the highest N content while the control (10.65 g kg^{-1}) had the least (Table 4.32). This trend was not observed throughout the duration of the study. However, there were significant differences between sole NSC and CF treatments. NSC also interacted positively with CF to affect sorghum plant mineral composition (Table 4.33).

Phosphorus

There was no significant increase from the treatments on P concentration in sorghum plant tissue. P concentration was found to decrease with increasing levels of sole CF and NSC in 2010 (Table 4.32). However, the highest P concentration (2.83 g kg^{-1} and 0.49 g kg^{-1}) was recorded from 1 TC + ¼ RR and FRR in 2009 and 2010 respectively while the least was from 2 TC + FRR (1.96 g kg^{-1}) in 2009 and 4 TC + ½ RR and 4 TC + RR in 2010 (Table 4.33).

Potassium

The treatment had no significant effect on sorghum K concentration. Plants treated with ¼ RR gave the highest concentration in 2009 (50.15 g kg^{-1}) while 2 TC had the least (0.48 g kg^{-1}). In 2010, 1 TC + ½ RR (29.07 g kg^{-1}) had plants with the highest P concentration and 4 TC (5.53 g kg^{-1}) the least (Table 4.33). K increase between the levels of the NSC and CF were inconsistent. The indiscernible patterns of nutrients concentration in sorghum plant in the two years conform to findings of Garba (2010).

4. 5.3.2 Effect of NSC and CF on nutrient uptake by sorghum in the field

Data on nutrient uptake by sorghum biomass in the field are presented in Table 4.34 for 2009 and 2010.

Nitrogen

There was no significant difference on N uptake with treatment in the sole NPK plants in 2009. ½ RR recorded the least (4.47 g kg^{-1}) N uptake while FRR gave the highest (4.98 g kg^{-1}) which were not statistically different from other treatments in 2009. There was significant difference ($p < 0.05$) in N uptake in 2010. Control recorded the least N uptake (1.07 g kg^{-1}) which was statistically at par with ¼ RR (1.14 g kg^{-1}); while, ½ RR recorded the highest N uptake (1.79 g kg^{-1}) which was statistically at par with FRR (1.62 g kg^{-1}) but different from the control (Table 4.34). There was no discernible pattern in N uptake from sole NPK treatments in both years.

Table 4.34: Main effect of NSC and NPK fertilizer on nutrient uptake by sorghum in 2009 and 2010 field study

	N uptake (g kg^{-1})		**P uptake** (g kg^{-1})		**K uptake** (g kg^{-1})	
Treatment	2009	2010	2009	2010	2009	2010
NPK (kg ha^{-1})						
0 RR	4.50	1.07b	0.44	0.04	0.67	0.54
¼ RR	4.88	1.14b	0.59	0.06	0.59	0.81
½ RR	4.46	1.79a	0.43	0.07	0.50	1.17
FRR	4.98	1.62a	0.55	0.05	1.03	0.91
SE ±	0.56	0.14	0.09	0.01	0.12	0.22
NSC (t ha^{-1})						
0 TC	4.68	1.18	0.58	0.06	0.62	0.74
1 TC	4.84	1.52	0.40	0.06	0.42	0.71
2 TC	4.36	1.44	0.41	0.05	1.04	0.81
4 TC	4.95	1.49	0.61	0.05	0.72	1.17
SE ±	0.56	0.14	0.09	0.01	0.12	0.22
Interaction (N × S)						
N × S	NS	NS	NS	NS	NS	NS

Means followed by the same letter (s) within the same column are not significantly different at $P < 0.05$
NS= Not significant
TC = ton ha^{-1} NSC
RR= recommended rate
FRR= Full recommended rate

However, there was a decrease in N uptake over years (Table 4.34). N uptake was not significantly different with treatments in sole NSC plots in 2009 and 2010. 2 TC recorded the least (4.36 g kg^{-1}) N uptake while 4 TC gave the highest (4.95 g kg^{-1}) in 2009 while Control recorded the least (1.18 g kg^{-1}) N uptake and 1 TC gave the highest (1.52 g kg^{-1}) in 2010.

Phosphorus

There was no significant difference in P uptake in 2009 and 2010 with sole NPK treatments. ½ RR recorded the least P uptake (0.43 mg kg^{-1}) which was slightly lower than the control (0.44 mg kg^{-1}) while ¼ RR recorded the highest P uptake (0.59 mg kg^{-1}) which was not statistically different from the other treatments. In 2010, control recorded the least (0.04 mg kg^{-1}) P uptake while ½ RR gave the highest (0.07 mg kg^{-1}). There was no significant difference in K uptake with treatments in sole NPK plants. ¼ RR recorded the least K uptake (0.50 g kg^{-1}) while FRR gave the highest (1.03 g kg^{-1}) which was not statistically different from other treatments. In 2010, control recorded the least (0.54 g kg^{-1}) K uptake while ½ RR gave the highest (1.17 g kg^{-1}). There was however no discernible pattern of nutrient uptake in the both years.

There was no significant difference in P uptake in sole NSC plots with treatments in both years. 1 TC recorded the least P uptake (0.40 mg kg^{-1}) while 4 TC gave the highest (0.61 mg kg^{-1}) (Table 4.34). 2 TC and 4 TC recorded the least P uptake (0.05 mg kg^{-1}) while control and 1 TC gave the highest (0.06 mg kg^{-1}) in 2010 (Table 4.34). Effect of NPK and NSC interaction was not significant in both years. However, highest P uptake (1.11 mg kg^{-1}) in 2009 was obtained from 1 TC + FRR (Table 4.35).

Potassium

1 TC recorded the least K uptake (0.42 g kg^{-1}) while 2 TC gave the highest (1.04 g kg^{-1}) in 2009. K uptake in sole NSC treatments increased with increase in quantity of organic amendment in 2010. 1 TC recorded the least K uptake (0.71 g kg^{-1}) while 4 TC gave the highest (1.17 g kg^{-1})

Table 4.35: Interaction of NSC and NPK fertilizer on nutrient uptake in 2009 and 2010

	N uptake (g kg^{-1})		P uptake (g kg^{-1})		K uptake (g kg^{-1})	
Treatment	2009	2010	2009	2010	2009	2010
Control	3.98	0.80	0.48	0.05	1.31	0.53
¼ RR	2.84	0.50	0.37	0.05	0.83	0.55
½ RR	5.85	1.61	0.63	0.04	0.14	0.68
FRR	6.06	1.81	0.85	0.10	0.19	1.19
1 TC	6.60	1.12	0.44	0.02	0.19	0.47
1 TC + ¼ RR	5.04	0.91	0.35	0.06	1.13	0.59
1 TC + ½ RR	5.30	1.39	0.51	0.05	0.21	1.32
1 TC + FRR	6.34	1.76	1.11	0.07	0.19	0.79
2 TC	4.19	1.15	0.43	0.06	0.18	0.56
2 TC + ¼ RR	2.84	2.39	0.35	0.08	0.16	0.95
2 TC + ½ RR	3.71	1.63	0.33	0.06	0.24	0.69
2 TC + FRR	5.47	1.53	0.42	0.09	1.45	2.38
4 TC	3.21	1.23	0.40	0.02	1.01	0.59
4 TC + ¼ RR	4.86	1.65	0.46	0.06	0.19	0.82
4 TC + ½ RR	4.24	1.58	0.38	0.02	3.52	0.68
4 TC + FRR	4.76	1.44	0.51	0.02	0.22	0.94

TC = ton ha^{-1} NSC
RR = recommended rate
FRR= Full recommended rate

which was not statistically different from other treatments in 2010 (Table 4.34). Effect of NPK and NSC interaction was not significant in both years. However, highest K uptake was recorded from 4 TC + ½ RR (3.52 g kg^{-1}) in 2009 and 2 TC + FRR (2.38 g kg^{-1}) in 2010 (Table 4.35).

It is known that inorganic fertilizers release their nutrients rather fast for plants to utilize. This accounts for the observed high value of the N content of crops fertilized with NPK fertilizer. N leaching and gaseous emissions have been reported lowest with reduced N application (Guo *et al.*, 2007). NSC which released a higher percentage of its initial nutrients slowly had higher plant nutrient contents in 2009. This is consistent with reports in literature (Palmer, 1995). The non significant treatment effect on nutrient uptake could be attributed to the complex problem of soil fertility management (Nambiar, 1994). This could only be examined by long-term field trials as it takes time for the crops, crop rotations, fertilizers and manures to have a reasonable impact on soil fertility (Ravankar *et al*., 2001).

In 2010, analysis showed that N concentrations were lower in the control than all the other treatments. The data also showed that plant N contents decreased with years of cropping in the control and treatment plots; it signifies low soil fertility. This could be inferred from the shortcomings of monocropping since crops would be susceptible to the same pests and diseases as was experienced in the second cropping season when stem borer infestation was on the increase. Also, the soil would be mined of the same mineral constituents whose replacement with either organic or inorganic amendments might not be commensurate with plant uptake. However, since the combined analysis showed that lower rates of CF were superior to higher rates (Tables 4.34 and 4.35), it indicates that for short term sorghum production programmes, the combined use of lower rates CF (¼RR) and NSC (1 TC) would be superior to either of the amendments used alone.

4.5.4 Effect of NSC and CF on selected soil properties.

The effect of sixteen treatments employed in this study on soil physico-chemical properties are presented in Table 4.36a and b, and the interactive effects in Table 4.36c and d.

4.5.4.1 pH in water and 0.1M $CaCl_2$

Effect of the treatments singly and combined on soil pH in water was not significant at both the 0.01 and 0.05 level of probability at the end of experiment in 2009 and 2010. Also, application of CF alone in both years decreased soil pH (Table 4.36a) although values recorded were not statistically different with respect to treatments. Soil pH_{water} at planting were significant in both years but the effect was not significant even when F-value at the different sampling periods across growth stage was considered. F-value decreased across the sampling periods in 2009 and 2010 for the CF treatments alone (Appendix).

The effect of NSC on soil pH in water was also not significant and statistically different across the different inclusion levels. However, F-value increased from planting to side-dressing before eventually decreasing at harvest in both years. The decrease at harvest from NSC-amended treatments could be attributed to decomposition-mineralization process prior to nutrient uptake by the sorghum plants. Also, the non significant effect observed with respect to NSC treatment could be attributed to the ability of neem seed cake to neutralize acidic soils by a unique property of calcium mining (Hedge *et al*., 1995).

The pH in calcium chloride was less than that of water in both years and not significantly different with respect to treatments. Also, there were no significant or statistical differences across the NPK or NSC treatments alone in both years. In 2009 and 2010, pH_{CaCl2} decreased

Table 4.36a: Main effects of NSC and CF on selected soil properties

Treatment	pH_{water}			pH_{CaCl2}			Organic carbon g kg^{-1}			Available Phosphorus mg kg^{-1}			Total Nitrogen kg ha^{-1}		
	2009	2010	combined	2009	2010	combined	2009	2010	combined	2009	2010	combined	2009	2010	combined
NPK kg ha^{-1} (N)															
0	5.81	4.90	5.35	5.23	4.44	4.84	5.56	5.15	5.36	13.71	12.54	13.13	0.76	0.62	0.69
1/4RR	5.79	4.89	5.37	5.11	4.42	4.76	5.74	5.52	5.63	14.44	15.31	14.98	0.57	0.67	0.62
1/2RR	5.82	4.94	5.38	5.09	4.38	4.74	5.66	5.42	5.54	13.85	12.40	13.13	0.67	0.66	0.67
FRR	5.79	4.86	5.33	5.20	4.38	4.79	6.27	5.45	5.86	15.17	15.02	15.09	0.62	0.75	0.68
SE ±	0.02	0.01	0.05	0.01	0.003	0.03	0.01	0.004	0.03	3.56	4.01	0.78	0.04	0.00	0.06
NSC t ha^{-1} (S)															
0 TC	5.78	4.89	5.33	5.19	4.40	4.80	4.83b	4.81b	4.82b	15.02ab	13.13	14.07	0.60	0.69	0.64
1 TC	5.75	4.88	5.32	5.18	4.40	4.79	5.52ab	5.00ab	5.26b	15.60a	14.22	14.91	0.69	0.67	0.68
2 TC	5.88	4.89	5.38	5.15	4.41	4.78	5.80ab	5.64ab	5.72ab	12.40b	12.62	12.51	0.54	0.70	0.62
4 TC	5.81	4.93	5.37	5.11	4.42	4.76	7.08a	6.07a	6.58a	14.15ab	15.53	14.84	0.79	0.63	0.71
SE ±	0.02	0.01	0.05	0.01	0.003	0.03	0.01	0.004	0.03	3.56	4.01	0.78	0.04	0.00	0.06
Interaction (N × S)															
N x S	NS	NS	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS

NB: Means followed by the same letter (s) within the same column are not significantly different at $p < 0.05$
NS= not significant
TC = ton ha^{-1} NSC
RR = recommended rate
FRR = full recommended rate

Table 4.36b: Main effects of NSC and CF on selected soil properties

Treatment	Exchangeable Potassium cmol kg^{-1}			Exchangeable Magnesium cmol kg^{-1}			Exchangeable Sodium cmol kg^{-1}			Exchangeable Calcium Cmol kg^{-1}			Exchangeable Acidity cmol kg^{-1}		
	2009	2010	combined	2009	2010	combined	2009	2010	combined	2009	2010	combined	2009	2010	combined
NPK kg ha^{-1} (N)															
0	0.10	0.07b	0.08	0.41	0.84	0.62	0.25	0.07	0.16	2.10	3.12b	2.61	0.39	0.27ab	0.33
¼ RR	0.11	0.07ab	0.09	0.40	1.11	0.76	0.29	0.08	0.18	2.18	3.85a	3.01	0.44	0.29ab	0.37
½ RR	0.18	0.09a	0.13	0.40	1.02	0.71	0.25	0.09	0.17	2.02	3.63ab	2.82	0.43	0.33a	0.38
FRR	0.11	0.06b	0.08	0.41	1.05	0.73	0.25	0.06	0.16	2.01	3.33ab	2.67	0.41	0.26b	0.33
SE ±	0.004	0.00	0.02	0.00	0.09	0.08	0.002	0.001	0.01	0.05	0.16	0.13	0.004	0.001	0.02
NSC t ha^{-1} (S)															
0 TC	0.10	0.05b	0.08	0.39	1.16	0.77	0.26	0.05	0.15	2.08	3.50	2.79	0.43	0.28	0.36
1 TC	0.10	0.09a	0.09	0.39	0.72	0.56	0.26	0.09	0.17	1.94	3.20	2.57	0.44	0.31	0.38
2 TC	0.12	0.08a	0.10	0.43	1.13	0.78	0.28	0.08	0.18	2.13	3.60	2.87	0.42	0.28	0.35
4 TC	0.17	0.08a	0.13	0.41	1.02	0.72	0.26	0.08	0.17	2.15	3.63	2.89	0.38	0.28	0.33
SE ±	0.004	0.00	0.02	0.00	0.09	0.08	0.002	0.001	0.01	0.05	0.16	0.13	0.004	0.001	0.02
Interaction (N × S)															
N x S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NB: Means followed by the same letter (s) within the same column are not significantly different at $p < 0.05$

NS= not significant

TC = ton ha^{-1} NSC

RR = recommended rate

FRR = full recommended rate

Table 4.36c: Interactive effects of NSC and CF on selected soil properties

Treatment	pH_{water}			pH_{CaCl2}			organic carbon g kg^{-1}			phosphorus mg kg^{-1}			nitrogen kg ha^{-1}		
	2009	2010	combined	2009	2010	combined	2009	2010	combined	2009	2010	combined	2009	2010	combined
Control	5.7	4.8	5.3	5.1	4.5	4.8	3.77	5.12	4.44	16.33	14.88	15.60	0.41	0.70	0.56
¼ RR	5.9	4.9	5.4	5.2	4.4	4.8	5.37	4.67	5.02	12.83	12.54	12.69	0.65	0.70	0.68
½ RR	5.9	5.0	5.5	5.4	4.5	4.9	6.08	5.95	6.01	12.25	9.63	10.94	0.53	0.58	0.56
FRR	5.7	4.9	5.3	5.2	4.4	4.8	7.03	4.86	5.95	13.42	13.13	13.27	1.46	0.47	0.97
1 TC	5.8	4.8	5.3	5.2	4.3	4.8	5.76	5.24	5.5	15.17	15.46	15.31	0.53	0.76	0.64
1 TC + ¼ RR	5.6	4.9	5.3	5.1	4.5	4.8	6.39	4.92	5.66	14.00	15.75	14.88	0.76	0.64	0.70
1 TC + ½ RR	5.9	4.9	5.4	5.0	4.4	4.7	5.69	4.67	5.18	12.83	13.13	12.98	0.53	0.64	0.59
1 TC + FRR	5.8	4.9	5.4	5.1	4.5	4.8	5.12	7.23	6.17	15.75	17.79	16.77	0.47	0.64	0.56
2 TC	5.8	4.9	5.4	5.2	4.4	4.8	5.69	4.48	5.08	14.00	11.08	12.54	0.64	0.59	0.62
2 TC + ¼ RR	5.6	4.8	5.2	5.1	4.4	4.8	3.96	5.18	4.57	16.92	12.83	14.88	0.76	0.64	0.70
2 TC + ½ RR	5.8	4.9	5.4	5.0	4.4	4.7	6.14	6.52	6.33	11.67	12.54	12.10	0.59	0.70	0.65
2 TC + FRR	6.0	5.1	5.6	5.0	4.3	4.7	6.84	5.5	6.17	12.83	13.13	12.98	0.70	0.70	0.70
4 TC	5.8	5.0	5.4	5.3	4.4	4.9	4.09	4.41	4.25	14.58	11.08	12.83	0.82	0.70	0.76
4 TC + ¼ RR	5.9	4.9	5.4	5.3	4.4	4.8	6.33	5.24	5.79	18.67	15.75	17.21	0.59	0.70	0.65
4 TC + ½ RR	5.9	4.7	5.3	5.2	4.4	4.8	5.31	5.44	5.37	12.83	15.17	14.00	0.53	0.88	0.70
4 TC + FRR	5.6	4.8	5.2	5.0	4.4	4.7	9.34	6.71	8.02	14.58	18.08	16.33	0.53	0.70	0.62
SE ±	0.06	0.03	0.04	0.05	0.02	0.03	0.05	0.03	0.03	0.88	0.93	0.68	0.09	0.04	0.05

TC = ton ha^{-1} NSC
RR = recommended rate
FRR = full recommended rate

Table 4.36d: Interactive effects of NSC and CF on selected soil properties

Treatment	Exchangeable potassium cmol kg^{-1}			Exchangeable magnesium cmol kg^{-1}			Exchangeable sodium cmol kg^{-1}			Exchangeable calcium cmol kg^{-1}			Exchangeable acidity cmol kg^{-1}		
	2009	2010	combined	2009	2010	combined	2009	2010	combined	2009	2010	combined	2009	2010	combined
Control	0.08	0.04	0.06	0.41	1.20	0.81	0.24	0.04	0.15	2.07	3.33	2.70	0.47	0.27	0.37
¼ RR	0.11	0.09	0.1	0.40	0.63	0.52	0.28	0.12	0.20	2.07	2.80	2.43	0.33	0.30	0.32
½ RR	0.09	0.08	0.09	0.46	0.40	0.43	0.26	0.08	0.17	2.07	2.87	2.47	0.40	0.27	0.33
FRR	0.12	0.06	0.09	0.35	1.13	0.74	0.24	0.05	0.14	2.20	3.47	2.83	0.37	0.23	0.30
1 TC	0.11	0.06	0.09	0.42	1.03	0.73	0.29	0.04	0.17	2.37	3.70	3.03	0.40	0.30	0.35
1 TC + ¼ RR	0.11	0.07	0.09	0.40	0.82	0.61	0.25	0.07	0.16	1.83	3.40	2.62	0.50	0.30	0.40
1 TC + ½ RR	0.15	0.06	0.11	0.38	1.45	0.92	0.36	0.12	0.24	2.40	4.10	3.25	0.43	0.23	0.33
1 TC + FRR	0.09	0.09	0.09	0.40	1.13	0.77	0.27	0.07	0.17	2.10	4.20	3.15	0.43	0.33	0.38
2 TC	0.08	0.05	0.07	0.36	1.40	0.88	0.23	0.07	0.15	1.93	3.87	2.90	0.43	0.30	0.37
2 TC + ¼ RR	0.10	0.13	0.12	0.36	0.38	0.37	0.24	0.09	0.16	1.97	3.20	2.58	0.53	0.33	0.43
2 TC + ½ RR	0.14	0.1	0.12	0.45	1.68	1.07	0.26	0.06	0.16	2.03	4.23	3.13	0.47	0.37	0.42
2 TC + FRR	0.38	0.08	0.23	0.44	0.62	0.53	0.28	0.14	0.21	2.13	3.20	2.67	0.30	0.30	0.30
4 TC	0.13	0.05	0.09	0.36	1.02	0.69	0.26	0.06	0.16	1.93	3.10	2.52	0.43	0.27	0.35
4 TC + ¼ RR	0.09	0.05	0.07	0.41	1.03	0.72	0.26	0.09	0.17	1.90	3.40	2.65	0.40	0.30	0.35
4 TC + ½ RR	0.09	0.05	0.07	0.42	0.97	0.69	0.22	0.05	0.14	2.03	3.20	2.62	0.37	0.23	0.30
4 TC + FRR	0.11	0.07	0.09	0.45	1.20	0.82	0.26	0.05	0.15	2.17	3.63	2.90	0.43	0.23	0.33
SE ±	0.03	0.01	0.02	0.02	0.14	0.07	0.02	0.01	0.01	0.10	0.19	0.12	0.03	0.02	0.02

TC = ton ha^{-1} NSC
RR = recommended rate
FRR = full recommended rate

with increase in nutrient content of CF treatment plots alone (Table 4.36a). For NSC-amended plots, the control was slightly higher than the organic treatments in 2009. The trend was control > 1 NSC > 2 NSC > 4 NSC in 2009 while in the year 2010, the pH_{CaCl2} increased with increase in NSC.

The decrease in pH over years in CF amended plots was consistent with acid producing nature of fertilizer due to its nitrogen and phosphorus content (Pestov, 1994). This implies that continous use of CF will increase soil acidity which will result in crop yield reduction. The remarkable decrease over years corroborates with the submission of Bache and Heathcote (1969) that sandy parent materials and low organic matter content have rendered the savanna soils low in buffering capacity, hence significant changes in the soil pH. The reduction in soil pH following incorporation of NSC could be due to its high sulphur content (not determined). Organic residues with high amount of S could reduce soil pH as a result of the addition of sulphate thereby increasing the acidity produced by oxidation of N during decomposition (Obatolu and Agboola, 1993; Van Der Meersh *et al*., 1993).

4.5.4.2 Organic Carbon

Effect of inorganic fertilizer on soil organic carbon was not significant ($P < 0.05$) at the end of experiment in 2009 and 2010 in the sole CF plots. There was a decrease in the organic carbon content in 2009 and 2010 (Table 4.36a). In 2009, FRR gave the highest organic carbon content (6.27 g kg^{-1}) while control recorded the least (5.56 g kg^{-1}). In 2010, ¼ RR recorded the highest (5.52 g kg^{-1}) while control had the least organic carbon content (5.15 g kg^{-1}) (Table 4.36a) which were not statistically different in both years.

The use of NSC as an organic amendment had significant effect on organic matter in the soil in both years. 4 TC had the highest (7.08 g kg^{-1} in 2009 and 6.07 g kg^{-1} in 2010) while control recorded the least (4.83 g kg^{-1} and 4.81 g kg^{-1}) in 2009 and 2010 respectively which were statistically different from other treatments (Table 4.36a). Organic carbon increased with increasing levels of NSC. The low OC in 2010 compared with 2009 conforms to the findings of Papendick (1994) who reported a decrease in soil organic matter levels following cultivation. However, Solomon *et* al. (2008) and Garba (2010) reported non-significant effects on OC in field trials conducted.

4.5.4.3 Available Phosphorus

Results of the soil chemical analysis showed that available phosphorus at the end of the experiment in both years was not significantly influenced by the treatments (Table 4.36a) in the sole NPK plots. Soil available P in 2009 was slightly higher in FRR (15.17 mg kg^{-1}) than at other rates while control (13.71 mg kg^{-1}) recorded the least mean P concentration. But, the differences were not statistically significant at both the 0.01 and 0.05 levels of probability. In 2010, ¼ RR gave the highest concentration (15.31 mg kg^{-1}) while ½ RR recorded the least P concentration (12.40 mg kg^{-1}). However, application of CF treatments did not show a discernible pattern on P content in the soil after cropping in both years.

NSC amended plots alone in 2009 were significantly influenced by the treatments (Table 4.36a). 1 TC gave the highest P concentration (15.60 mg kg^{-1}) while the control gave the least P concentration (12.40 mg kg^{-1}). However, in 2010, there was no significant difference in P concentration with treatments. 4 TC recorded the highest (15.33 mg kg^{-1}) while 2 TC had the least P concentration (12.62 mg kg^{-1}) (Table 4.36a). The non significant difference between control and treatment plots in 2010 could be attributed to the ability of the soil to maintain an

equilibrium concentration of solution P with the adsorbed P; since solution P was rapidly replenished by P from labile inorganic P (P_i) minerals and by biochemical mineralization of labile organic P (P_0) (Van Noordwijk *et al*., 2004). This was probably due to the effect of temperature in 2010 (Acquaye, 1963). Black and Goring (1953) reported that self fertilization, arising from return of organic P in litter and its subsequent mineralization, constitutes the primary means of increasing P availability from low level usually found in parent materials. This sort of turnover could be substantial in tropical soils, especially in regions where rains are preceded by a drought as was experienced in the course of the present study.

4.5.4.4 Total Nitrogen

The analysis of variance (ANOVA) for total nitrogen (TN) showed that there were no significant differences on total N irrespective of treatment and sampling date; i. e. before NSC incorporation, planting, heading and harvest. However, there was a slight decrease in the control treatment in 2009 to 2010. There was an increase in the CF amended plot over years (Table 4.36a) except ½ RR which recorded a slight decrease (0.67 kg ha^{-1} in 2009 to 0.66 kg ha^{-1} in 2010). In 2009, CF amendment had a positive effect on total soil N evident from the increase in F-value from planting to harvest, although not significant both in 2009 and 2010. The positive effect, though not significant, could be attributed to high residual mineral-N (0.473 g kg^{-1}) from cowpea that preceded sorghum in 2009.

NSC as an organic amendment had a positive effect on TN although this was not high enough to have a significant effect on soil quality index in both years. The decrease in F-value in 2009 from side-dressing to harvest could be attributed to inadequate moisture and temperature in the late season in spite of the slow growth rate and consequently, low soil N uptake by the plants that were expected (Wedin and Tilman, 1990). Giller and Wilson (1991) reported that in the

absence of disturbance, which was the situation from side-dressing to harvest in this trial, virtually the entire mineral-N in soil is present as ammonium ion, and nitrification, which was substantially lost through leaching of nitrate. Also, this was a period of high nutrient demand by the crop (grain filling) aside the loss of more labile fraction before side-dressing leaving behind the recalcitrant fraction. The increase from planting to side-dressing in the same year could be due to the dramatic release of available soil N two or three months later in acid savanna soil emanating from disturbance of the soil due to cultivation (Sylvester-Bradley *et al*., 1988).

However in 2010, the effect of NSC on soil TN was not significant. The positive effect in 2010 could be attributed to increase in the relative quantity of N in NSC after decomposition; as a result of nitrogenous complexes which are rendered resistant to further rapid decomposition (Millar *et al*., 1965). Soil TN was highest for control treatment (0.76 kg ha^{-1}) in 2009 while ¼ RR had the least (0.57 kg ha^{-1}) than at other rates but the differences were not significant. In 2010, on the other hand, FRR (0.75 kg ha^{-1}) was slightly higher than the other rates including the control which had the least (0.62 kg ha^{-1}) although the difference were not significant at both the 0.01 and 0.05 level of probability.

In 2009, 4 TC (0.79 kg ha^{-1}) was slightly higher than the other sole NSC levels including the control (0.60 kg ha^{-1}). While, in 2010, 2 TC gave the highest N concentration (0.70 kg ha^{-1}) and 4 TC (0.63 kg ha^{-1}) had the least (Table 4.36a). The non significant differences with treatments over years could be attributed to the slow decomposition of NSC such that absorbed plant nutrients were not enough to warrant a significant change in the soil. There were no significant interactions between treatments for soil TN concentrations, indicating that all NSC treatments responded to NPK fertilizer about equally.

4.5.4.5 Exchangeable potassium

At the end of experiment in 2009, sole CF and NSC treatments did not significantly affect exchangeable K contents in soil (Table 4.36b). However, main effect from sole NSC treatments exhibited a positive effect on soil exchangeable K for the three sampling periods evident from increase in F-value across the periods, although this was not high enough to be significant. For CF treatments, result of ½ RR was slightly higher (0.18 cmol kg^{-1}) than others but not statistically different from other treatments including the control which had the least (0.10 cmol kg^{-1}) exchangeable K concentration in 2009 (Table 4.36b). 4 TC recorded the highest (0.17 cmol kg^{-1}) K content while control and 1 TC both had the least (0.10 cmol kg^{-1}) K concentration.

In 2010, exchangeable K for sole CF and NSC treatment plots were significant at the 0.01 level of probability. Result of 1 TC was slightly higher (0.09 cmol kg^{-1}) than others but not statistically different (Table 4.36b). However, control recorded the least (0.05 cmol kg^{-1}) which was statistically different from the other NSC treatments (Table 4.36b). There were no significant interactions between treatments for soil K concentrations, indicating that all NSC treatments responded to NPK fertilizer about equally.

4.5.4.6 Exchangeable magnesium

No significant difference was observed in exchangeable magnesium among treatments over years. In 2009, control and FRR had higher concentration (0.41 cmol kg^{-1}) while ½ and ¼ RR had the least (0.40 cmol kg^{-1}). In 2010, magnesium content after cropping decreased with increasing CF treatments (Table 4.36b). The highest content (1.11 cmol kg^{-1}) was recorded from ¼ RR while the least (0.84 cmol kg^{-1}) was obtained from control. The increase in exchangeable Mg in 2010 from CF treatments could be attributed to the high rate of nitrate

uptake favoured by low pH conditions. When plants absorb high levels of nitrate, there is an increase in organic anion synthesis within the plant coupled with a corresponding increase in the accumulation of inorganic cations (calcium, magnesium, potassium) (Tisdale *et al*., 2003).

Similarly, there was no significant effect on exchangeable Mg concentration with treatments in sole NSC plots in both years of the experiment. 2 TC recorded the highest Mg concentration (0.43 cmol kg^{-1}) in 2009 while control and 1 TC gave the least concentration (0.39 cmol kg^{-1}). In 2010, control gave the highest concentration (1.16 cmol kg^{-1}) while 1 TC recorded the least (0.72 cmol kg^{-1}). Effect of CF and NSC interaction was not significant in both years (Table 4.36b).

4.5.4.7 Exchangeable sodium

At the end of experiment in 2009 and 2010, main effects of the treatments did not significantly affect exchangeable sodium in the soil. Treatment plots were not significantly different in their exchangeable sodium across the years (Table 4.36b). Exchangeable sodium at planting in 2009 was highly significant ($P < 0.01$). In spite of the high significance at planting in 2009 from CF treatments, the effect was negative as the trend decreased drastically across the sampling periods (F-value). In 2010 on the other hand, the trend was not consistent although the exchangeable Na decreased with increase in NPK fertilizer: ½ RR (0.09 cmol kg^{-1}) > ¼ RR (0.08 cmol kg^{-1}) > FRR (0.06 cmol kg^{-1}) (Table 4.36b) while the control recorded a slightly higher value (0.07 cmol kg^{-1}) than FRR.

In sole NSC treatments, there were no significant differences with treatments in both years. Also, there was a sharp decrease in sodium concentration across the two years. 2 TC recorded the highest (0.28 cmol kg^{-1}) concentration in 2009 while 1 TC and 4 TC both gave same value

with the control which was the least (0.26 cmol kg^{-1}). There were no significant interactions between treatments for soil Na concentrations.

4.5.4.8 Exchangeable calcium

Sole CF treatments had a positive effect on the soil chemical property in 2010. Exchangeable Ca decreased with increasing CF treatments in both years. The highest exchangeable Ca (3.85 cmol kg^{-1}) was obtained from ¼ RR treatments which was statistically different from the control (3.12 cmol kg^{-1}) which has the least content but similar to ½ RR (3.63 cmol kg^{-1}) and FRR (3.33 cmol kg^{-1}) which were statistically the same in 2010 (Table 4.36b). In the NSC amended plots, 4 TC (3.63 cmol kg^{-1}) was slightly higher than the other treatments in both years (Table 4.36b), which were not statistically different at 0.01 and 0.05 level of probability. Also, exchangeable Ca increased with increase in the organic amendments: 4 NSC > 2 NSC > 1 NSC (Table 4.36b). The highest exchangeable Ca (3.63 cmol kg^{-1}) was obtained from 4 TC while 1 TC recorded the least concentration (3.20 cmol kg^{-1}). There were no significant interactions between treatments for soil Ca concentrations.

The increase in exchangeable Ca in 2010 from CF treatments could be attributed to high rate of nitrate uptake favoured at low pH conditions. When plants adsorb high levels of nitrate, there is an increase in organic origin anion synthesis within the plant coupled with a corresponding increase in the accumulation of inorganic cations (calcium, magnesium, potassium) (Tisdale *et al*., 2003).

4.5.4.9 Exchangeable Acidity

There was no significant difference in exchangeable acidity in 2009 at both 0.01 and 0.05 level of probability. Exchangeable acidity decreased with increase in CF treatments (Table 4.36b). ¼

RR (0.44 cmol kg^{-1}) recorded the highest while control had the least (0.39 cmol kg^{-1}) in 2009. In 2010, no discernible pattern was followed but ½ RR (0.33 cmol kg^{-1}) gave the highest which were statistically different from FRR (0.26 cmol kg^{-1}) that had the least. In sole NSC treatments, exchangeable acidity decreased with increasing rates. In 2009, 1 TC recorded the highest (0.44 cmol kg^{-1}) EA value while 4 TC had the least (0.38 cmol kg^{-1}) which was lower than control (0.43 cmol kg^{-1}). Also, 1 TC (0.31 cmol kg^{-1}) recorded the highest EA while control and the other treatments (0.28 cmol kg^{-1}) had the least which were statistically at par in 2010 (Table 4.36b).

4.5.5 Inter-relationships of soil chemical properties in the field following NSC and NPK incorporation in 2009 and 2010 by factor analysis

Factor analysis (FA), using principal components extraction and varimax rotation was performed on standardized values of 11 measured field soil properties representing soil chemical/ nutrient indicators with each variables having a zero mean and unit variance with total variance = number of variables (Garson, 2007) in 2009 and 2010.

4.5.5.1 Principal component analysis of selected soil properties in the field following NSC and NPK incorporation in 2009 and 2010

The results presented in Table 4.37 showed that four factors were extracted in 2009. Factor 1 explained 21% of the variance in the original variables and factor 2 explained an additional 20% of the variance while factor 3 and 4 explained 13% each of the variance in the original variables respectively. In 2010 on the other hand, five factors were extracted (Table 4.37). Factor 1

Table 4.37: Eigenvalue, proportion and cummulative variance explained by factor analysis using correlation matrix of 11 soil properties in 2009 and 2010 on the field.

	← 2009 →			← 2010 →		
		← % →			← % →	
Component	Eigenvalue	Proportion	Cummulative	Eigenvalue	Proportion	Cummulative
1	2.320	21.095	21.095	2.886	26.239	26.239
2	2.183	19.844	40.939	1.803	16.390	42.629
3	1.389	12.630	53.568	1.429	12.995	55.623
4	1.384	12.583	66.151	1.374	12.495	68.118
5				1.262	11.472	79.591

explained 26% of the variance in the original variables and factor 2 explained an additional 16% of the variance while factor 3, 4 and 5 explained 13%, 12% and 11% of the variance in the original variables respectively. The factor components (FCs) with eigenvalues > 1 were retained, since eigenvalues < 1 indicated the factor could explain less variance than an additional soil property. Eigenvalues from the correlation analysis indicated that the first four FCs accounted for 66% of the variance of soil properties standardized value (Table 4.37) in 2009 while the first five FCs accounted for 80% of the variance of soil properties standardized value in 2010.

In 2009, the FC 1 explained 21% which included exchangeable calcium, exchangeable magnesium and effective cation exchange capacity (ECEC) (communality estimates varied between 0.62 and 0.89 for different variables in 2009) as the major contributing variables (Table 4.38). The FC 2 accounted for 20% which included pH_{water}, exchangeable K, Na and available P (communality estimates varied between 0.48 and 0.81) as the major contributing variables (Table 4.38). The FC 3 and FC 4 both explained 13% of the total variance which included exchangeable acidity (EA) and pH_{CaCl2} in FC 3, and organic carbon (OC) and nitrogen in FC 4 (communality estimates for EA = 0.53 and for pH_{CaCl2} = 0.64 from FC 3 whereas FC 4 had communality estimates for OC = 0.53 and nitrogen = 0.76).

In 2010, the FC 1 explained 26% which included exchangeable calcium, exchangeable magnesium and effective cation exchange capacity (ECEC) (communality estimates > 0.90) as the major contributing variables (Table 4.38). The FC 2 accounted for 16% which included pH_{water}, exchangeable acidity and available P (communality estimates varied between 0.61 and 0.82) as the major contributing variables (Table 4.38). The FC 3 and FC 4 both explained 13% of the total variance which included exchangeable K and Na (communality estimate for K = 0.80 and for Na = 0.68) in FC 3, while FC 4 included pH_{CaCl2} and organic carbon (OC) (communality

Table 4.38: Proportion of variance using varimax rotation and kaiser normalized, and communality estimates for 11 soil properties (principal component method) in 2009 and 2010 on the field.

	FC 1		FC 2		FC 3		FC 4		FC 5	
Soil properties	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
pH_{water}	0.043	0.316	**0.865**	**-0.669**	-0.193	0.449	-0.14	0.234		-0.108
pH_{CaCl2}	-0.141	0.138	0.003	-0.155	**-0.786**	-0.143	-0.036	**0.722**		-0.323
Exchangeable acidity	-0.4	-0.121	-0.155	**0.758**	**0.479**	0.146	-0.341	-0.082		-0.32
Organic carbon	0.339	-0.01	-0.144	0.216	0.053	0.481	**0.621**	**0.636**		0.423
Calcium	**0.873**	**0.901**	-0.099	0.3	0.119	-0.086	0.179	0.048		0.005
Magnesium	**0.654**	**0.946**	0.062	0.044	-0.351	-0.114	-0.252	0.041		0.039
Potassium	0.064	-0.142	**0.736**	0.322	0.146	**0.793**	0.169	0.127		-0.17
Sodium	0.207	0.282	**0.641**	0.044	0.384	**0.497**	-0.114	-0.475		-0.36
Available phosphorus	0.119	-0.251	**-0.608**	**0.629**	0.309	-0.199	-0.022	0.175		0.286
Nitrogen	-0.169	0.244	0.093	-0.12	-0.068	0.326	**0.849**	-0.353		**0.675**
Effective Cation Exchange Capacity	**0.862**	**0.964**	0.211	0.244	0.31	-0.074	0.054	0.024		-0.013

The rotation converged in 12 iterations. Factor scores of variables in bold letters indicate the major contributors in the group. FC – factor component

estimates for pH_{CaCl2} = 0.69 and for OC = 0.86). The FC 5 explained 11% of total variance which included nitrogen (communality estimates for N = 0.76) as the major contributing variable (Table 4.38).

In 2009, FA reduced 11 measured soil properties into four FC groups that explained 66% of the total variability. FC 1 was directly related to 'soil potential exchange capacity properties' which explained 21% of the total variance (Table 4.38) with a positive loading of exchangeable calcium, magnesium and ECEC explaining the major variation of exchange capacity of the treatment. The FC 2, named 'soil additional potential nutrients' explained 20% of variance with a positive loading from pH_{water}, exchangeable K and sodium and a negative loading from available P (Table 4.38). The positive loading from pH_{water} would have contributed to the loss of pH-dependent charges. Thus, the increase in pH with increase in treatments resulted in more positively charged ions in the soil; evident from the high positive loading from K and Na, and the negative loading from available P. FC 3, called 'soil acidifying properties' explained 13% of the variance had positive loading from EA and a negative loading for pH_{CaCl2}. However, this acidifying effect favoured the release of available P, evident from the positive loading in FC 3. The FC 4 called 'organic properties' explained 13% of the variance had positive loading from organic carbon and nitrogen.

In 2010, FA reduced the 11 measured soil properties into five FC groups that explained 80% of the total variability (Table 4.37). FC 1 was directly related to 'soil potential exchange capacity properties', which explained 26% of the total variance (Table 4.37). The FC 2 named, 'soil acidifying properties' explained 16% of the total variance (communality estimates was between 0.61 to 0.82 for different variables) as the major contributing variables, with positive loadings for EA (0.76) and available P (0.63), and a negative loading for pH_{water} (-0.67) (Table 4.38). The

FC 3, called 'soil additional potential nutrients' explained 13% of the total variance which included Na and K (communality estimates for Na = 0.68 and for K = 0.80) as the major contributing variables. FC 4 was the 'organic potential properties' which included SOC and pH_{CaCl2} explained 12% of the total variable (communality estimates for pH_{CaCl2} = 0.69 and for OC = 0.88) while FC 5 was called the 'soil highly potential nutrient properties' which included nitrogen explained 11% of the total variance (communality estimate for N = 0.76) as the major contributing variable (Table 4.38).

The 'soil potential exchange capacity' has significant influence on acidifying capacity and nutrient availability. Significant highest positive and negative inter-relationships were observed between ECEC, Ca and Mg, and available P. SOM and N influenced water holding capacity and nutrients in soil system, which was essential for sorghum production. Soil N influenced early growth of sorghum in 2009 whereas inherently low soil N status in 2010 allowed for a clear manifestation of treatment effect. Thus, NSC being a slow nutrient releasing organic amendment had plants with an initial slow growth but the two weeks incorporation was adequate as it synchronized nutrient release later in the year with period of optimum uptake (grain filling) by the sorghum plants.

The dominant factor in assessing soil quality varied with N concentration. Soil pH and EA were the most discriminating factor in FC 2 which influenced biomass yield and return of biomass to the soil (nutrient availability). However, NSC did not acidify the soil to the same degree under field conditions as it did in the laboratory and greenhouse controlled-system studies because protons generated from the nitrification of NH_4-N were neutralized by OH^- ions released by plant roots when NO_3-N was absorbed (Mohammed, 2009; Boumann *et al*., 1995). Also, the production of carbonates of Ca and Mg evident from the positive loading of Ca and Mg in FC 5,

simultaneously with certain free organic acids formed tend to make the environment alkaline aside modification of acidity of the environment by plants themselves (Leeper, 1964).

4.6 Effect of NSC and CF on nutritional status of sorghum

4.6.1 Effect of NSC and CF on crude protein

Data on sorghum nutritional status as affected by neem seed cake and inorganic fertilizer in 2009, 2010 and combined are presented in Table 4.39 for main effects and 4.40 for interaction. In 2009, the least crude protein content (7.07%) was obtained from 1 TC treatment which was closely followed by the control (7.24%) while the 1 TC + FRR gave the highest crude protein content of 10% in the grain in the same year. In 2010 on the other hand, the least grain crude protein content (7.06%) was obtained from the 2 TC which was closely followed by the 1 TC + ¼ RR, 2 TC + FRR and 4 TC treatments (7.23%) while the control recorded the highest grain crude protein content of 8.44%. However, sorghum grain crude protein showed no significance difference among treatments – sole NPK, and NSC as well as interactions (NPK plus NSC) in 2010 year of the study. 1 TC + FRR and 4 TC + ½ RR gave the highest crude protein content (8.87%) in the two years combined.

Variation in the quantity and quality of crude protein in the grain sorghum for both years could be attributed to the level of nitrogen in the soil. The level of nitrogen fertilizer influences quantity and quality of protein in sorghum (Deosthale and Visweswar, 1972; Waggle *et al*., 1967). Also, Warsi and Wright (1973) noted that application of nitrogen fertilizer increased grain yield and protein. Higher protein in response to fertilizer nitrogen was mainly the result of increased accumulation of prolanin, a poor-quality protein, in the grain (Sawhney and Naik, 1969). Consequently, year 2009 which experienced higher residual mineral-N owing to the legume that preceded sorghum in the first year of the study recorded higher crude protein range

Table 4.39: Main effects of neem seed cake and inorganic fertilizer on grain sorghum crude protein and tannin contents

	2009	2010	Combined	2009	2010	Combined
Treatment	Crude protein (%)			Tannin (mg kg^{-1})		
NPK kg ha^{-1} (N)						
0	7.45b	7.57	7.51	0.42	0.92	0.67
¼ RR	8.36ab	7.70	8.03	0.41	0.94	0.68
½ RR	8.69ab	7.75	8.22	0.37	0.75	0.56
FRR	9.17a	7.44	8.31	0.38	0.81	0.60
SE ±	0.43	0.25	0.28	0.03	0.08	0.07
NSC t ha^{-1} (S)						
0 TC	8.18	7.79	7.99	0.45	0.99	0.72
1 TC	8.32	7.62	7.97	0.36	0.89	0.62
2 TC	8.10	7.49	7.79	0.38	0.81	0.60
4 TC	9.08	7.57	8.33	0.39	0.74	0.57
SE ±	0.43	0.25	0.28	0.04	0.08	0.06
Interaction (N × S)						
N × S	NS	NS	NS	NS	NS	NS

NB: Means followed by the same letter (s) within the same column are not significantly different at $p < 0.05$
NS=Not Significant
TC = ton ha^{-1} NSC
RR = recommended rate
FRR = full recommended rate

Table 4.40: Interaction effect of neem seed cake and inorganic fertilizer on grain sorghum crude protein and tannin contents

Treatment	Crude protein (%)			Tannin (mg kg^{-1})		
	2009	2010	Combined	2009	2010	Combined
Control	7.24	8.44	7.84	0.43	0.99	0.71
¼ RR	8.96	8.09	8.52	0.56	0.93	0.75
½ RR	8.26	7.4	7.83	0.39	1.11	0.75
FRR	8.27	7.23	7.75	0.41	0.93	0.67
1 TC	7.07	7.57	7.32	0.39	1.22	0.81
1 TC + ¼ RR	7.93	7.23	7.58	0.39	1.11	0.75
1 TC + ½ RR	8.27	7.91	8.09	0.37	0.58	0.47
1 TC + FRR	10.00	7.74	8.87	0.31	0.64	0.47
2 TC	7.75	7.06	7.40	0.41	0.81	0.61
2 TC + ¼ RR	7.75	7.75	7.75	0.33	0.76	0.54
2 TC + ½ RR	8.26	7.92	8.09	0.37	0.70	0.53
2 TC + FRR	8.62	7.23	7.92	0.41	0.99	0.70
4 TC	7.75	7.23	7.49	0.45	0.64	0.54
4 TC + ¼ RR	8.78	7.75	8.26	0.37	0.99	0.68
4 TC + ½ RR	9.98	7.75	8.87	0.37	0.64	0.50
4 TC + FRR	9.81	7.57	8.69	0.39	0.70	0.54
Mean	8.42	7.62	8.02	0.40	0.86	0.63
CV %	20.23	13.37	13.84	35.52	37.41	27.95
SE ±	0.48	0.18	0.28	0.03	0.08	0.04

TC = ton ha^{-1} NSC
RR = recommended rate
FRR = full recommended rate

(7.07 -9.99%) while 2010 with less residual mineral-N at planting which emanated from the sorghum following sorghum in the second year had less range (7.06 – 8.44%).

4.6.2 Effect of NSC and CF on tannin content

The 2010 grain sorghum recorded a higher tannin concentration in spite of the less crude protein for the year which was contrary to the submission of Myer *et al*. (1994) who reported that high tannin grain sorghum tended to have higher contents of crude protein, lysine, methionine and ether extract than low tannin grain sorghum. However, the level of tannin in the grain sorghum for both years and the combined fall within the range of 1.3 – 3.6% in very high tannin sorghum and 0.1 -0.7% in high tannin sorghum reported by the researchers (Myer *et al*., 1994). The increase in tannin content which was higher than 0.75% threshold level (Berkel and Voragen, 2002) for some treatment plots (Table 4.40) for the year 2010 could be attributed to solubilization occurring as the grain took up water or to synthesis of polyphenols during germination (Hamid, 2001). For the two years combined, tannin content ranged between 0.47 mg kg^{-1} – 0.81 mg kg^{-1}, thus, the variety used could be classified as containing low tannin except the 1 TC (0.81 mg kg^{-1}) which could be said to be moderate.

4.7 Correlation between growth, yield and yield components

The correlation coefficients between some plant indicators (leaf area index, leaf number, stem girth, plant height and dry matter yield); yield components such as days to 50% - panicle emergence and – flowering, harvest index, threshing percentage, 1000 grain weight, etc and sorghum performance (grain and stover yield, crude protein and tannin contents) for 2009, 2010 and the two years combined are shown in Table 4.41 (a to c). A large number of the associations were positive, however some were negatively correlated.

Table 4.41a: Matrix of Simple correlation coefficient between yield, yield components and some growth parameters in 2009 cropping season.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1.0000																
2	0.5957***	1.0000															
3	0.8040***	0.6457***	1.0000														
4	0.4541**	0.4491**	0.4916**	1.0000													
5	0.5565***	0.5743***	0.5562***	0.7109***	1.0000												
6	-0.3991**	-0.4513**	-0.5205***	-0.5379***	-0.6549***	1.0000											
7	-0.3699**	-0.4254**	-0.4756**	-0.5000**	-0.6244**	0.9790***	1.0000										
8	0.2508	0.3274*	0.2876*	0.2533	0.2498	-0.3517**	-0.3540**	1.0000									
9	0.3122*	0.3419*	0.2972*	0.3450**	0.2529	-0.3919**	-0.3944**	0.8952***	1.0000								
10	-0.0312	-0.0833	-0.0102	0.2165	0.2205	0.0195	0.0392	0.0272	-0.0177	1.0000							
11	0.3124*	0.3432*	0.2992*	0.3453*	0.2535	-0.3931**	-0.3947**	0.8979***	0.8979***	-0.0218	1.0000						
12	0.4375**	0.5218***	0.5458***	0.4213**	0.6441***	-0.6498***	-0.6533***	0.5290***	0.5291***	0.3381*	0.5259***	1.0000					
13	0.4471**	0.5280***	0.5417***	0.4384**	0.6216***	-0.6515***	-0.6549***	0.6328***	0.6508***	0.2988*	0.6481***	0.9886***	1.0000				
14	-0.0684	-0.1015	-0.2008	-0.0112	-0.2971*	0.1582	0.1545	0.4989**	0.5995***	-0.3335*	0.6024***	-0.3482*	-0.2050	1.0000			
15	-0.0382	-0.0999	-0.1165	0.2102	0.0472	-0.04792	-0.2624	-0.2542	0.07147	0.3526**	0.1610	0.3481*	0.0764	0.3059*	1.0000		
16	-0.2661	-0.2593	-0.2081	-0.3326*	-0.4469**	0.3314*	0.3434*	-0.2116	-0.3284*	0.1043	-0.3302*	-0.2499	-0.2822	-0.1609	-0.3356*	1.0000	
17	0.2722	0.0585	0.3136*	0.0169	-0.0017	-0.0485	-0.0920	0.2732	0.1360	0.0462	0.1353	0.2125	0.2143	-0.0446	-0.2818	-0.0017	1.0000

N. B: 1. Leaf area index
2. Leaf number
3. Dry matter yield
4. Stem girth
5. Plant height
6. Days to 50% panicle emergence
7. Days to 50% flowering
8. Weight per panicle
9. Grain weight per panicle
10. 1000 grain weight
11. Grain yield
12. Stover yield
13. Total dry matter yield
14. Harvest index
15. Threshing percentage
16. Tannin
17. Crude protein

*, ** and *** denote significant at $P \leq 0.05$, 0.01 and <0.0001 respectively.

Table 4.41b: Matrix of Simple correlation coefficient between yield, yield components and some growth parameters in 2010 cropping season.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1.0000																
2	0.5926***	1.0000															
3	0.9304***	0.8201***	1.0000														
4	0.7343***	0.5926***	0.7648***	1.0000													
5	0.7509***	0.5900***	0.7669***	0.9404***	1.0000												
6	-0.6051***	-0.4639***	-0.6371***	-0.8209***	-0.9012***	1.0000											
7	-0.6113***	-0.4656**	-0.6647***	-0.8392***	-0.9048***	0.9893***	1.0000										
8	0.4827**	0.4475***	0.3882**	0.6061***	0.5038**	-0.4137**	-0.4160**	1.0000									
9	0.3481*	0.3450*	0.3368*	0.5042**	0.3857**	-0.3491*	-0.3549*	0.8194***	1.0000								
10	-0.3107*	0.1955	0.3308*	0.4941**	0.4958**	-0.4059**	-0.4185**	0.1181	0.1447	1.0000							
11	0.3368*	0.3368*	0.3204*	0.4944*	0.3726**	-0.3328*	-0.3377*	0.8239***	0.9987***	0.1464	1.0000						
12	0.6667***	0.5526***	0.6231***	0.7186***	0.7290***	-0.6255***	-0.6527***	0.4516**	0.2634	0.3413*	0.2542	1.0000					
13	0.6821***	0.5721***	0.6381***	0.7506***	0.7463***	-0.6419***	-0.6687***	0.5321***	0.3713**	0.3461*	0.3627*	0.9935***	1.0000				
14	-0.3245*	-0.2320	-0.3046*	-0.2876*	-0.3949**	0.3616*	0.3664*	0.1937	0.4898**	-0.1896	0.4991**	-0.6709***	-0.5877***	1.0000			
15	-02008	-0.1416	-0.0761	-0.1166	-0.1544	-0.0604	0.0604	-0.2050	0.3816**	0.0321	0.3746**	-0.2899*	-0.2353	0.5208***	1.0000		
16	-0.2012	-0.0848	-0.2472	-0.3054*	-0.3054*	0.2350	0.2160	-0.0758	-0.0737	-0.2869*	-0.0830	-0.1396	-0.1443	0.1148	0.0083	1.0000	
17	- 0.0349	-0.0361	-0.0450	-0.1188	-0.1188	0.0523	0.0580	-0.1763	-0.1773	-0.2558	-0.1696	-0.0406	-0.0590	-0.0939	-0.0006	-0.2186	1.0000

N. B: 1. Leaf area index
2. Leaf number
3. Dry matter yield
4. Stem girth
5. Plant height
6. Days to 50% panicle emergence
7. Days to 50% flowering
8. Weight per panicle
9. Grain weight per panicle
10. 1000 grain weight
11. Grain yield
12. Stover yield
13. Total dry matter yield
14. Harvest index
15. Threshing percentage
16. Tannin
17. Crude protein

*, ** and *** denote significant at $P \leq 0.05$, 0.01 and <0.0001 respectively.

Table 4.41c: Matrix of Simple correlation coefficient between yield, yield components and some growth parameters for the two years combined.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1.0000																
2	0.8383***	1.0000															
3	0.9007***	0.8503***	1.0000														
4	0.6942***	0.6345***	0.7154***	1.0000													
5	0.7283***	0.6422***	0.7215***	0.8794***	1.0000												
6	-0.1118	0.1255	-0.0244	-0.3230**	-0.4376***	1.0000											
7	-0.3300**	-0.1406	-0.2896**	-0.5507***	-0.6618***	0.9271***	1.0000										
8	0.5563***	0.7213***	0.6513***	0.5176	0.4655***	0.3502**	0.0556	1.0000									
9	0.5419***	0.7084***	0.6448***	0.5056***	0.4300***	0.3858***	0.0895	0.9675***	1.0000								
10	0.4685***	0.5841***	0.5696***	0.5328***	0.5126***	0.2938**	0.0113	0.6827***	0.6893***	1.0000							
11	0.5406***	0.7073***	0.6432***	0.5047***	0.4284***	0.3865***	0.0914	0.9682***	0.9999***	0.6877***	1.0000						
12	0.6474***	0.7820***	0.7562***	0.5957***	0.6154***	0.2560*	-0.0613	0.8669***	0.8634***	0.7725***	0.8617***	1.0000					
13	0.6425***	0.7848***	0.7524***	0.5924***	0.5972***	0.2815**	-0.0381	0.8993***	0.9013***	0.7735***	0.8999***	0.9967***	1.0000				
14	-0.1141	-0.0087	-0.0918	-0.1019	-0.2697**	0.3560**	0.3461**	0.3189**	0.3820***	0.0055	0.3853***	0.0857	-0.0124	1.0000			
15	0.2329*	0.4089***	0.3722**	0.2564**	0.1758	0.3903***	0.1746	0.5610***	0.6979***	0.5640***	0.6960***	0.5425***	0.5771***	0.4577***	1.0000		
16	-0.4609***	-0.5408***	-0.5499***	-0.4471***	-0.4672***	-0.2436*	-0.0063	-0.6264***	-0.6497***	-0.6214***	-0.6504***	-0.6468***	-0.6595***	-0.0839	-0.4972****	1.0000	
17	0.2488	0.1956	0.2962**	0.0605	0.0558	0.1525	0.0585	0.3149**	0.2698**	0.1699	0.2699**	0.2998**	0.3006**	-0.0047	0.1022	-0.2448*	1.0000

N. B: 1. Leaf area index
2. Leaf number
3. Dry matter yield
4. Stem girth
5. Plant height
6. Days to 50% panicle emergence
7. Days to 50% flowering
8. Weight per panicle
9. Grain weight per panicle
10. 1000 grain weight
11. Grain yield
12. Stover yield
13. Total dry matter yield
14. Harvest index
15. Threshing percentage
16. Tannin
17. Crude protein

*, ** and *** denote significant at $P \leq 0.05$, 0.01 and <0.0001 respectively.

Leaf area index

Leaf area index (LAI) and other plant indicators was positively and highly significant in 2009, 2010 and the two years combined. However, the relationship between LAI and the yield components were negative and significantly correlated for days to 50% panicle emergence r = -0.3991**, -0.6051*** in 2009 and 2010, respectively. Days to 50% flowering was negatively and highly significant, r = -0.3699**; -0.6113*** and -0.3300** in 2009, 2010 and the two years combined respectively. In the two years combined results (Table 4.41c), LAI correlated with weight per panicle (r = 0.5563***), grain weight per panicle (r = 0.5419***), 1000 grain weight (r = 0.4685***), grain yield (r = 0.5406***), stover yield (r = 0.6474***), threshing percentage (r = 0.2329*) and total dry matter yield (r = 0.6425***). LAI correlated positively and highly significantly with grain weight per panicle (r = 0.3122*, 0.3481*); grain yield (r = 0.3124*, r = 0.3368*); stover yield (r = 0.4375**, r = 0.6667***) and total dry matter yield (r =0.4471**, r = 0.6821***) in 2009 and 2010 respectively. LAI correlated negatively with HI (r = -0.3245*) in 2010. The relationship between LAI and plant height, stem girth, stover yield and grain yield observed in this study, agreed with the report of Garba (2010) who studied the response of maize to NSC.

Leaf number

Leaf number was positively and highly correlated with other plant indicators in 2009, 2010 and the two years combined (Table 4.41a-c). However, it was negatively and significantly correlated with days to 50% panicle emergence (r = -0.4513**, r = -0.4639***), days to 50% flowering (r = -0.4254**, r = -0.4656**) in 2009 and 2010 respectively. The analysis of the combined result showed that leaf number was positively and highly correlated with stem girth (0.6345***), plant height (0.6422***), 1000 grain weight (r = 0.5841***) and threshing percentage (r = 0.4089***).

Dry matter yield

Dry matter yield was related negatively with days to 50% panicle emergence (r = -0.5205***, r = -0.6371***) and days to 50% flowering (r = -0.4756**, r = -0.6647***) in 2009 and 2010 respectively, and days to 50% flowering (r = -0.2896**) in the combined. It was negatively correlated with 1000 grain weight (r = -0.0102); harvest index (r = -0.2008) and threshing percentage (r = -0.1165) in 2009. The relationship between dry matter yield and stem girth (r = 0.4916**, r = 0.0.7648*** and r = 0.7154***); plant height (r = 0.5562***, r = 0.7669*** and r = 0.7215***) were positively and highly significant in 2009, 2010 and the combined. The correlation between dry matter yield (DMY) and the yield components were generally significant, except 1000 grain weight, harvest index and threshing percentage; while days to 50% panicle emergence and flowering were negatively significant in 2009. In 2010, all the parameters determined significantly correlated with DMY except threshing percentage. The analysis of the combined data showed that the correlation of dry matter yield with the yield components were highly significant except days to 50% panicle emergence (r = -0.0244) and harvest index (r = -0.0918).

Grain yield

Grain yield was positively and highly significantly correlated with stover yield (r = 0.5259***), total dry matter yield (r = 0.6481***) and harvest index (r = 0.6024***) in 2009. The relationship between grain yield and threshing percentage was not significant in the same year. A similar trend was also observed in 2010, except the stover yield which was not significant (r = 0.2542). The combined analysis was however highly significant for grain yield and stover yield (r = 0.8617***), total dry matter yield (0.8999***), harvest index (0.3853***) and threshing percentage (r = 0.6960***). Non-significant and negative relationship existed between tannin concentration and LAI, leaf number, weight per panicle, stover yield and harvest index in 2009.

Grain yield and yield components reflect growing season conditions. Thus, negative and non significant correlation between 1000 grain weight and grain yield in 2009 probably indicated late season stress (Krieg and Lascano, 1990). This was also evident from the positive and highly significant grain weight per panicle which could be an index of plant stress during early growing season. Also, significant negative correlation between LAI and yield components implied that favourable conditions early in the growing season promoted tillering and increased LAI at the expense of grain yields (Bandaru *et al*., 2006). Richards (2000) reported that crops with greater leaf area at the beginning of the growing season yield better since they use radiation more effectively.

In 2010, grain yield was highly correlated with LAI but not with HI indicating that production of biomass was more important in yield attainment than partitioning of biomass to yield. This could be inferred from more photosynthetic assimilates in LAI in 2009 which yield more under potential condition. Such partitioning pattern resulted in higher grain yield due to a higher HI. Higher HI indicates a better partitioning of dry matter into reproductive organs. LAI also correlated with leaf number in both years, thus maintaining high green leaf number at the grain filling period. Borrell *et al*. (2000a) reported that leaf number is an important determinant of sorghum plant leaf area, since it sets the initial benchmark of green leaf area per plant. So, if a sorghum plant can maintain higher number of leaves at the grain filling period and as a consequent higher photosynthesis, it may yield more. This is especially the case where the carbohydrate is a main harvest component (Thomas and Smart 1993).This caused longer photosynthesis period and more contribution of green leaves to the grains. This explanation was supported by the significant correlation observed in 1000 grain weight. This corroborates the findings of researchers who emphasized on the important role of stay-green characteristic in

achieving high grain yield in sorghum (Borrell *et al*., 2000a and b). Significant correlation of LAI and plant height implied the key role of appropriate height to reach suitable yield.

From a physiological standpoint, there are two main approaches in order to achieve higher grain yields; that is, increase in harvest index (HI) and increase in dry matter accumulation (Specht *et al*., 1999). Grain yield of sorghum may also be described as a function of dry matter accumulation and the amount of the dry matter partitioned to the grain. Thus, lower and thicker height has direct relationship with HI and grain yield. Longer flowering period is an advantage for sorghum, because it provides the flexibility power for facing inappropriate condition. It means that plant can decrease the negative effect of stress in early flowering. So, longer flowering period in sorghum is one of the important characters to reach an appropriate grain yield. Thus, the negative correlation observed in 2009 for days to 50% flowering and grain yield implied that flowering period was not high enough for the crop to overcome the negative effect of stress during the growing period.

4.8 Fertilizer equivalence of neem seed cake

Fertilizer equivalencies; the specific amounts of an organic material that can have the same effect on crop yield as a certain amount of inorganic fertilizer (Mugendi *et al*., 2009) was estimated and presented in Tables 4.42 and 4.43 for 2009 and 2010 trials respectively. The high FE values of 145.32 and 163.41 obtained at 1 tonnes NSC application level for years 2009 and 2010 respectively, were the highest for both years.

Table 4.42: Sorghum grain yield (kg ha^{-1}) and fertilizer equivalencies (kg N ha^{-1}) at different levels of neem seed cake during the 2009 cropping season at Samaru.

NSC level	Grain yield (kg ha^{-1})	FE	% FE
1	3144.67	55.95	145.32
2	2461.09	undefined	undefined
4	3172.08	57.11	37.08

Table 4.43: Sorghum grain yield (kg ha^{-1}) and fertilizer equivalencies (kg N ha^{-1}) at different levels of neem seed cake during the 2010 cropping season at Samaru.

NSC level	Grain yield (kg ha^{-1})	FE	% FE
1	1367.10	87.23	163.41
2	1088.57	51.48	48.22
4	1330.38	83.00	38.87

However, the higher FE value of 2010, which indicates residual effect of NSC in 2009, implies that the NSC performed better in terms of increasing sorghum grain yields than an equivalent amount of mineral fertilizer. This corroborates with other findings of Bationo *et al*. (2007) and Mugendi *et al*. (2009) who reported N equivalency values of above 100% in their studies with different organic amendments. These high yields from 1 TC treatments could also be inferred as being due to positive effects of the NSC on soil physical and chemical properties, such as moisture retention and addition of micronutrients at this incorporation level.

Furthermore, the FE for the NSC soil amendments studied with %N > 2.5 (3.85 in 2009 and 5.34 in 2010 as shown in Table 4.2) were positively correlated (r = 0.73 in 2009 and 0.76 in 2010, P = 0.01) to their N content, showing dependency of FE of this organic material on its N content. The linear functions indicated that an increase of 0.1% N in NSC could result in about 7% increase in fertilizer value in both years. Critical level of N content of NSC for the transition for increasing crop yield relative to 0N was 236.49 kg ha^{-1} in 2009 and 295.09 kg ha^{-1} in 2010 (Figure 4.4).

In the treatment combinations of neem seed cake and inorganic fertilizer, the 1 TC + ¼ RR with fertilizer equivalency of 35.86 and 79.52 gave highest percent fertilizer equivalency value of 65.80 and 114.62 in 2009 and 2010 years respectively. At this inclusion level of NSC and a quarter rate of N (16 kg N ha^{-1}) in the soil studied, a total of 54.50 and 69.38 kg N ha^{-1} respectively, was applied which together with the residual mineral-N gave a significantly higher percent fertilizer equivalency value. In years 2009 and 2010, 2 TC + FRR, though had higher grain yield (3245.43 and 1471.04 kg ha^{-1} respectively) as against 1 TC + ¼ RR (2775.34 and 1301.00 kg ha^{-1} for 2009 and 2010 respectively) the former had less percent equivalencies

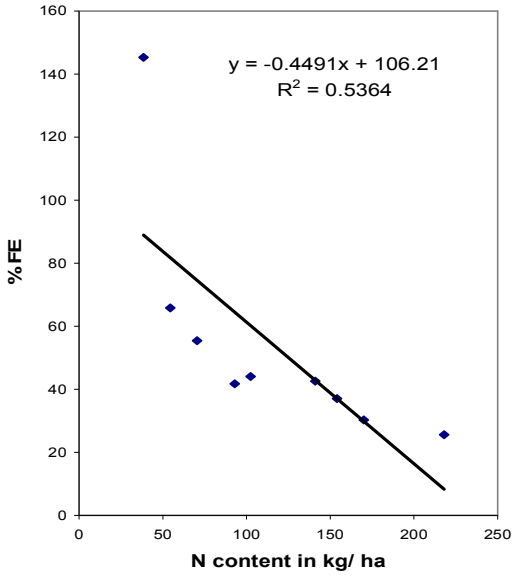
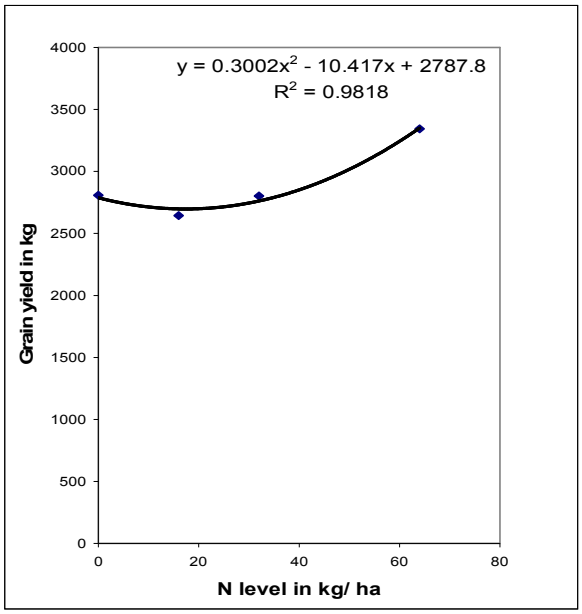


Figure 4.4a:
Relationship between the N fertilizer Equivalencies and N content of applied NSC and inorganic fertilizer in 2009.



2009 sorghum grain yield response to N in Samaru

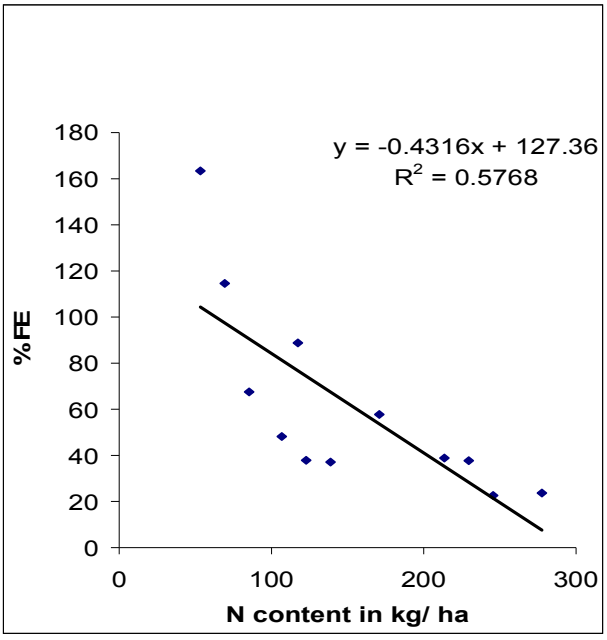
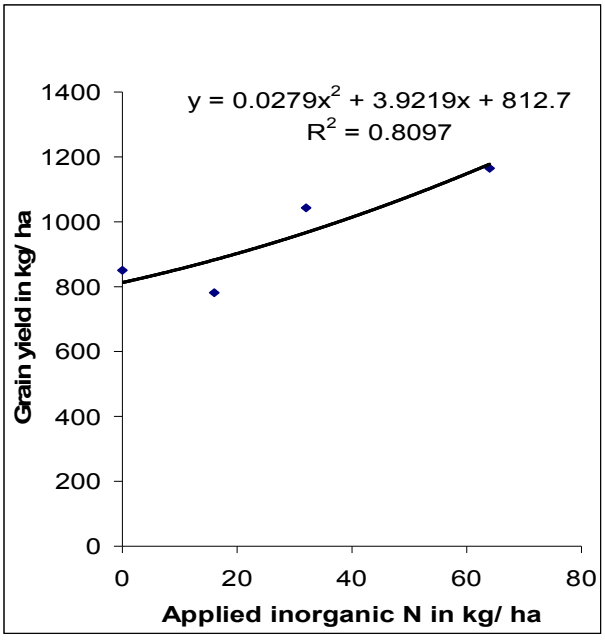


Figure 4.4b:
Relationship between the N fertilizer Equivalencies and N content of applied NSC and inorganic fertilizer in 2010.



2010 sorghum grain yield response to N in Samaru

Figure 4.4: The relationship between percent fertilizer equivalencies and N content of neem seed cake.

(42.61 and 57.77 respectively) which implied that there was an increase in sorghum grain yield perhaps, due to luxury consumption. This was also the case for the 4 TC + ¼ RR and 4 TC + FRR with grain yields of 3047.64 kg ha^{-1} (% FE = 30.30) and 3141.99 kg ha^{-1} (% FE = 25.61) as presented in Table 4.44 and 4.45 for 2009 and 2010 respectively. The 4 TC + ¼ RR also would be recommended as a suitable combination because about 102.5 and 117.38 kg N ha^{-1} (≈ 50% of ¼ NPK plus 1 tonne NSC) was used to produce an additional 154.39 (5.26%) and 223.04 (14.63%) kg ha^{-1} grains in 2009 and 2010 years respectively.

Combining mineral and inorganic inputs result in greater benefits than either input alone through positive interactions on soil biological, chemical and physical properties (Sanchez, 1994). Inorganic fertilizer not only improves crop yields but also increases the quantity of available crop residues useful as livestock feed or organic inputs to the soil (Bationo *et* al., 2004). In view of the aforementioned reasons, from the fertilizer equivalency results obtained in the two years field study, the 1 TC + ¼ RR treatment would be suggested as optimum and suitable combination of NSC and inorganic fertilizer for sorghum grain production in Alfisols of the Northern Guinea Savanna of Nigeria.

Table 4.44: Interaction of NSC and NPK on fertilizer equivalence in 2009

NPK combination Rates (kg ha^{-1})	Neem seed cake levels (tonnes ha^{-1}) 0	1	2	4
0	(2605.45)	(3144.67) 145.32 38.5	(2461.09) Undefined 77.0	(3172.08) 37.08 154.0
16	(2362.30) - 16.0	(2775.34) 65.80 54.5	(2835.77) 41.74 93.0	(3047.64) 30.30 170.0
32	(2537.60) - 32.0	(2839.29) 55.45 70.5	(2587.93) Undefined 109.0	(2593.66) Undefined 186.0
64	(3346.81) - 64.0	(2929.73) 44.07 102.5	(3245.43) 42.61 141.0	(3141.99) 25.61 218.0

Data in parenthesis at the top is grain yield in kg ha^{-1}; data in the middle is fertilizer equivalence value for the treatment combination and the data at the bottom of each row is the N applied per treatment combination in kg

Table 4.45: Interaction of NSC and NPK on fertilizer equivalence in 2010

NPK combination Rates (kg ha^{-1})	Neem seed cake levels (tonnes ha^{-1}) 0	1	2	4
0	(850.71)	(1367.10)	(1088.98)	(1330.38)
		163.41	48.22	38.87
		53.38	106.76	213.52
16	(781.20)	(1301.00)	(1055.50)	(1360.67)
	-	114.62	37.90	37.69
	16.0	69.38	122.76	229.52
32	(1042.75)	(1131.44)	(1088.98)	(1116.87)
	-	67.51	37.14	22.64
	32.0	85.38	138.76	245.52
64	(1165.10)	(1524.04)	(1471.04)	(1191.45)
	-	88.75	57.77	23.71
	64.0	117.38	170.76	277.52

Data in parenthesis at the top is grain yield in kg ha^{-1}; data in the middle is fertilizer equivalence value for the treatment combination and the data at the bottom of each row is the N applied per treatment combination in kg

4.9 Effect of NSC and CF on sorghum harvest index and nitrogen use efficiency.

4.9.1 Response of NPK treatment on harvest index

Effect of the treatments on sorghum harvest index was not significant in 2009. However in 2010, ¼ RR recorded the highest value (0.1584) which was statistically different from the other treatments including the control with the least harvest index (0.1244) (Table 4.46) for sole CF treatment.

4.9.2 Response of NSC treatment on harvest index

In the sole NSC treatments, the control gave the highest harvest index (0.1517) while 2 TC recorded the least (0.1170). The control was statistically similar with 1 TC while 2 TC and 4 TC were also the same, although, they differ from the control and 1 TC statistically (Table 4.46).

4.9.3 Response of treatment interaction on harvest index (HI)

1 TC + ¼ RR gave the highest harvest index in the combination of NSC and NPK fertilizer in 2009 and 2010 as well as the two years combined (Table 4.47). This higher HI obtained in this study at the 1 TC + ¼ RR implies the ability of a better partitioning of dry matter into reproductive organs. Consequently, indicating the significant role of this rate in increasing yield, net benefit and nutrient use efficiency to merit the extra production cost that may be incurred at other rates with marginal yield increase.

4.9.4 Response of NSC and NPK treatment on N-use efficiency

The N-use efficiency of neem seed cake and/ or inorganic fertilizer used for the study is presented in Figures 4.5 and 4.6 for the sixteen different treatments used in this study in 2009 and 2010 years respectively. The regression between N applied in each treatment and N recovery (%) of the mean of cumulative above ground biomass (kg ha^{-1}) gave an r value of

Table 4.46: Main effects of NSC and CF on sorghum harvest index

Treatment	2009	2010	Combined
NPK kg ha^{-1} (N)			
0	0.1536	0.1244b	0.1526a
¼ RR	0.1448	0.1584a	0.1470ab
½ RR	0.1389	0.1280b	0.1279c
FRR	0.1466	0.1291b	0.1343bc
SE ±	0.0070	0.0084	0.9958
NSC t ha^{-1} (S)			
0 TC	0.1517	0.1517a	0.1381b
1 TC	0.1527	0.1493a	0.1556a

2 TC	0.1388	0.1170b	0.1334b
4 TC	0.1406	0.1220b	0.1349b
SE ±	0.0070	0.0084	0.9958
Interaction (N × S)			
N × S	NS	NS	NS

Means followed by the same letter (s) within the same column are not significantly different at $P < 0.05$
NS= Not significant
TC = ton ha^{-1} NSC
RR= recommended rate
FRR= Full recommended rate

Table 4.47: Interaction of NSC and CF on sorghum harvest index

Treatment	2009	2010	Combined
Control	0.1487	0.1488	0.1487
¼ RR	0.1462	0.1189	0.1326
½ RR	0.1451	0.119	0.1321
FRR	0.1669	0.1108	0.1389
1 TC	0.1605	0.179	0.1697
1 TC + ¼ RR	0.1512	0.1854	0.1683
1 TC + ½ RR	0.141	0.1346	0.1378
1 TC + FRR	0.141	0.1581	0.1496
2 TC	0.1414	0.1257	0.1336
2 TC + ¼ RR	0.1568	0.1176	0.1372
2 TC + ½ RR	0.1337	0.1257	0.1297
2 TC + FRR	0.1197	0.1057	0.1127
4 TC	0.1639	0.1533	0.1586
4 TC + ¼ RR	0.1424	0.1517	0.1471
4 TC + ½ RR	0.1392	0.126	0.1326
4 TC + FRR	0.1378	0.0994	0.1186
SE ±	0.006	0.007	0.007

TC = ton ha^{-1} NSC
RR = recommended rate
FRR = full recommended rate

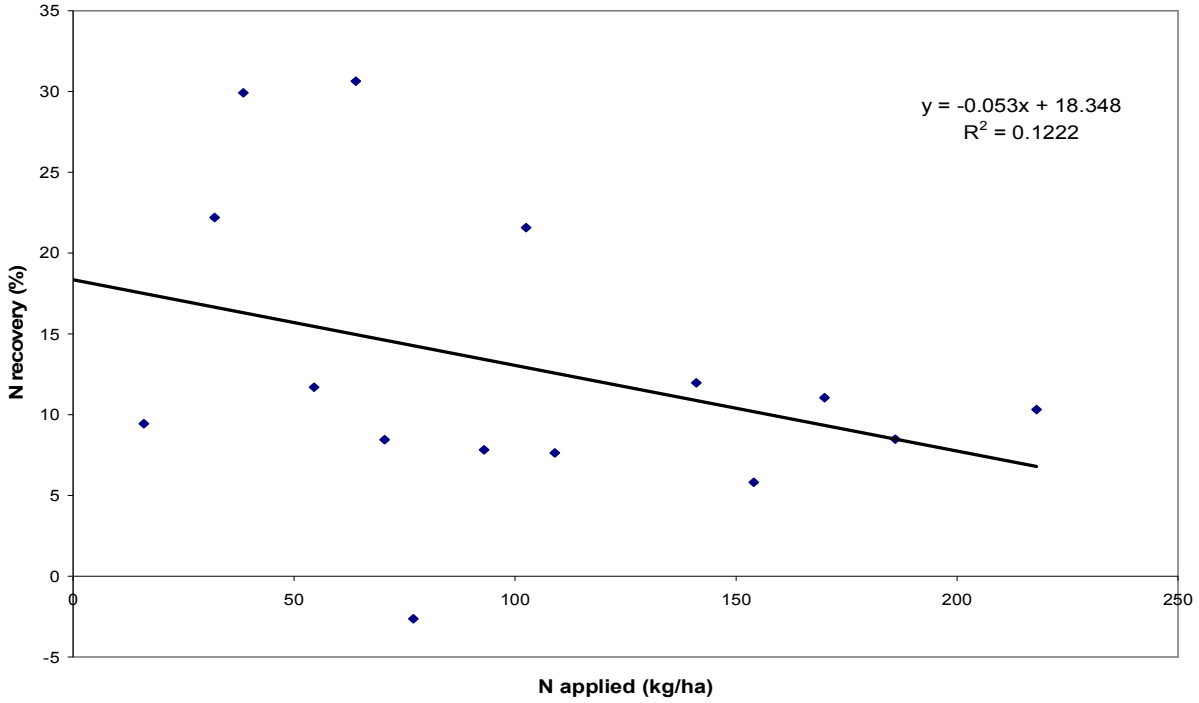


Figure 4.5: Relationship between N applied and N recovery by sorghum in 2009

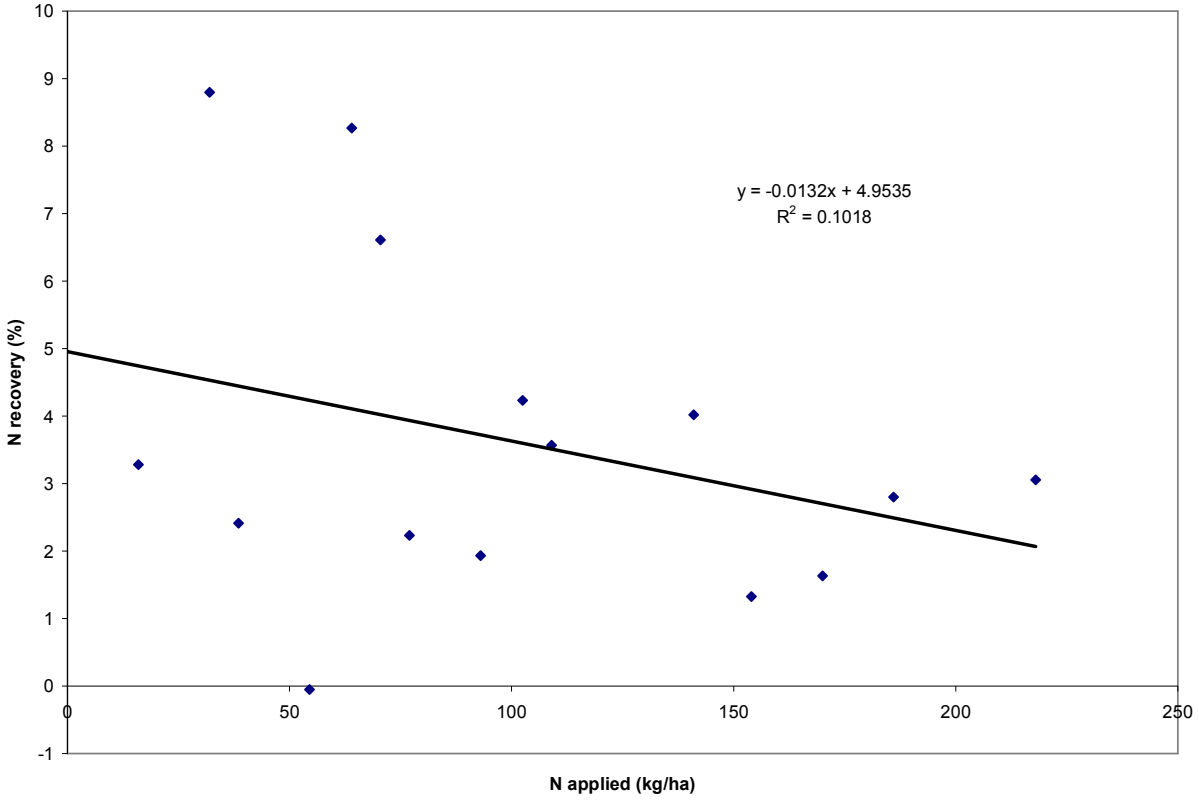


Figure 4.6: Relationship between N applied and N recovery by sorghum in 2010

0.3496 and 0.3191 respectively. Although, theses values were low, they conform to earlier submissions that N-use efficiency of organic amendments (manures) are low (Vanlauwe and Sanginga, 1995: Cadisch and Giller, 1997; Okalebo *et al*., 2002). The crop availability of N in NSC alone or in combination with NPK fertilizer was generally lower than N from optimum recommended fertilizer rate. This could be attributed to the slow release of organically bound-N, part of which became available at a later stage that may not synchronize with time of actual demand. However, the non-decomposed fraction has additional benefits to the soil (Okalebo *et al*., 2002).

4.10 Derivations from the field experiment

The following observations were drawn from the field experiment:

- Highest growth parameters – leaf number (12), dry matter yield (57.56 g plant^{-1}), LAI (4.11), stem girth (2.77), and plant height (135.52 cm) were obtained from the combination of NSC and NPK fertilizer at the 4 TC + FRR for the two years combined;
- Highest yield parameters – grain yield (2321.56 kg ha^{-1}) and stover yield (15277.76 kg ha^{-1})- were obtained from the combination of 2 TC + FRR and 4 TC + FRR respectively;
- From the factor analysis, the dominant factor in assessing soil quality varied with N concentration. Soil pH and EA were the most discriminating factor in FC 2 which influenced biomass yield and return of biomass to the soil (nutrient availability). Also, the production of carbonates of Ca and Mg evident from the positive loading of Ca and Mg in FC 5, simultaneously with certain free organic acids formed tend to make the environment alkaline aside modification of acidity of the environment by plant themselves;
- The nutritional status of sorghum was enhanced with the combined use of NSC and NPK fertilizer at 4 TC + ¼ RR for crude protein (8.87%) while highest tannin content of 0.81

mg kg^{-1} was recorded at the 1 TC level. Consequently, the grain be classified as containing moderate tannin content;

- From the fertilizer equivalence study of NSC, 1 TC + ¼ RR complementary use of NSC and NPK fertilizer with fertilizer equivalence of 35.86 and 79.52 gave highest percent fertilizer equivalency value of 65.80 and 114.62 in 2009 and 2010 years respectively;
- The highest harvest index (0.1683) was obtained from the combination of NSC and CF at 1 TC + ¼ RR, signifying the ability of the combination of both inputs at this rate in enhancement of partitioning of dry matter into reproductive organs.

CHAPTER FIVE

SUMMARY AND CONCLUSION

The objective of this study was to assess the nutrient potential of neem seed cake (NSC) in improving growth and nutrition of sorghum in an Alfisol of the Nigerian Savanna. The NSC was sourced from the National Research Institute for Chemical Technology (NARICT), Basawa-Zaria and characterized for its chemical contents. Results obtained showed high organic carbon content from the cake as well as substantial amounts of nitrogen and phosphorus. C: N ratio of the residues was also found to be low indicating its high potential for improving fertility and productivity of soil through its rapid decomposition hence, organic matter accumulation and nutrient released on application to the soil. In the first phase of the study, NSC was evaluated in the greenhouse to assess its immediate nutrient contribution to sorghum growth. The treatment consisted of four rates of NSC and inorganic fertilizer. Results from this evaluation show that NSC had high nutrient contents, good residue quality and promoted sorghum growth in the greenhouse. Also, sorghum dry matter yield (DMY), plant height and leaf area generally increased with increase in the rate of NPK applied. Best results were however obtained when NSC was complemented with NPK at the 4 t NSC ha^{-1} + FRR.

In the second phase study, an experiment was set up to determine rate of N mineralization in the laboratory. Cumulative N mineralized showed initial rapid release rate in the first twenty-one (21) days followed by slower release with time. 50% of total N applied as NSC was mineralized at 98 days. NH_4^+-N fraction exceeded NO_3^- - N fraction in the soil, accounting for 92% of the N mineralized from the NSC. N mineralization pattern from NSC was best described by a consecutive (h=k) model. In the field, cumulative N mineralized with time showed initial rapid release rate in the first six (6) weeks after incubation followed by slower release in both years. Data for net N mineralized by NSC observed from 0 - 83 days displayed the best fit with

Gompertz function. The goodness-of-fit statistics showed that estimated potentially mineralized N values was 67.26 mg kg^{-1} for the consecutive model (h=k).

In the third phase of the study, the same treatment combinations in phase 1 were employed for litterbag technique decomposition. Asymptotic negative exponential model predicted the decomposition rate of the residue to be relatively higher in the first pool, indicative of insoluble, non-structural carbohydrates and low C: N compounds. Thus, depicting that incorporated NSC was removed in the soil system rapidly with 70% lost in within twenty-eight days. Incorporation of NSC for two weeks before sowing would synchronize with period of high nutrient demand. Generally, decomposition of NSC was faster where NPK was applied and decreased with increasing NPK rates.

The fourth phase study involved a two-year field evaluation of NSC. This was applied alone and in combination with ¼, ½ and optimum NPK recommended rate for sorghum in the Northern Guinea Savanna of Nigeria. The absolute control and optimum NPK rate served as checks. Application of NSC alone increased both grain and stover yields over that of the absolute control. Both grain and stover yields increased as the rate of NPK increased. Relative yields of treatments with NSC without CF and low CF rates were higher at the end of the study. Complementary use of the organic amendments with NPK generally increased grain and stover yields above that of NSC alone. The treatment significantly ($P < 0.05$) increased dry matter yield and number of leaves; with the highest values recorded in plots with 4 TC + FRR in both years. Similarly, sole application of NSC significantly ($P < 0.05$) improved sorghum contents of total N, P and K over the control. Application of sole NPK had no significant effect on nitrogen concentration in sorghum tissue in 2009. However, significant difference ($P < 0.05$) was

obtained in 2010 with ½ RR recording the highest N concentration. NSC also interacted positively with NPK fertilizer to affect sorghum plant mineral composition.

The nutritional status of sorghum was not significantly different with treatments in both years. There was significant difference ($P < 0.05$) in the crude protein content of sorghum grains in the sole NSC plots in both years. However, in the sole CF treatments, significant ($P < 0.05$) difference was obtained in 2009 with FRR recording the highest (9.17%) crude protein content and the least (7.45%) from the control. In 2010, there was no significant difference ($P < 0.05$) in both crude protein and tannin contents of the sorghum grains. Also, interaction effect was not significant. But, the highest crude protein content was recorded from the combination of 1 TC and ¼ RR (10 .00%) in 2009 and the control (8.44%) in 2010 while the highest tannin concentration (0.56 mg kg^{-1}) in 2009 was obtained from ¼ RR and 1.22 mg kg^{-1} from 1 TC in 2010.

The following conclusions were drawn based on the results obtained in this study:

- Based on the nutrient content of neem seed cake, the organic material was classified as high quality resource materials.
- The study shows that combined applications of neem seed cake and inorganic fertilizers led to higher values of OC (8.02 g kg^{-1}) with 4 TC + FRR; available P (17.21 mg kg^{-1}) with 4 TC + ¼ RR; while sole NSC application at 4 TC gave the highest N content of 0.76 g kg^{-1} soil nutrients.
- In sole NSC treatments, exchangeable acidity decreased with increasing levels with the 1 TC recording the highest value.
- Sole NSC resulted in reduction in soil pH following first application.

- The rate of decomposition of neem seed cake followed a two pool, first order, three parameters Asymptotic negative exponential model ($Y = X_L e^{-kLt} + X_R$) with the relative rate of decomposition for the labile pool (k_L) of 0.05 for the control, ¼ and ½ NPK and 0.03 for full recommended r ate. Consequently, combination of NSC with lower NPK rates (¼ RR) would be ideal for optimum economic yield goals.
- The mineralization pattern of neem seed cake was best described by the Gompertz model with a rate of 0.095 which implied that 50% of the N content of NSC would be released in the available form (ammonium-nitrogen) for plant use in a week.
- The laboratory incubation experiment demonstrated the unreliable index of field rates of laboratory measures of mineralization evident from the relatively high chi-square value obtained for the asymptotic negative exponential model inspite of the corresponding R^2 and RMSE values.
- The pot experiment demonstrated that adequate nutrient required for early crop growth can be supplied from combined applications of organic and inorganic fertilizer nutrients, thus: 1 TC + ½ RR (9.91 g kg^{-1} OC); 1 TC + ¼ RR (12.83 mg kg^{-1} P); while sole application of NSC at 2 TC gave the highest N content of 1.23 g kg^{-1}.
- Field application of neem seed cake was observed to increase sorghum grain yield. Grain yield fertilizer equivalencies were seen to vary with the addition of inorganic fertilizer. Based on agronomic yield goals, the 1 TC + ¼ RR treatment would be suggested as the optimum and suitable combination of NSC and inorganic fertilizer for sorghum production in Alfisols of the Northern Guinea Savanna of Nigeria
- The study demonstrated that in low input systems, application of neem seed cake could reduce the inorganic fertilizer by a quarter of the recommended rate of 64-32-32 for sorghum in this region. The results also show that under intensive systems a combination

of 4 tonnes neem seed cake ha^{-1} and recommended optimum inorganic fertilizer rate of 64-32-32 could sustain the required high yields.

The importance of complementary use of NSC and NPK fertilizer in improving soil fertility status and sustainable sorghum production was demonstrated clearly in the increased grain yield recorded across the two years. Results of the study showed that decomposition rate was 0.095 which amounted to two weeks of 50% mass loss, thus, two weeks of incorporation being adequate with period of optimum nutrient uptake by sorghum. Also, mineration was rapid with 50% of the N in NH_4^+-N form being released within one week thereby preventing N loss through leaching or volatilization of NO_3^--N. Sole use of NSC at 1 t ha^{-1} increased tannin content to the moderate class, which might reduce the nutritive value of the grain. However, complementary use of NSC and NPK fertilizer did not affect the tannin and crude protein content adversely. Similarly, results of the fertilizer equivalence, nutrient use efficiency and harvest index showed that complementary use of 2 and 4 t NSC ha^{-1} with ¼, ½ and full NPK rates obviously added to the cost of production, but did not add significantly to output. This is evidenced by the fact that the main effect of increasing treatment levels from 1 to 2 or 4 t NSC ha^{-1} did not result in corresponding increase in grain yield, and inturn economic benefits or nutrient use efficiency to merit the extra cost that may be incurred. Thus, maximum economic grain yields for sorghum would be expected to occur with complementary use of 1 TC + ¼ RR. Hence, complementary use of 1t NSC ha^{-1} plus ¼ recommended NPK rate for sorghum in the Northern Guinea Savanna of Nigeria will be the suitable combination for optimum growth and yield of sorghum.

However, an integrated approach involving liming, management practices, and plant tolerance would be pertinent. These include using less acidifying fertilizers, improving nutrient use

efficiency, reducing nutrient leaching losses, and reducing product removal. Also, the relatively high loading for soil acidifying properties which included pH, EA and available P which explained 16% of the total variance in the second component (communality estimates varied between 0.61 and 0.82) with the incorporation of NSC could be studied in the future for possibility of exploitation in the solubilization of P from rock phosphate in field studies thereby enhancing maximum and timely utilization by plants.

REFERENCES

Aba, D. A., Abu, E., Chindo, P.S., Marle, P.S., Maigida, D.N., Ogungbile, A.O. 2005. Characterization of some released sorghum varieties and for food and industrial utilization in Nigeria. Agricultura Tropica et Subtropica 38 (2):

Abubakar, S. Z., Jibrin, J. M. and Sulaiman, A. 2004. Effects of soil and water management practices on irrigation environment in Kano River Irrigation Project (KRIP), Nigeria. Proceedings of the 5th International conference and 26th Annual General Meeting of the Nigerian Institute of Agricultural Engineers, 26: 189-197.

Acquaye, D. K. 1963. Some significance of soil organic phosphorus mineralization in the phosphorus nutrition of cocoa in Ghana. Plant and Soil XIX, no. 1: 65-80.

Acquaye, D. K. 1993. Sustaining soil productivity in intensive Africa Agriculture. Seminar proceedings. Accra-Ghana. 15th-19th, Nov. 1993.

Adams, F. 1984. Crop responses to lime in southern United States. In Soil acidity and liming; Adams, F. (ed.). ASA, CSSA, and SSSA; Madison, Wisconsin pp. 211-265.

Adams, M. A. and Attiwill, P. M. 1986. Nutrient cycling and nitrogen mineralization in eucalypt forests of south-eastern Australia. II. Indices of nitrogen mineralization. Plant Soil 92: 341-362.

Adegbite, E. A. and Olayinka, A. 2010. Effect of organic amendments and nitrogen on microbial activity, nitrogen and phosphorus mineralization in an alfisol. Nigerian J. Soil Sci. 20(2): 87-91

Adeoye, K. B. 1984. Influence of grass mulch on soil temperature, soil moisture and yield of maize and “gero" millet in a savanna zone soil. Samaru J. Agric. Research 2: 87-97.

Aduayi, E. A., Chude, V. O., Adebusuji, L. O. and Olayiwola, S. O. 2002. Fertilizer use and management practices for crops in Nigeria. Abuja: Federal Ministry of Agric. And Rural Development.

Agbenin, J. O.,Agbaji, E. B., Suleiman, I. and Agbaji, A. S. 1999. Assessment of nitrogen mineralization potential and availability from neem seed residue in a savanna soil. Boil. Fertil. Soils 29: 408-412.

Agbenin, J. O., Ibitoye, S. O. and Agbaji, A. S. 2008. Nutrient mineralization from deoiled neem seed in a savanna soil from Nigeria. Commun. Soil Sci. Plt. Analysis 39: 527-537.

Agbim, N. N. 1980. Potentials of cassava peels as a soil amendment (ii): field evaluation. J. Env. Qual. 14: 411-415.

Agbim, N. N. and Adeoye, K. B. 1991. The role of crop residues in soil fertility maintenance and conservation. Paper presented at the organic fertilizer seminar, Durbar Hotel Kaduna.

Ajiboye, B., Akinremi, O. O. and Racz, G. J. 2004. Laboratory characterization of phosphorus in fresh and oven-dried organic amendments. J. Environ. Qual. 33: 1062-1069.

Al-Abbas, A. H. and Barber, S. A. 1964. A soil test for P based upon fractionation of soil P. I. Correlation of soil P fraction with plant-available phosphorus. Soil Sci. Soc. Am. Proc. 28: 218-221.

Alexander, M. 1977. Introduction to soil microbiology, 2nd ed. New York: Wiley.

Alexander, M. 1961. Introduction to soil microbiology, New York: John Wiley.

Allen, S. E. 1989. Chemical analysis of ecological materials. 2nd ed. Oxford: Blackwell scientific publications.

Allison, F. E. and Kleen, C. J. 1962. Rates of immobilization and release of N following additions of carbonaceous materials and N to soils. Soil Sc. 93: 383-386.

Allison, F. E. 1973. Soil organic matter and its role in crop production. The Netherlands:Elsevier Scientific Publ. Co., Amsterdam.

Anderson, J. M., Leonard, M. A., Ineson, P. and Huish, S. 1985. Faunal biomass: a key component of a general model of nitrogen mineralization. Soil Biol. Biochem. 17: 735-737.

Anderson, J. M. and Ingram, S. J. 1993. Tropical biology and fertility: A handbook of methods. England, Wallingford: CAB Int.

Andren, O. and Paustian, K. 1987. Barley straw decomposition in the field: Comparison of models. Ecology 68: 1190-1200.

Arihara, J. 2001. Cropping systems and their mechanisms of nutrient uptake. Issues in the management of agricultural resources. FFTC book, proceedings of a seminar in commemoration of FFTC's 30th anniversary, National Taiwan University, Taipei, Taiwon ROC, September 6 - 8, 2000.

Austin, R. B, Bingham, J., Blackwell, R. D., Evans, L. T., Ford, M. A, Morgan, C. L. and Taylor, M. 1980. Genetic improvements in winter wheat yields since 1900 and associated physiological changes. J. Agric. Sci. 94: 675-689.

Avnimelech, Y. 1986. Organic residues in modern agriculture. In: The role of organic matter in modern agriculture. Chen, Y. and Avnimelech, Y. (eds.) Developments in plant and soil sciences 25: 1-10 Nijhoff publishers.

Avnimelech, Y., Polachek, Y., Moses, A. and Cohen, E. 1971. The effects of manures on the fertility of compacted soils.Hasadeh 51: 316-318.

Ayoola, O. T. and Makinde, E. A. 2009. Maize Growth, Yield and Soil Nutrient Changes with N-Enriched Organic Fertilizers. In: African Journal of Food, Agriculture, Nutrition and Development, Vol. 9, Nr. 1, 2009, S. 580-592.

Ayuke, F. O., Rao, M. R., Swift, M. J. and Opondo-Mbai, M. L. 2004. Effect of organic and inorganic nutrient sources on soil mineral nitrogen and maize yields in western Kenya. In: Bationo, A. (eds.). Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa. Nairobi: Academy Science publishers pp. 65-76.

Bache, B. W. and Heathcote, R. G. 1969. Long-term effects of fertilizers and manure on the soil and leaves of cotton. Exptl. Agric. 5: 241-247.

Badaruddin, M. And Meyer, D. W. 1989. Forage legume effects on soil nitrogen and grain yield and nitorgen nutirition of wheat. Agron. J. 81: 419-424.

Bagayoko, M., Buerkert, A., Lung, G., Bationo, A. And Römheld, V. 2000. Cereal/ legume rotation effects on cerael growth in Sudano-Sahelian West Africa: Soil mineral nitrogen, mycorrhizae and nematodes. Plant Soil 28: 103-116.

Bagepalli, S., Rao, N., and Prabhavathi, T. 1982. Tannin content of foods commonly consumed in India and its influence on ionizable iron. J. Food Sc. 33: 89-96

Balasubramanian, V. and Nnadi, L. A. 1980. Crop residence management and soil conservation in savanna areas. FAO soil bulletin No. 43, Rome.

Barak, P., Molina, J. A. E., Hadas, A. And Clapp, C. E. 1990. Mineralization of amino acids and evidence of direct assimilation of organic nitrogen. Soil Sci. Soc. Am. J. 54: 769-774.

Barajas-Aceves, M., Grace, C., Ansorena, J., Dendooven, L. And Brookes, P. C. 1999. Soil microbial biomass and organic carbon in a gradient of zinc concentrations in soils around a mine spoil tip. Soil Biology and Biochem. 31 (6): 867-876.

Barajas-Aceves, M., Grace, C., Ansorena, J., Dendooven, L. And Brookes, P. C. 2005. Comparison of different microbial biomass and activity measurement methods in metal-contaminated soils. Bioresource Technology 96 (12): 1405-1414.

Barrow, N. J. 1960. The effects of varying the nitrogen, sulphur and phosphorus content of organic matter on its decomposition. Aust. J. Agric. Res. 11: 317-330.

Bationo, A., Buerkert, A., Sedogo, M. P., Christianson, B. C. and Mokwunye, A. U. 1995. A critical review of crop residue use as soil amendment in the West Africa Semi-Arid Tropics. p. 305-322. In: Powell, J. M., Fernandez-Rivera, S., Williams, T. O. and Renard, C. (eds.). Livestocl and sustainable nutrient cycling in mixed farming systems of sub Saharan Africa. Volume II. Technical papers. Proceedings of an International Conference 22-26 Nov. 1993. International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia, ILCA, Addis Ababa, Ethiopia.

Bationo, A., Waswa, B., Adamon, A., Bado, V., Bonzi, M., Iwuafor, E., Kibunja, C., Kihara, J., Mucheru, M., Mugendi, D., Mugwe, J., Mwale, C., Okeyo, J., Olle, A., Roing, K., and Sedogo, M. 2007. Lessons learnt from long term trials in Africa. Paper presented in Stockholm, Sweden.

Bell, L. C. and Besho,T. 1993. Assessment of aluminum detoxification by organic materials in an ultisol using soil solution characterization and plant response. In: soil organic matter dynamics and sustainability of tropical agriculture. K. Mulongoy and R. Merckx (eds). Wiley-Sayce Co-publication, Chichester, U. K. Pp 317-330.

Belyea, L. R. 1996. Separting the effects of litter quality and microenvironment on decomposition rates in a patterned peatland. Oikos 77: 529-539.

Bending, G. D., Turner, M. K. and Burns, I. G. 1998. Fate of nitrogen from crop residues as affected by biochemical quality and the microbial biomass. Soil Biol. Biochem. 30: 2055-2065.

Bending, G. D. and Turner, M. K. 1999. Interaction of biochemical quality and particle size of crop residues and its effect on the microbial biomass and nitrogen dynamics following incorporation into soil. Biol. Fertil. Soils 29: 319-327.

Benton, T. G., Lapsley, C. T. and Beckerman, A. P. 2001. Population synchrony and environmental variation: an experimental demonstration 4 (3): 236-243.

Berg, B. and McClaugherty, C. 2008. Models that describe litter decomposition. In. Plant litter. Springer-Verlag Berlin Heidelberg 10:211-223.

Berg, B. and McClaugherty, C. 2003. Plant litter-decomposition, humus formation, carbon sequestration. Springer. Berlin.

Berg, B., Berg, M. P, Bottner, P., Box, E., Breymeyer, A., Calvo de Gallardo, A, Kratz, W., Madeira, M., Malkonen, E., McClaugherty, C., Meetemeyer, V., Munoz, F., Piussi, P., Remade, J. and Vrizo de Santo, A. 1993. litter mass loss rates in pine forests of Europe and Eastern United states: some relationships with climate and litter quality. Biogeochemistry 20: 127-159.

Berg, B. and McClaugherty, 1987. Nitrogen release from litter in relation to the disappearance of lignin. Biogeochemistry 4: 219-224.

Berg, B. and Staaf, H. 1981. Decomposition rate and chemical changes of scots pine needle litter: II. Influence of chemical composition. In T. Person (ed.) Structure and function of northern coniferous forests. An ecosystem study. Ecol. Bull. 32: 373-390.

Berkel, W. J. H. and Voragen, A. G. 2002. Biochemical Jul. 15; 306 (2): 336-339. http:// www. Google.com

Billes, G., Gandias-Riollet, N. and Bottner, P. 1986. Effet d'une culture de graminèes sur la decomposition d'une litière vègètale marquee au ^{14}C et ^{15}N, dans le sol en conditions controlees. Acta Oecological/ Oecologica Plantarum 7: 273-286.

Binkley, D. and Matson, P. 1983. Ion exchange resin bag method for assessing forest soil nitrogen availability. Soil Sci. Soc.Am. J. 47: 1050-1052.

Birch, H. F. 1961. Phosphorus transformations during plant decomposition. Plant and Soil 15: 347-366.

Biswas, T. D. and Mukherjee, S. K. 2005. Textbook of soil science (14th reprint). New Delhi: Tata McGraw-Hill publishing company limited.

Black, C. A. and Goring, C. A. I. 1953. Organic phosphorus in soils. Soil and fertilizer phosphorus. New York: Academic press.

Black, C. A. 1968. Soil plant relationships. New York: John Wiley and sons Inc.

Black, C. A. 1973. Soil property changes associated with crop residue management in a wheat-fallow rotation. Soil Sci. Soc. Am. J. 37: 943-946.

Blair, J. M. 1988. Nitrogen, sulphur and phosphorus dynamics in decomposing deciduous leaf litter in the southern Appalachians. Soil Biol. Biochem. 20: 693-701.

Blair, G. J. and Boland, O. W. 1978. The release of phosphorus from plant material added to soil. Aust. J. Soil Res. 16: 101-111.

Boehm, M. J., Wu, T., Stone, A. G., Kraakman, B., Iannotti, D. A., Wilson, G. E., Madden, L. V. and Hoitink, H. A. J. 1997. Cross-polarized magic angle spinning ^{13}C nuclear magnetic resonance spectroscopic characterization of soil organic matter relative to culturable bacteria species composition and sustained biological control of *Pythium* root rot. Appl. Environ. Microbiol. 63: 162-168.

Borrell, A. K., Hammer, G. L. and Douglas, A. C. L. 2000a. Does maintaining green leaf area in sorghum improve yield under drought? I. Leaf growth and senescence. Crop Sci. 40:1026-1037.

Borrell, A. K., Hammer, G. L. and Henzell, R. G. 2000b. Does maintaining green leaf area in sorghum improve yield under drought? II. Dry matter production and yield. Crop Sci. 40: 1037-1048.

Bot, A. J. 2009. The importance of soil organic matter. http://www.fao.org

Bottner, P., Pansu, M. and Sallih, Z. 1999. Modelling the effect of active roots on soil organic matter turnover. Plant Soil 216: 15-25.

Bottner, P., Mneimme, Z. and Billes, G. 1984. Rèsponse de la biomasse microbienne à l'adjontion au sol de materiel vegetal marquee au ^{14}C: role des raciness vivantes. Soil Biol. Biochem. 16: 305-314.

Bouldin, D. R. 1987. Soil organic matter in sustainable agriculture. http://www.crcnetbase.com

Boumann, O. T., Curtin, D., Campbell, C. A., Beiderbeck, V. O. and Ukrainetz, H. 1995. Soil acidification from long-term use of anhydrous ammonia and urea. Soil Sci. Soc. Am. J. 59: 1488-1494.

Brahmachari, G. B. 2004. Neem – an omnipotent plant: A retrospection. Chem. Biochem. 5: 408-421.

Bremmer, J. M. 1996. Nitrogen-total. In Methods of chemical analysis, part 3- Chemical methods. D. L. Sparks (Ed) p. 1085-1121. Am. Soc. Of Agron. Madison, Wisconsin, USA.

Bremner, J. M. and Keeney, D. R. 1965. Steam distillation methods for determination of ammonium, nitrate and nitrite. Analytica Chimica Acta 32: 485-495.

Bremner, J. M. and Van Kessel, 1992. Seasonal microbial biomass dynamics after addition of lentil and wheat residues. Soil Sci. Soc. Am. J. 56: 1141-1146.

Brinson, M. 1981. Primary productivity decomposition and consumer activity in freshwater wetlands. Rev. Ecol. Syst. 12: 123-161

Brookes, P. C., Landman, A., Pruden, G. and Jenkinson, D. S. 1985. Chloroform fumigation and release of soil nitrogen: A rapid direct extraction method to measure microbial biomass nitrogen in soil. Soil Biol. Biochem. 17: 837-842.

Brookes, P. C., Powlson, D. S. and Jenkinson, D. S. 1984. Phosphorus in the soil microbial biomass. Soil Biol. Biochem. 16: 169-184.

Brookes, P. C., Powlson, D. S. and Jenkinson, D. S. 1982. Measurement of microbial biomass phosphorus in soil. Soil Biol. Biochem. 14: 319-329.

Bruce, R. R., Langdale, G. W., Dillard, A. L. 1990. Tillage and crop rotation effect on characteristics of a sandy surface soil. Soil Sci. Soc. Am. J. 54: 1744-1747.

Brunner, W. and Focht, D. D. 1984. Deterministic three-half-order kinetic model for microbial degradation of added carbon substrates in soil. Appl. Environ. Microbiol. 47: 162-167.

Budelman, A. 1989. Nutrient composition of the leaf biomass of three selected woody leguminous species. Agroforestry Systems 8: 39-57.

Buhler, S., Oberson, A., Rao, I. M., Frieson, D. K. and Frossard, E. 2002. Sequential P extraction of a ^{32}P-labelled oxisol under constraining agricultural systems. Soil Sci. Soc. Am. J. 66: 868-877.

Bumaya, A. H. and Naylor, D. V. 1988. Phosphorus sorption and extractability in Andic soil incubated with plant residues of variable P content. Plant Soil 112: 77-81.

Buresh, R. J., Sanchez, P. A. and Calhoun, F. 1997. Replenishing soil fertility in Africa. SSSA special publication.SI. SSSA and ASA, Madison, WI. In: Vanlauwe et al. (2001). Maize yield as affected by organic input and urea in the West Africa Moist Savanna. Agron. J. 93: 1191-1199.

Burnett, E. and Tackett, J. L. 1958. Effect of soil profile modification on plant root development. Trans. 9th Int. Cong. Soil Sci. 3: 329-337.

Burns, R. G. 1982. Enzyme activity in soil: Location and a possible role in microbial ecology. Soil Biol. Biochem. 12: 423-427.

Busman, L., Lamb, J., Randall, G., Rehm, G. and Schmitt, M. 2008. The nature of phosphorus in soils. In: Phosphorus in the agricultural environment. Minnesota: Communication and Education Technology Services, University of Minnesota Extension.

Cadisch, G. and Giller, K. 1997. Driven by nature: plant litter quality and decomposition. Wallingford: CAB International

Cambardella, C. A. and Elliot, E. T. 1992. Particulate soil organic matter changes across a grassland cultivation sequence. Soil Sci Soc Am J 56:777-83.

Cameron, D. R. and Kowalenko, C. G. 1976. Modeling nitrogen processes in soil: mathematical development and relationships. Can. J. Soil Sci. 56: 71-78.

Campbell, C. A., Jame, Y. W., Akinremi, O. O. and Cabrera, M. L. 1995. Adapting the potentially mineralizable concept for the prediction of fertilizer N requirements. Fert. Res. 42: 16-75.

Campbell, C. A. 1978. Soil organic carbon, nitrogen and fertility. P. 212-220. In M. Schnitzer and S. U. Khan (ed.). Soil organic matter. Developments in Soil Science 8. New York: Elsevier Sci. Publ.

Carlyle, J. C. and Malcoln, D. C. 1986. Nitrogen availability beneath pure spruce and mixed larch + spruce stands growing on a deep peat. I. Net mineralization measured by field and laboratory incubations. Plant Soil 93: 95-113.

Carter, M. R. 2001. Organic matter and sustainability, In. R. M. Rees et al (eds.), Sustainable Management.

Cassman, K. G. and Munns, D. N. 1980. Nitrogen mineralization as affected by soil moisture, temperature and depth. SSSA J. 44: 1233-1237.

Chang, C., Sommerfield, T. G. and Entz, T. 1993. Barley performance under heavy applications of cattle feedlot manure. Agron. J. 85: 1013-1018.

Chang, S. C. and Jackson, M. L. 1957. Fractionation of soil phosphorus. Soil Sci. 12: 286-293.

Chantereau, J and Nicou, 1994. Sorghum. London and Basingstoke: The Macmillan Press Ltd.

Chapin, F. S., Barsdate, R. J. and Barel, D. 1978. Phosphorus cycling in Alaskan coastal tundra: A hypothesis for the regulation of nutrient cycling. Oikos 31: 189-199.

Chari, M. S. 1996. Neem and transfer of technology. In: Neem and environment, Sinh, R. P., M. S. Chari, A. K. Raheja and W. Kraus (eds.). pp. 27-38. New Delhi, India: Oxford and IBH Publishing Co. Pvt. Ltd.

Chauhan, B. S., Stewart, J. W. B. and Paul, E. A. 1979. Effect of carbon additions on soil labile inorganic, organic and microbially held phosphate. Can. J. Soil Sci. 59: 387-396.

Chauhan, B. S., Stewart, J. W. B. and Paul, E. A. 1981. Effect of labile inorganic phosphate status and organic carbon additions on the microbial uptake of phosphorus in soils. Can. J. Soil Sci. 61: 373-385.

Chaussod, R.; Houat, S. and Guiraud, G. 1988. Size and Turnover of the Microbial Biomass in Agricultural Soils, Laboratory and Field Measurements. In Nitrogen Efficiency in Agricultural Soils; Jenkinson, D.S., Smith, K.A., Eds. New York: Elsevier pp. 312–328.

Chen, Y. and Avnimelech, Y. 1986. The role of organic matter in modern agriculture. The Netherlands: Martins Nijhoff publishers, Dordrecht.

Chen, G. C. and He, Z. L. 2002. Microbial biomass phosphorus turnover in variable-charge soils in China. Commun. Soil Sci. Plant Anal. , 33 (13 & 14): 2101-2117.

Chen, G.C.; He, Z.L. and Huang, C.Y. 2002. Turnover Period of Microbial Biomass C in Red Soils and Its Significance in Evaluating Soil Fertility. Acta Pedol. Sin.

Cheng, W. and Coleman, D. C. 1990. Effect of living roots on the soil organic matter decomposition. Soil Biol. Biochem. 22: 781-787.

Chien, S. H., Sale, P. W. G. and Freisen, O. K. 1990. A discussion of the methods for comparing the relative effectiveness of phosphate fertilizers varying in solubility. Fertilizer Research 24: 149-157.

Christensen, B. T. 1985. Wheat and barley straw decomposition under field conditions: effects of soil type and plant cover on weight loss, nitrogen and potassium content. Soil Biol. Biochem. 17: 93-97.

Christensen, B. T. 1987. Decomposability of organic matter in particle size fractions from field soils with straw incorporation. Soil Biol. Biochem. 19: 429-435.

Clarholm, M. 1985. Interactions of bacteria, protozoa and plants leading to mineralization of soil nitrogen. Soil Biol. Biochem. 17: 181-187.

Clemente, R., Paredes, C., and Bernal, M. P. 2007. A field experiment investigating the effects of olive husk and cow manure on heavy metal availability in a contaminated calcareous soil from Murcia (Spain). J. Agric., Ecosystems and Environment 118 (1): 319-326

Cole, C. V., Innis, G. S. and Stewart, J. W. B. 1977. Stimulation of phosphorus cycling in semi-arid grasslands. Ecology 58: 1-15.

CTAHR (College of Tropical Agriculture and Human Resources) 2009. Soil nutrient management for Main country. University of Hawaii, Mānoa http://www.ctahr.hawaii.edu/oc/freepubs/pdf.

Cornelissen, J. H. C. 1996. An experimental comparison of leaf decomposition rates in a wide range of temperate plant species and types. J. Ecol. 84: 573-582.

Cotrufo, M. F., De Santo, A. V., Alfani, A., Bartoil, G. and De Cristofaro, A. 1995. Effects of urban heavy metal pollution on organic matter decomposition in Quercus ilex L. Woods. Environ. Pollut. 89: 81-87

Couteax, M. M., McTiernan, B. B., Szuberia, D., Pardenne, P. and Bottner, P. 1998. Chemical composition and carbon materialization potential of scots pine needles at different stages of decomposition. Soil Biol. Biochem. 30(5): 583-595.

Cregan, P. D., Hirth, J. R., and Conyers, M. K. 1989. Amelioration of soil acidity by liming and other amendments. In: A. D. Robson, ed. Soil acidity and plant growth. Sydney: Academic Press, pp. 205-264.

CTA, 1989. Land and food: The challenge of sustainable agriculture in the tropic. Published under the direction of Robert Dellere.

Dalal, R. C. 1998. Soil microbial biomass: What do the numbers really mean? Aust. J. Exp. Agric. 38: 649-665.

Dalal, R. C. 1979. Mineralization of carbon and phosphorus from carbon-14 and phosphorus-32 labelled plant material added to soil. Soil Sci. Soc. Am. J. 43: 913-916.

Dalal, R. C. 1977. Soil organic phosphorus. Adv. Agron. 29: 83-117.

Daudu, C. K. 2004. An evaluation of different sources of organic matter on the fertility and productivity of an Alfisol in the Nigerian savanna. Ph. D. Thesis. Department of Soil Science, ABU, Zaria Nigeria.

Day, F. P. 1982. Litter decomposition rates in the seasonally flooded great dismal swamp. Ecology 63: 670-678.

Dennison, E. B. 1961. Value of farmyard manure in maintaining fertility in Northern Nigeria. Emp. J. Exp. Agric. 29: 330-336.

Deosthale, Y. G., Nagarajan, V, and Visweswar Rao, K. 1972. Some factors influencing the nutrient composition of sorghum grain. Indian J. Agric. Sci. 42: 100-108

Deosthale, Y. G and Mohan, V. S. 1970. Locational differnences in protein, lysine and leucine content of sorghum varieties. Indian J. Agric. Sci. 40: 935-941

de Ridder, N. and van Kuelen, H. 1990. Some aspects of the role of organic matter in sustainable intensified arable farming systems in West Africa. Fert. Res. 26: 299-310.

Deyoe, C. W. and Shellenberger, I. A. 1965. Amino acids and proteins in sorghum grain. J. Agric. Food Chent 13: 446-450

Diaz-Firroz, F., Villar, M. C., Gil, M., Carballas, M., Leiros, M. C.,Carballas, T. and

Cabaneiro, A. 1988. Effect of cattle slurry fractions on nitrogen mineralization in soil. J. Agric. Sci .Camb. 110: 491-497.

Doggett, H. 1965. Striga hermonthica on sorghum in East Africa. J. Agric. Sc. 65 (2): 183-194

Dolling, P. J. 1995. Effect of lupins and location on soil acidification rates. Aust J. Exp. Agric. 35: 753-763.

Donald, E. H. F. 1952. Agricultural chemistry: A reference text. Vol 1 & 2. Canada: D. Van Nostrand company, Inc.

Donaldson, J. M. and Henderson, G. S. 1990. Nitrification potential of secondary-succession upland oak forests: 1. Mineralization and nitrification during laboratory incubations. SSSA J. 54: 892-897.

Donnelly, P., Entry, J. E., Crawford, D. L. and Cromack, K. 1990. Cellulose and lignin degradation in forest soils: Response to moisture, temperature and acidity. Microbial Ecol. 20: 289-295.

Dou, Z., Toth, J. D., Galligan, D. T., Ramberg (Jr.), C. F. and Ferguson, J. D. 2000. Laboratory procedures for characterizing manure phosphorus. J. Environ. Qual. 29: 508-514.

Draper, N. R. and Smith, H. 1981. Applied regression analysis (2nd Ed.). New York: John Wiley and sons, Inc.

Dudal, R. and Deckers, J. 1993. Soil organic matter in relation to soil productivity. In: Soil organic matter dynamics and sustainability of tropical agriculture. Mulongoy, K. and Merckx, R. (eds). John Wiley and Sons, Chichester, pp 377-380.

Duncan, R. R., Bockholt, A. J. and Miller, F. R. 1981. Descriptive comparison of senescent and nonsenescent sorghum genotypes. Agron. J. 73: 849-853.

Dunteman, G. H. 1989. Principal components analysis. Sage publications, Thousand Oaks, CA: Quantitative applications in the Social Sciences Series, No. 69: 80-87.

Dwyer, L. M., Ma, B. L., Gregorich, E. and Tollenaar, M. (1993). Field maize N levels and relationships to growth and yield. p. 133. In 1993 Agronomy abstracts. Madison, WI: ASA.

Dykes, L. and Rooney, L. W. 2006. Sorghum and millet phenols and antioxidants. J. Cereal Sci. 44: 236-251.

Easterwood, G. W. and Sartain, J. B. 1990. Clover residue effectiveness in reducing orthophosphate sorption on ferric hydroxide coated soil. Soil Sci. Soc. Am. J. 54: 1345-1350.

Eckert, D. J. 1995. Nitrogen management key in conservation tillage crop production. Fluid J. 3 No. 1, issue # 8.

Egbe, O. M., Kalu, B. A. and Idoga, S. 2009. Contribution of common food legumes to the fertility status of sandy soils of the moist savanna woodland of Nigeria. Report and opininon J. 1 (1): 45-62.

Eghball, B., Wienhold, B. J., Woodbury, B. L. and Eigenberg, R. A. 2005. Plant availability of phosphorus in swine slurry and cattle feedlot manure. Agron. J. 97: 542-548.

Eid, M. T., Black, C. A. and Kempthrone, O. 1954. Significance of soil organic phosphorus to plant growth. Iowa Agric. Expt. Sta. Research Bull. 406

Elkin, R. G., Freed, M. B., Hamaker, B. R., Zhang, Y. and Person, C. M. 1995. Condensed tannins are only partially responsible for variations in nutrient digestibilities of sorghum grain cultivars. Poult. Sci. 74 (1): 125

Ellert, B. H. and Bettany, J. R. 1988. Comparison of kinetic models for describing net sulphur and nitrogen mineralization. Soil Sci. Soc. Am. J. 52:169 -1702.

Eno, C. F. 1960. Nitrate production in the field by incubating the soil in polyethylene bags. Soil Sci. Soc. Am. Proc. 24: 277-279.

Enwezor, W. O. 1966. The biological transformation of phosphorus during the incubation of a soil treated with soluble inorganic phosphorus and with fresh and rotted organic materials. Plant and Soil 25: 463-466.

Enwezor, W. O., Udo, E. J., Osoroh, N. J. , Ayotade, K. A., Adepetu, J. A., Chude, V. O. and Udegbe, C. I. 1989. Fertilizer use and management practices of crops in Nigeria. Fed. Min. Agric. Water Res. And Rural Dev. Lagos

Enwezor. W. O., Udo, E. J., Ayotade, K. A., Adepetu, J. A. and Chude, V. O. 1990. A review of soil and fertilizer use in Nigeria. pp. 241-281. In: FPDD. Literature review on soil fertility investigations in Nigeria. (Volume 5 Northwest zone). Lagos: Federal Ministry of Agriculture and National Resources.

Espanol, 2009. http://www.neemuses.com/azadirachta.php.

Esu, I. E. and Ojanuga, A. G. 1985. Morphological physical and chemical properties of Alfisols in the Kaduna area of Nigeria. Samaru J. Aric. Res. 3 (1 and 2): 39-49.

Evanylo, G.K. and Alley, M.M. 1997. Presidedress soil nitrogen test for corn in Virginia. Commun. Soil Sci. Plant Anal., 28: 1285-1301.

Fabry, G. 1963. The biological transformation of phosphorus in some characteristic profiles of brown forest soil regions. Agrokem. Talajt. 12: 427-438.

Facelli, J. M. and Pickett, S. T. A. 1991. Plant litter: its dynamics and effects on plant community structure. Bot. Rev. 57: 1-32.

Food and Agricultural Organization (FAO), 1978. Soil erosion by water: some measures for its control on cultivated lands. FAO land and water development series No. 7. Rome.

FAO, 1999. Soil fertility initiative for sub-Saharan Africa. Proc. SFI/ FAO consultation, Rome. 19th-20th, Nov. 1999. FAO, Rome. In: Vanlauwe et al. (2001). Maize yield as affected by organic input and urea in the West African Moist Savanna. Agron. J. 93: 1191-1199.

Feinerman, E., Choi, E. K. and Johnson, S. R. 1990. Uncertainty and split nitrogen application in crop production. Am. J. Agr. Econ. 72: 975-984.

Fernandez, E. C. M. and Sanchez, F. A. 1990. The role of organic inputs and soil organic matter for nutrient cycling in tropical soils. IBSRAM proc. No. 10: 169-187.

Floate, M. J. S. 1970. Mineralization of nitrogen and phosphorus from organic materials of plant and animal origin and its significance in the nutrient cycle of grazed upland and hill soils. J. Brit. Grass Soc. 25: 295-302.

Fox, R. H., Myers, R. J. K. and Vallis, I. 1990. The nitrogen mineralization rate of legume residues in soil as influenced by their polyphenol, lignin and N contents. Plant Soil 129: 251-259.

France, J. and Thornley, J. H. M. 1984. Mathematical models in agriculture. London: Butterworth and Co. Ltd.

Frankenberger, W. T. and Abdelmagid, H. M. 1985. Kinetic parameters of leguminous crops incorporated into soil. Plant Soil 87: 257-271.

Freney, J, R. and Spencer, K. 1960. Soil sulphate changes in the presence and absence of growing plants. Australian J. Agric. Research 2: 339-345.

Friend, M. T. and Birch, H. F. 1960. Phosphate responses in relation to soil tests and organic phosphorus. J. Agric. Sci. 54: 341-347.

Frossard, E., López-Hernandez, D. and Brossard, M. 1996. Can isotopic exchange kinetics give valuable information on the rate of mineralization of organic phosphorus in soils? Soil Biol. Biochem. 28: 857-864.

Frye, W. W., Ebelhar, S. A., Murkock, L. W. and Blerins, R. L. 1982. Soil erosion effects on properties and productivity of two Kentucky soils. Soil Sc. Soc. Am. J. 46: 1051-1055.

Garba, J. 2010. Effect of neem seed cake and inorganic fertilizer on soil fertility and productivity of maize in a savanna alfisol. M.Sc. Thesis. Dept. Soil Sci., Ahmadu Bello University, Zaria.

Garson, G. D. 2007. Canonical correlation, and SPSS canonical correlation output, http://www2.chass.ncsu.edu/garson/pa765/canonic.htm and http://www2.chass.ncsu.edu/garson/pa765/cancorr.htm.

Gee, G. W. and Bauder, J.W. 1986. Particle size analysis. In Aklute Ed. Methods of soil analysis (2nd Ed.) No 9 ASA Inc. SSA. Inc. Madison, Washington, DC. Pp. 383-409.

George, T. S., Gregory, P. J., Robinson, J. S., Buresh, R. and Jama, B. 1999. Tithonia diversifolia in Western Kenya: Relationship of tissue phosphorus concentration to soil phosphorus. Agrofor. Forum 9: 33-37.

Gessner, M. O. 2005. Proximate lignin and cellulose. In: Graca, M. A. S. et al. (eds). Methods to study litter decomposition. The Netherlands: Springer pp. 115-120.

Gessner, M. O. and Chauvet, F. 1994. Importance of stream microfungi in controlling breakdown rates of leaf litter. Ecology 75: 1807-1817.

Gijsman, A. J., Oberson, A., Friesen, D. K., Sanz, J. I. and Thomas, R. J. 1997. Nutrient cycling through microbial biomass under rice-pasture rotations replacing native savanna. Soil Biol. Biochem. 9: 1433-1441.

Gilani, G. S., Cockell, K. A. and Sepehr, E. 2005. Effects of antinutritional factors on protein digestibility and amino acid available in foods. J. AOAC Int., 88 (3): 967-987.

Gilchrist, S. 1967. A practical course in Agricultural Chemistry. London: Pergamon Press

Gil, J. L. and Fick, W. F. 2001. Soil nitrogen mineralization in mixtures of eastern Gama grass with alfalfa and red clover. Agron. J. 93: 902-910.

Giller, K. E. 2001. Nitrogen fixation in tropical cropping systems. http//: www.ebay.com.

Giller, K. E. 2000. Translating science into action for agricultural development in the tropics: An example from decomposition studies. Applied Soil Ecology 14: 1-3

Giller, K. E. and Wilson, K. J. 1991. Nitrogen fixation in tropical cropping systems. U. K.: C. A. B. International Wallingford.

Goladi, J. T. and Abenin, J. O. 1997. The cation exchange properties and microbial carbon, nitrogen and phosphorus in savanna alfisol under continous cultivation. J. Sc. Fd. Agric. 75(4): 412-418.

Goncalves, J. L. and Carlyle, J. C. 1994. Modelling the influence of moisture and temperature on net nitrogen mineralization in a forested sandy soil. Soil Biol. Biochem. 26: 1557-1564.

Gonzaga, S. J. A. 1988. Nitrogen mineralization from selected nitrogen ^{15}N-labelled crop residues and humus as affected by inorganic nitrogen. Dissertation Abstracts International, section B, 48:2150.

Gordillo, R. M. and Canberra, 1997. Mineralizable nitrogen in broiler litter: I. Effect of selected litter chemical characteristics. J. Environ. Qual. 26: 1672-1679

Gravelle, W. D., Alley, M. M., Brann, D. E. and Joseph, K. D. S. M.1988. Split spring nitrogen application affects on yield, lodging and nutrient uotake of soft red winter wheat. J. Prod. Agric. 1: 249-256.

Greb, B. and Olsen, S. R. 1967. Organic phosphorus in calcareous Colorado soils. Soil Soc. Am. Proc. 31: 85-89.

Greenland, D. J. and Szabolcs, I. 1994. Soil resilence and sustainable land use (ed.). Wallingford, UK: CAB International

Grierson, P. F., Comerford, N. B. and Jokela, E. J. 1999. Phosphorus mineralization and microbial biomass in a Florida Spodosol: Effects of water potential, temperature and fertilizer application. Biol. Fertil. Soils 28: 244-252.

Grigal, D. F. and McColl, 1977. Litter decomposition following forest fire in northern Minnesota. Journal of Applied Ecol. 14:531-538.

Groffman, P. M., Hanson, G. C., Kiviat, E. and Stevens, G. 1996. Variations in microbial biomass and activity in four different wetland types. Soil Sci. Soc. Am. J. 60: 622-629.

Groffman, P. M., Hendrix, P. F. and Crossley (Jr.), D. A. 1987. Effects of a winter legume on phosphorus, potassium, calcium and magnesium cycling in a humid subtropical agroecosystem. Agric. Ecosyst. Environ. 18: 281-289.

Guo, H., Guangbe, L., Zhang, D., Zhang, X. and Lu, C. 2007. Nitrogen balance and dynamic as affected by water table and fertilization management in Celery cropping systems. South-Western China. Agric. J. Agric. Res. 2 (4): 139-149.

Guo, F. and Yost, R. 1998. Partitioning soil P into the three discrete pools of differing availability. Soil Sci. 163: 822-833.

Hadas, A., Feigenbaum, S., Feigni, A. and Portnoy, R. 1986. Nitrogen mineralization rate in profiles of differently managed soil types. Soil Sci. Soc. Am. J. 50: 314-319.

Hadas, A., Feigin, A., Feigenbaum, S. and Portnoy, R. 1989. Nitrogen mineralization in the field at various soil depths. J .Soil Sci. 40: 131-137.

Halvorson, H. O. and Nakata, A. 1987. Phosphate regulation in diverse microorganisms. P. 41-42. In A. Torriani-Gorini et al. (ed.). Phosphate metabolisms and cellular regulation in microorganisms. Am. Soc. Microbiol., Washington DC.

Hamid, F. H. 2001. The effects of germination and fermentation processes on chemical composition and nutritional value of low-tannin grain sorghum. M. Sc. Thesis Faculty of Animal Production, University of Khartoum.

Hardin, E. D. and Wistendahl, W. A. 1983. The effects of flood plain trees on herbaceous vegetation patterns, microtopography and litter. Bull. Toney Bot. Club 110: 23-30.

Harmsen, G. W. and Lindenbergh, D. J. 1949. Investigations on the nitrogen nutrition of plants. I. A new method for determination of nitrogen-requirement of soils. Plant Soil 2: 1-29.

Harmsen, G. W. and van Schreven, D. A. 1955. Mineralization of organic nitrogen in soil.

Adv. Agron. 7: 299.

Harpstead, M. 1973. A classification of some Nigerian soils. Soil Sci. 116: 437-443.

Harrison, A. F. 1987. Soil organic phosphorus- A review of world literature. Wallingsford, U.K.: C. A. B. Int.

Hart, S. C. and Binkley, D. 1985. Correlations among indices of forest soil nutrient availability in fertilized and unfertilized loblolly pine plantations. Plant and Soil 85: 11-21.

Haslam, E. 1981. Vegetable tannins. In E. E. Conn (ed.). The biochemistry of plants. Vol. 7. London and New York: Academic Press, pp. 527-556

Havlin, J. L., Westfall, D. G. and Golus, H. M. 1984. Six years of phosphorus and potassium fertilization of irrigated alfalfa on calcareous soils. Soil Sci. Soc. Am. J. 48: 331-336.

Haynes, R. J. 1986. The decomposition process: Mineralization, immobilization, humus formation, and degradation. p. 52-109. In R. J. Haynes (ed.) Mineral nitrogen in plant-soil system. Madison, WI: Academic press.

Haynes, R. J. 1983. Soil acidification induced by leguminous crops. Grass Forage Sci. 38: 1-11.

Heal, O. W., Anderson, J. M. and Swift, M. J. 1997. Plant litter quality and decomposition: An historical overview. p. 3-30. In G. Cadisch and K. Giller (ed.) Driven by nature: Plant litter quality and decomposition. Wallingford, England: CAB Int.

Heathcote, R. G. and Stocking, K. R. 1970. Soil fertility under continous cultivation in northern Nigeria. II. Responses to fertilizers in the absence of organic manures. Expl. Agric. 6: 345-350.

Hedley, M. J., Stewart, J. W. B. and Chauhan, B. S. 1982. Changes in inorganic and organic soil phosphorus fractions by cultivation practice and by laboratory incubations. Soil Sci. Soc. Am. J. 46: 970-976.

Hedley, M. J. and Stewart, J. W. B. 1982. Method to measure microbial biomass phosphorus in soils. Soil Biol. Biochem. 14: 377-385.

Hegde, N. G. 1995. Neem and small farmers constraints at grass root level. Indian For. 121: 1040-1048.

Helyar, K. R. 1991. The management of acid soils. In: R. J. Wright, V. C. Wright, V. C. Baligar, R. P. Murrmann eds. Plant soil interactions at low pH. Dordrecht: Kluwer Academic publishers pp. 365-382.

Helyar, K. R. and Porter, W. M. 1989. Soil acidification, its measurement and the processes involved. In: A. D. Robson, ed. Soil acidity and plant growth. Sydney: Academic press, pp. 61-102

Henzell, R. G., Brengman, R. L., Fletcher, D. S. and McCosker, A. N. 1992. Relationships between yield and non-senescence (stay-green) in some grain sorghum hybrids grown under terminal drought stress, p. 355-358. In M. A. Foale, R. G. Henzell and P. N. Vance (ed.). Proceedings of the second Autralian Sorghum conference. Gatton, Feb 4-6, 1992. Australian Institute of Agricultural Science, Melbourne, Occassional Publication No. 68.

Henzell, R. G., Dodman, R. L., Done, A. A., Brengman, R. L. and Mayers, P. E. 1984. Lodging, stalk rot and root rot in sorghum in Australia, p. 225-235. in L. K. Mughogho (ed.). Sorghum root and stalk diseases, a critical review. Proc. Consultative group discussion of research needs and strategies for control of sorghum root and stalk disesases. Bellagio, Italy. 27 Nov.-2 Dec. 1983. ICRISAT, Patancheru, A. P., India.

Herman, W. A., McGill, W. B. and Dormaar, J. F. 1977. Effects of initial chemical composition on decomposition of roots of three grass species. Cacnadian J. Soil Sci. 57: 205-215.

Hesse, P. R. 1957. Sulphur and nitrogen changes in forest soils of East Africa. Plant and Soil 9: 86-96.

Hobbie, S. E. 1996. Temperature and plant species control over litter decomposition in Alaskan tundra. Ecol. Monogr. 66: 503-522.

Howard, P. J. A. and Howard, D. M. 1974. Microbial decomposition of tree and shrub leaf litter 1. Weight loss and chemical composition of decomposing litter. Dikos 25: 341-352.

Hoyt, P. B. and Turner, R. C. 1975. Effects of organic materials added to very acid soils on pH, aluminium, exchangeable ammonium and crop yields. Soil Sci. 119: 227-237.

Hue, N. U. and Ameni, I. 1989. Aluminium detoxification with green manures. Comm. Soil Sci. Plant Anal. 20; 1499-1511.

Hunt, H. W. 1977. A simulation model for decomposition in grasslands. Ecology 58: 469-484

Ibewiro, B., Sanginga, N., Vanlauwe, B. and Merckx, R. 2000. Nitrogen contribution from decomposing cover crop residues to maize in a tropical derived savanna. Nutrient cycling in Agrosystems 57: 131-140.

Idris, S. O., Agbaji, E. B., Agbaji, A. S. and Agbenin, J. O. 1995. Nitrogen mineralization in soil incubated with neem cake. J. Chem. Soc. Nig. 20: 23-27.

Ingham, R. E., Trofymow, J. A., Ingram, E. R. and Coleman, D. C. 1985. Interactions of bacteria, fungi and their nematode grazers: effects on nutrient cycling and plant growth. Ecological Monographs 55: 119-140.

IITA (International Institute of Tropical Agriculture) 1979. Selected methods for soil and plant analysis. Manual series no. 1. International Institute of tropical Agriculture, Ibadan, Nigeria.

Iritani, W. M. and Arnold, C. Y. 1960. Nitrogen release of vegetable crop residues during

incubation as related to their chemical composition. Soil Sci. 89: 74-82.

Iwuafor, E. N. O., Kang, B. T. and Ike, I. F. 1991. Effects of different tillage and crop residue management systems on chemical properties of an Alfisol. Proceedings of International Soil Tillage Research organization, Ibadan, Nigeria. 8-12 July, pp53-62

Iwuafor, E. N. O. 1986. The effect of tillage and crop residue management practices on the soil of Southern Guinea Savanna zone of Nigeria. Ph. D. Thesis, Ahmadu Bello University, Zaria Nigeria.

Iyamuremye, F. and Dick, R. P. 1996. Organic amendments and phosphorus sorption by soils.Adv. Agron. 56: 139-181.

James, L. E. 2002. Recovery of ^{15}N labeled fertilizers by maize using different methods of organic and inorganic N application. M. Sc. Thesis, Department of Soil Sciences, Ahmadu Bello University, Zaria.

Janssen, B. H. 1993. Integrated nutrient management: The use of organic and mineral fertilizers. In H. van Reuler and W. H. Prins (eds.). The role of plant nutrients for sustainable food crop production in sub-Saharan Africa. Dutch Association of fertilizer producers, Wageningen, The Netherlands.

Jansson, S. L. and Person, J. 1982. Mineralization and immobilization of soil nitrogen. p. 229-252. In F. J. Stevenson (ed.). Nitrogen in agricultural soils. Agron. Monogr. 22. ASA, CSSA and SSSA. Madison, WI, USA.

Jattan, S. S., Shashikumar, M. and Pujar, G. 1995. Perspectives in intensive management of neem plantations. Indian For., 121:981-988.

Jenkinson, D. S. 1977a. Studies on the decomposition of plant material in soil. IV. The effect of rate of addition. J. Soil Sci. 28: 417-423.

Jenkinson, D. S. 1977b. Studies on the decomposition of plant material in soil. V. The effect of plant cover and soil type on the loss of carbon from ^{14}C labeled ryegrass decomposing under field conditions. J. Soil Sci. 28: 424-434.

Jenkinson, D. S. 1981. The fate of plant and animal residues in soil. In: The chemistry of soil processes (eds. D. J. Greenland and M. H. B. Hayes), pp. 505-561. New York: John-Wiley.

Jenkinson, D. S. and Ladd, J. N. 1981. Microbial biomass in soil: measurement and turnover. In: Soil biochemistry (Paul, E. A., Ladd, J. N., eds), vol. 5 pp. 415-471. New York: Marcel Dekker, Inc.

Jenny, H., Gessel, S. and Bigham, F. T. 1949. Comparative study of decomposition of organic matter in temperate and tropical regions. Soil Sci. 68: 419-432.

Jensen, S. S. 1994a. Dynamics of mature pea residue nitrogen turnover in unplanted soil under field conditions. Soil Biol. Biochem. 26: 458-464

Jensen, S. S. 1994b. Mineralization-immobilization of nitrogen in soil amended with low C: N ratio plant residues with different particle sizes. Soil Biol. Biochem. 26: 519-521.

Jocteur Monrozier, L., Ladd, J. N., Fitzpatrick, R. W., Foster, R. C. and Raupauch, M. 1991. Components and microbial biomass content of size fraction in soils of contrasting aggregation. Geoderma 49: 37-62.

Johnson, D. W. 1992. Nitrogen retention in forest soils. J. Environ. Qual. 21: 1-12.

Johnson, R. 1978. Multivariate statistical analysis in geography. New York: Longman.

Johnston, A. M. and Fowler, D. B. 1991. No-till winter wheat production: response to spring applied nitrogen fertilizer form and placement. Agron. J. 83:722-728.

Jokela, W. E. 1992. Nitrogen fertilizer and dairy manure effects on corn yield and soil nitrate. Soil Sc. Soc, Am. J. 56: 148-154.

Jones, O. L. 1998. Organic acids in the rhizosphere – a critical review. Plant Soil 205: 25-44
.

Jones, J. B. (Jr.) 1991. Plant tissue analysis in micronutrients. In: Mortvedt, J. J., Cox, F. R., Shuman, L. M. and R. M. Welch (eds.) Micronutrients in Agriculture (2^{nd} ed.) (SSSA Book series No. 4) SSSA, Madison, WI, pp. 477-521.

Jones, C. A. 1984. Estimation of active fraction of soil nitrogen. Communication Soil Sci. Plant Anal. 15: 23-32.

Jones, M. J. 1976. The significance of crop residues to the maintenance of fertility under continous cultivation of Samaru, Nigeria. J. Agric. Sci. Camb. 86: 117-125.

Jones, M. J. 1973. The organic matter content of savanna soils of West Africa. Journal of soil science 24: 42-53.

Jones, M. J. and Wild, A. 1975. Soils of the West Africa savanna (Tech. Comm. No. 55). Harpenden, U. K.: Commonwealth of soils.

Jörgensen, R. G. and Möller, T. 1996. The fumigation-extraction method to estimate soil microbial biomass: Calibration of the k_{ec} value. Soil Biol. Biochem. 28: 33-37.

Jörgensen, R. G. 1996. The fumigation-extraction method to estimate soil microbial biomass: Calibration of the k_{ec} value. Soil Biol. Biochem. 28: 25-31.

Kaboneka, S., Sabbe, W. E. and Mauromoustakos, A. 1997. Carbon decomposition kinetics and nitrogen mineralization from corn, soybean, and wheat. Commun. Soil Sci. Plant Anal. 28: 1359-1373.

Kachaka, S., Vanlauwe, B. and Merckx, R. 1993. Decomposition and nitrogen mineralization of prunings of different quality. p. 199-208. In K. Mulongoy and R. Merckx (ed.) Soil organic matter dynamics and sustainability of tropical agriculture. Chichester, England: John-Wiley & Sons.

Kafkafi, U., Bar-Yosef, B., Rosenberg, R. and Sposito, G. 1988. Phosphorus adsorption by kaolinite and montmorillonite: II. Organic anion competition. Soil Sci. Soc. Am. J. 52: 1585-1589.

Kamprath, E. J. 1972. Soil acidity and liming in soils of the humid tropics. National Academy of science, Washington, D. C. pp.30-149.

Kang, B. T. and Spain, K. M. 1986. Management of low activity clays with special references to alfisols, ultisols and oxisols in the tropics. p. 107-131. Proceedings of the symposium on low activity clay (LAC) soils. Washington DC, USA.

Karlen, D. L., Mausbach, M. J., Doran, J. W., Cline, R. G., Harris, R. F. and Schuman, G. E. 1997. Soil quality: A concept, definition and framework for evaluation. Soil Sci. Soc. Am. J. 61: 4-10.

Kaye, P. and Hart, S. C. 1997. Competition for nitrogen between plants and soil microorganisms. Trend Ecol. Evol. 12: 139-143.

Kayuki, K. C. and Wortmann, C. S. 2001. Plant materials for soil fertility management in sub-humid tropical areas. Tropical soil management. Agron. J. 93: 929-935.

Kethar, C. M. and Kethar, M. S. 1995. Neem seed crush and deoiled cake as manure and as nitrification inhibitors. In: Schmutterer, H. (Ed.). The neem tree. New york: VCH.

Kethar, C. M. 1974. Neem cake blended urea for nitrogen economy. Fertilizer News, 19: 25-26.

Khosla, R. and Persaud, N. 1997. Performance of a non-linear resonant frequency capacitance probe II. Measurement of dryland crop water use. Commun. Soil Sci. Plant Anal. 28: 1347-1357.

Knoepp, J. D. and Swank, W. T. 1995. Comparison of available soil nitrogen assays in control and burned forested sites. Soil Sci. Soc. Am. 59: 1750-1754.

Korsaeth, A., Molstad, L. and Bakken, L. R. 2001. Modeling the competition for nitrogen between plants and microflora as a function of soil heterogeneity. Soil Biol. Biochem. 33: 215-226.

Kowal, J. M. and Kassam, A. H. 1978. Agricultural ecology of savanna. A study of West Africa. Clarendon: Oxford.

Kowal, J.M. and Knabe, D. 1972. An agro-climatological atlas of the Northern states of Nigeria. Zaria: Ahmadu Bello University Press

.

Kretzschmar, R. M., Hafner, H., Bationo, A. and Marschner, H. 1991. Long and short term effects of crop residues on aluminium toxicity, phosphorus availability and growth of pearl millet in an acid sandy soil. Plant Soil 136: 215-223.

Kuo, S. 1996. Phosphorus. In Methods of soil analysis, part 3 – chemical methods. D. L. Sparks (Ed.). Am. Soc. Agron., Madison, WI, pp.869-919.

Kuzyakov, Y., Friedel, J. K. and Stahr, K. 2000. Review of mechanisms and quantification of priming effects. Soil Biol. Biochem. 32: 1485-1498.

Lal, R. 1975. Role of mulching techniques in tropical soil and water management. Technical bulletin No. 1 IITA, Ibadan.

Lal, R. and Kang, B. T. 1982. Management of organic matter in soil of the tropics and sub-tropics. In: Non-symbiotic N-fixation and organic matter in the tropics. Proceedings of the XIIth International Congress of Soil Science, New-Delhi.

Lale, N. E. S. 2002. Bioactivity and limitation against widespread use of neem products for the management of insect pests. Nigerian J. Applied Biol. 3: 115-124.

Lamb, D. 1980. Soil nitrogen mineralization in a secondary rainforest succession. Oecologia 47: 257-263.

Lambert, C. 1983. Influence de la précocité sur le développement du mil (*Pennisetum typhoides* Stapf & Hubb.) en conditions naturelles. I. Elaboration de la touffe. Agronomie Tropicale 38 (1): 7-15.

Lamond, R. E. and Whitney, D. A. 1991. Evaluation of starter fertilizer for grain sorghum production. J. Fert. Issues 8: 20-24.

Larson, W. E., Clapp, C. E., Pierre, W. H. and Morachan, Y. B. 1972. Effects of increasing amounts of organic residues on continous corn: II. Organic carbon, nitrogen, phosphorus and sulphur.Agron. J. 64: 204-208.

Lawes, D. A. 1977. Yield improvement in spring oats. J. Agric. Sci. 89: 751-757.

Leeper, G. W. 1964. Introduction to soil science. London and New York: Cambridge University Press

Legg, J. O., Chichester, F. W., Stanford, G. and DeMar, W. H. 1971. Incorporation of ^{15}N-tagged mineral nitrogen into stable forms of soil organic nitrogen. Soil Sci. Soc. Am. Proc. 35: 273-276.

Lehmann, J., Cravo, M. S., Macedo, J. L. V., Moreira, A. and Schroth, G. 2001. Phosphorus management for perennial crops in Central Amazonian upland soils. Plant and Soil 237: 309-319.

Lehman, J., Schroth, G. and Zech, W. 1995. Decomposition and nutrient release from legumes, twigs and roots of three alley-cropped tree legumes in central Togo. Agroforestry Systems 29: 21-36.

Leita, L., De Nobili, M., Mondini, C., Muhlbachova, G., Marchiol, L., Bragato, G. and Contin, M. 1999. Influence of inorganic and organic fertilization on soil microbial biomass, metabolic quotient and heavy metal bioavailability. Biol. Fertil. Soils 28: 371-

376.

Leprince, F. and Quiquampoix, H. 1996. Extracellular enzyme activity in soil: Effect of pH and ionic strength on the interaction with montmorillonite of two acid phosphatases secreted by the ectomycorrhizal fungus, Hebeloma cylindrosporum. Eur. J. Soil Sc. 47: 511-522

.

Lewandowski, A., Zumwinkle, M. and Fish, A. 1999. Assessing the soil system: A review of soil quality literature. Minnesota Dept. of Agriculture, Energy and Sustainable Agriculture Program, St. Paul.

Li, G. C., Mahler, R. L. and Everson, D. O. 1990. Effects of plant residues and environmental factors on phosphorus availability in soils. Commun. Soil Sci. Plant Anal. 21: 471-491.

Lockaby, B. G. and Walbridge, M. R. 1998. Biogeochemistry In: M. G. Messina and W. H. Conner (ed.) Southern forestedwetlands: ecology and management. Boca Raton, FI: Lewis publishers pp. 149-172.

Lockaby, B. G., Murphy, A. L. and Somers, G. L. 1996. Hydroperiod influences on nutrient dynamics in decomposing litter of a flood plain forest. Soil Sci. Soc. Am. J. 60: 1267-1272.

Lockaby, B. G., Miller, J. H. and Clausson, R. G. 1995. Influences of community composition on biogeochemistry of loblolly pine (pinus taeda) systems. Am. Midl. Nat. 134: 176-184.

Lombin, G., Adepetu, J. A. and Ayotade, K. A. 1991. Complementary use of organic manures and inorganic fertilizers in arable crop production. Paper presented at the organic farmer seminar, Kaduna. March 6^{th}-8^{th}, 1991.

Lopez-Gutièrrez, J. C., Toro, M. and López-Hernandez, D. 2004a. Seasonality of organic P mineralization in the rhizosphere of the native savanna grass, Trachypogon plumosus. Soil Biol. Biochem. 36 (10): 1675-1684.

Lopez-Gutièrrez, J. C., Toro, M. and López-Hernandez, D. 2004b. Arbuscular mycorrhiza and enzymatic activities in the rhizosphere of T. plumosus Ness in three acid savanna soils. Agric. Ecosys. Environ. 103 (2): 405-411.

López-Hernandez, D. and Niño, M. 1993. Phosphorus mineralization during laboratory incubation in soils derived from different textured parent material. Geoderma 56: 527-37.

Lughtenberg, B. 1987. Phosphate regulation in Escherichia coli. P. 1-2. In A. Torriani-Gorini et al. (ed.). Phosphate metabolisms and cellular regulation in microorganisms. Am. Soc. Microbiol., Washington DC.

Lundeberg, G. 1970. Utilization of various nitrogen sources, in particular bound soil nitrogen, by mycorrhizal fungi. Studia Forestolia Suecica 79.

Ma, B. L., Dwyer, L. M. and Gregorich, E. G. 1999. Soil nitrogen amendment effects on seasonal nitrogen mineralization and nitrogen cycling in maize production. Agron. J. 91: 1003-1009.

Macduff, J. H. and White, R. E. 1985. Net mineralization and nitrification rates in a clay soil measured and predicted in permanent grassland from soil temperature and moisture content. Plant and Soil 86: 151-172.

Macklon, A. E. S., Grayston, S. J., Shaud, C. A., Sim, A., Sellars, S., Ord, B. G. 1997. Uptake and transport of phosphorus by Agrostis capillaries seedlings from rapidly hydrolysed organic sources extracted from ^{32}P-labelled bacterial cultures. Plant Soil 190: 163-167.

Maconachie, R. 2007. Urban growth and land degradation in developing cities: change and challenges in Kano, Nigeria. Aldershot: Ashgate

MacRea, R. J. and Mehyus, G. R. 1985. The effect of green manuring on the physical properties of temperate area soils. Adv. Soil Sci. 3: 71-94.

Maddux, L. D., Kissel, D. E. and Barnes, P. L. 1984. Effects of nitrogen placement and application on irrigated corn. J. Fert. Issues 1: 86-89.

Mahamood, S. and Smithard, R. 1993. A comparison of effects of body weight and feed intake on digestion in broiler cockerels with effects of tannins. Br. J. Nutr. 70: 701-709

Maloney, P. C., Ambudkar, S. V. and Sonna, L. A. 1987. Anion exchange as the molecular basis of sugar transport in bacteria. In: Torriani-Gorini, A., Rothman, F. G., Silver, S., Wright, A. and Yagil, E. (eds.).Phosphate metabolisms and cellular regulation in microorganisms. Washington DC: American Society of microbiology pp.191-196.

Maman, N, Mason, S. C., Lyon, D. J. and Dhungana, P. 2004. Yield components of pearl millet and grain sorghum across environments in the Central Great Plains. Crop Sci. 44: 2138-2145.

Marchesni, A., Alefeni, L., Comotti, E. L. and Ferrari, A. 1988. Long term effects of quality compost treatment on soil. Plant and Soil 106: 253-261.

Marion, G. M., Kummerow, J. and Miller, P. C. 1981. Predicting nitrogen mineralization in chaparral soils. Soil Sci. Soc. Am. J. 45: 956-961.

Marschner, H. 1995. Mineral nutrition of higher plant. London: Academic Press.

Marschner, H. 1998. Role of root growth, arbuscular mycorrhiza, and root exudates for the efficiency in nutrient acquisition. Field Crops Res. 56: 203-207.

Marshall, C. E. 1964. The physical chemistry and mineralogy of soils. New York: John Wiley and Sons.

Martin, J. P. and Haider, K. 1980. Microbial degradation and stabilization of 14C labeled lignins, phenols and phonelic polymers in relation to soil humus formation. In: Kirk, T. K., Higachi, T. and Chang, H. M. (eds.). Lignin biodegradation: microbiology, chemistry and potential application. Vol. 2. Palm Beach, Florida, USA: CRC press.

Mary, B. and Recous, S. 1994. Measurement of nitrogen mineralization and immobilization fluxes in soils as a means of predicting net mineralization. Eur. J. Agron. 3: 291-300.

Matson, P. A. and Boone, R. D. 1984. Natural disturbance and nitrogen mineralization: wave-form dieback of mountain hemlock in the Oregon cascades. Ecology 65: 1511-1516.

Matson, P. A. and Vitousek, P. M. 1981. Nitrogen mineralization and nitrification potentials following clear-cutting in the Hoosier National Forest, Indiana. For. Sci. 27: 781-791.

Mayer, J., Buegger, F., Jensen, E. S., Schleter, M. and Heb, J. 2003. Residual nitrogen contribution from grain legumes to succeeding wheat and rape and related microbial process. Plant and Soil 253: 541-554.

Mazzarino, M. J., Oliva, L., Nuñez, A., Nuñez, G. and Buffa, E. 1991. Nitrogen mineralization and soil fertility in the dry Chaco ecosystem (Argentina). Soil Sci. Am. J. 55: 515-522.

Mbagwu, J. S. C., Unamba-Oparah, I. and Neabh, G. O. 1994. Physico-chemical properties and productivity of two tropical soils amended with dehydrated swine waste. Bioresource Technology 49: 163-171.

McAuliffe, C. D., Hall, N. S., Dean, L. A. and Hendricks, S. B. 1948. Exchange reactions between phosphates and soil: Hydroxylic surfaces of soil minerals. Soil Sci. Soc. Am. Proc. 12: 119-128.

McBee, G. G., Waskom III, R. M., Miller, F. R. and Creelman, R. A. 1983. Effect of senescence and nonsenescence on carbohydrates in sorghum during late kernel maturity states. Crop Sci 23: 372-376.

McClaugherty, C. and Berg, B. 1987. Cellulose, lignin and nitrogen levels as rate regulating factors in late stages of forest litter decomposition. Pedobiologia 30: 101-112.

McClaugherty, C. A., Pastor, J., Aber, J. D. and Melillo, J. M. 1985. Forest litter in relation to soil nitrogen dynamics and litter quality. Ecology: 66: 266-275.

McGill, W. B. and Cole, C. V. 1981. Comparative aspects of cycling of organic C, N, S and P through soil organic matter. Geoderma 26: 267-286.

McLaughlin, M. J. and Alston, A. M. 1986. The relative contribution of plant residues and fertilizer to the phosphorus nutrition of wheat in a pastore/cereal system. Aust. J. Soil Res. 24: 517-526.

McLaughlin, M. J., Alston, A. M. and Martin, J. K. 1986. Measurement of phosphorus in the soil microbial biomass: a modified procedure for field soils. Soil Biol. Biochem. 18: 437-

443.

McLaughlin, M. J., Alston, A. M. and Martin, J. K. 1988a. Phosphorus cycling in wheat-pasture rotations. II. The role of the microbial biomass in phosphorus cycling. Aust. J. Soil Res. 26: 333-342.

McLaughlin, M. J., Alston, A. M. and Martin, J. K. 1988b. Phosphorus cycling in wheat-pasture rotations. III. Organic phosphorus turnover and phosphorus cycling. Aust. J. Soil Res. 26: 343-353.

Meelu, O. P., Yadvinder, S. and Bijay, S. 1994. Green maturing for soil productivity improvement. World Soils Resource Report 76. FAO, Rome.

Meentemeyer, V. 1978. Macroclimate and lignin control of litter decomposition rates. Ecology 59: 465-472.

Mengel, K. and Kirkby, E. A. 2001. Principles of plant nutrition. 5th (ed.). Dordrecht, Boston, London: Kluwer Academic Publishers

Mengel, D. B., Nelson, D. W. and Huber, D. M. 1982. Placements of nitrogen fertilizers for no-till and conventional till corn. Agron. J. 74: 515-518.

Melillo, J. M. and Aber, J. D. 1984. Nutrient immobilization in decaying litter: An example of carbon-nutrient interactions. p. 193-215. In J. H. Cooley and F. B. Golley (ed.) Trends in ecological research for the 1980's. New York: Plenum.

Melillo, J. M. and Aber, J. D. and Mutarore, L. E. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. J. Ecol. 63: 621-626.

Meyer, W. L., Marsh, M., Arp, P. A. 1994. Cation exchange capacities of upland soils in eastern Canada. Can. J. Soil Sci. 74: 393-408.

Micheni, A., Kihanda, F. and Irunges, J. 2004. Soil organic matter: The basis for improved crop production in arid and semi-arid climates of Eastern Kenya. In: Bationo, A. (ed.). Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa. Kenya: Academy Science Publishers.

Microsoft student with Encarta Premium 2008 DVD. Tannins.

Millar, C. E., Turk, L. M. and Foth, H. D. 1965. Fundamentals of soil science (4th ed.). London: John-Wiley and sons, Inc.

Minderman, G. 1968. Addition, decomposition and accumulation of soil organic matter in forests. J. Ecology 56: 355-376.

Mishra, M. M., Neelankantan, S., Narayan, K. G. and Vyas, S. R. 1972. Studies on the decomposition of organic matter in soil – II: Effect of sesbania and bajra stubble plus neem cake. J. Res. Hissar 2, 150-155.

Mishra, M. M., Neelankantan, S., Khandelwal, K. C., Bhardwaj, S. K. and Vyas, S. R. 1975. Margosa (neem) seed cake as an inhibitor of nitrification. Soil Biol. Biochem. 7: 183-184.

Mitaru, B. N., Reichert, R. D. and Blair, R. 1984. Improvement of the nutritive value of high tannin sorghums for broiler chickens by light moisture storage. Poult. Sci. 62: 2065-2072

Mitsch, W. J. and Gosselink, J. G. 1993. Wetlands (2nd ed.). New York: van Nostrand Reinhold.

Moberg, J. P. and Esu, I. E. 1991. Characteristics and composition of some savanna soils in Nigeria. Geoderma 48: 113-129.

Mohammed, K. O. 2009. Contemporary challenges in research and sustainable development in the third world: The role of neem seed cake in maintaining soil fertility and health. Journal of Agricultural Research and Policies 4 (2): 28-35.

Mokunye, A., de Jager, A. and Smaling, E. M. A. 1996. Restoring and maintaining the productivity of West African soils: Key to sustainable development.

Mokwunye, A. V. 1979. Phosphorus needs of soils and crops of the savanna zones of Nigeria. Phosphorus Agric. 76: 87-95.

Mokwunye, A. V. 1991. Alleviating soil fertility constraints to increase crop production in West Africa. Netherlands: Kluwer Academic Publishers.

Moore, A. M. 1986. Temperature an moisture dependence of decomposition rates of hardwood and coniferous leaf litter. Soil Biol. Biochem. 18: 427-435.

Moorhead, D. L., Currie, W. S., Rastetter, E. B., Parton, W. J. and Harmon, M. E. 1999. Climate and litter quality controls on decomposition: An analysis of modeling approaches. Global Biogeochemical Cycles 13 (2): 575-589.

Moorhead, D. L., Sinsabaugh, R. L., Linkins, A. E., Reynolds, J. F. 1996. Decomposition processes: modeling approaches and applications. Sci. Total Environ. 183: 137-149.

Morel, C., Tiessen, H. and Stewart, W. B. 1996. Correction for P-sorption in the measurement of soil microbial biomass P by $CHCl_3$ fumigation. Soil Biol. Biochem. 28: 1699-1706.

Mugendi, D., Mucheru-Muna, M., Mugwe, J., Pypers, P., Vanlauwe, B. and Merckx, R. 2009. Nitrogen fertilizer equivalency of selected organic materials in the central highlands of Kenya. http:// www. Google.com.

Mugendi, D. N., Choge, B. O., Coulson, C. L., Stigter, C. J. and Sang, F. K. 1994. Decomposition of Cassia siamea loppings in semi arid Machalos, Kenya. Arid Soil Research and Rehabilitation 8: 363-372.

Mulongoy, K. and Sanginga, N. 1990. Nitrogen contribution by Leucaena in alley cropping. IITA Research 1 (1): 14-17.

Mulvaney, R. L. 1996. Nitrogen-inorganic forms. p. 869-920. In J. Bigham (ed.) Methods of soil analysis. Part 3. Chemical methods. SSSA and ASA, Madison, WI.

Murwira, H. K. and Kirchmann, H. 1993. Nitrogen dynamics and maize growth in a Zimbabwean sandy soil under manure fertilization. Commun. Soil Sci. Plant Anal. 24: 2343-2359.

Murwira, H. K., Mutuo, P., Nhamo, N., Marandu, A. E., Rabeson, R., Mwale, M. and Palm, C. A. 2002. Fertilizer equivqlency values of organic materials of differing quality. In: intergrated plant nutrient management in sub-Saharan Africa, Vanlaume, B., Diels, J., Sanginga, N. and Merckx, R. (eds.). CAB International, pp. 113-122.

Mutuo, P. K., Marandu, A. E., Raberson, R. M., Snapp, M. S. and Palm, C. A. 1999. Nitrogen fertilizer equivalencies based on organic input quality and optimum combinations of organic and inorganic nitrogen sources: Network trial results from East and southern Africa. In: SWNM report on the combating nutrient depletion EastbAfrica Highlands consortium.

Myers, R. J. K., Palm, C. A., Luevas, E., Gunatileke,, I. U. N. and Brossard, M. 1994. The synchronization of nutrient mineralization and plant nutrient demand. In: The biological management of tropical soil fertility, Woomer, P. L. and Swift, M. J. (eds.). Wiley-Sayce Pub. Pp 81-116.

Nadelhoffer, K. J., Aber, J. D. and Melillo, J. M. 1983. Leaf litter production and soil organic matter dynamics along a nitrogen-availability gradient in Southern Wisconsin (USA). Can. J. Forest Res. 13: 12-21.

Nadelhoffer, K. J., Aber, J. D. and Melillo, J. M. 1985. Fine roots, net primary production, and soil nitrogen availability: a new hypothesis. Ecology 66: 1377-1390.

NAERLS 1996. Prospects and problems of the 1996 cropping season. A report of study conducted by National Agric. Extension and Research Laision Services and Agricultural planning monitoring and Evaluation Unit (APMEU) 20TH September – 4th October 1996 NAERLS, Ahmadu Bello University, Zaria. Nigeria 62 pp

Nagarajah, S., Posner, A. M. and Quirk, J. P. 1970. Competitive adsorption of phosphate with polygalacturonate and other organic anions on kaolinite and oxide surfaces. Nature, London 228: 83-84.

Nambiar, K. K. M. 1994. Soil fertility and crop productivity under long term fertilizer use in India. New Delhi: ICAR.

Neem foundation. 2005. Neem for fertility and fertilizer management. http://www.neemfoundation.org/

Nelson, D. W. and Sommers, L. E. 1996. Total carbon, organic carbon and organic matter. In: Sparks, D. R. Ed. Methods of soil analysis. Part 3. Chemical methods. Madison, WI: Soil Sci. Soc. Am. Book Series pp. 961-1010.

Noggle, J. H. 1985. Physical chemistry. In Ellert, B. H. and Bettany, J. R. (1988). Comparison of kinetic models for describing net sulphur and nitrogen mineralization. Soil Sci. Soc. Am. J. 52:1692-1702.

Nye, P. H. and Bertheux, M. H. 1957. The distribution of phosphorus in forest and savanna soils of the Gold Coast and its agricultural significance. J. Agric. Sci. 49: 141-159.

Nye, P. H. and Greenland, D. J. 1960. The soil under shifting cultivation. Common wealths bureau of soils technical communications 51. Harpenden, U. K. 156pp.

Obatolu, C. R. and Agboola, A. A. 1993. The potential of Siam weed as a source of organic matter for soils in the humid tropics. In Soil organic dynamics.Mulong, K. and Merckx, R. 1993 pp.286.

Oberson, A., Besson, J. M., Maire, N. and Sticher, H. 1996. Microbiological processes in soil organic phosphorus transformations in conventional and biological farming systems. Biol. Fertil. Soils 21: 138-148.

Oberson, A., Friesen, D. K., Tiessen, H., Morel, C. and Stahel, W. 1999. Phosphorus status and cycling in native savanna and improved pastures on an acid low-P Colombian Oxisol. Nutr. Cycl. Agroecosyst. 55: 77-88.

Oberson, A., Frisen, D. K., Rao, I. M., Buhler, S. and Frossard, E. 2000. Phosphorus transformation in an oxisol under contrasting land use systems. The role of soil microbial biomass. Plant and Soil 237: 197-210.

Obi, M. E. and Ebo, P. O. 1995. The effects of organic and inorganic amendments on soil physical properties and maize production in a severity degraded sandy soil in southern Nigeria. Bioresource Tech. 51: 117-123.

Odion, E. C., Asiribo,O. E., Ogunlela, V. B., Singh, B. B. and Tarawali, S. A. 2007. Strategies to improve and sustain food production capacity in the savanna: The role of leguminous fodder crops in maintaining soil fertility and health. J. Food, Agric. And Environ. 5(2): 338-344.

Odunze, A. C. 2011. Use of meterological data in Agriculture. Training manual: Training of monitoring and evaluation staff handling weather data collection of Kaduna State Agricultural Development project (FSRP), Institute for Agricultural Research (IAR), ABU Zaria. Special publication 1: 1-6.

Odunze, A. C., Tarawali, G. and Magaji, S. O. 1996. Nigerian sub-humid savanna zone alfisols for sustainable crop and livestock production. Arid Soil Research and Rehabilitation. 10: 265-267.

Oehl, F., Oberson, A., Sinaj, S. and Frossard, E. 2001. Organic phosphorus mineralization studies using isotopic dilution techniques. SSSA J. 65: 780-787.

Ogbuewu, I.P., V.U. Odoemenam, H.O. Obikaonu, M.N. Opara and O.O. Emenalom et al.,

2011. The growing importance of neem (Azadirachta indica A. juss) in agriculture, industry, medicine and environment: A review. Res. J. Med. Plant, 5: 230-245.

Ogunlela, V. B. and Okoh, P. N. 1989. Response of three sorghum varieties to N supply and plant density in a tropical environment. Fertil. Res. 21: 67-74.

Ogunlela, V. B. 1988. Growth and yield responses of dryland grain sorghum to nitrogen and phosphorus fertilization in a ferruginous tropical soil (Haplustalf). Fertil. Res.17: 125-135.

Ogunlela, V. B. and Yusuf, Y. 1988. Yield and growth response to potassium of grain sorghum as influenced by variety in a savanna soil of Nigeria. Fertil. Res.16: 217-226.

Ogunlela, V. B. 1983. Striga, fertilizer application and hybrid sorghum performance in the Nigerian savanna. J. Agron. & Crop Sci. 152: 208-218.

Ogunwole, J. O. 2008. Soil aggregate characteristics and organic carbon concentration after forty-five annual application of manure and inorganic fertilizer. Biol. Agric. Hort. 25: 223-233.

Ojanuga, A. 1979. Clay mineralogy of soils in the Nigerian tropical savanna regions. Soil Sci. Soc. Am. J. 43: 1237-1242.

Ojeniyi, S. O. 2011. Advances in integrated nutrient management for crop production in Nigeria. Proceedings of the 35th Annual Conference of Soil Science Society of Nigeria p.35-42.

Okalebo, J. R., Gathua, K. W. and Woomer, P. L. 2002. Laboratory methods of soil and plant analysis: A working manual (2nd ed.). Nairobi, Kenya.

Okalebo, J. R. and Woomer, P. L. 1994. Use of rock and fertilizer phosphorus in Eastern and Southern Africa: A data summary. Proc. of the 14th conference of the Soil Science Society of East Africa, Mbarara, Uganda, November, 1994.

Okalebo, J. R., Simpson, J. R., Okwach, G. E., Probert, M. E. and McCown, R. L. 1997. Conservation of soil fertility under intensive maize cropping in semi-arid eastern Kenya. Proceedings of the African crop science conference proceedings 3: 429-437.

Okonkwo, E. M. 2005. Sustainable techniques for harvesting, processing, quality control and utilization of neem products. A paper presented at a seminar organized by the Central Bank of Nigeria at Gombe state: "Transfoming neem tree into wealth". 23rd-25th November.

Olson, J. S. 1963. Energy storage and the balance of producers and decomposers in ecological systems. Ecology 44: 322-331.

Ong, C. K. and Monteith, J. L. 1984. Response of pearl millet to light and temperature. Field Crop Res. 11: 141-160.

Oohara, H., Yoshida, N. and Chang, N. K. 1971. Balance of producers and decomposers in a grassland system in Obihiro. J. Japanese Grassland Sci. 17: 7-18.

Ortiz-Monasterio, J. I., Peña, R. J., Pfeiffer, W. H. and Hede, A. H. 2002. Phosphorus use efficiency, grain yield and quality of triticale and durum wheat under irrigated conditions. Proceedings of the 5th International Triticale symposium, Annex June 30-July , 2002, Radzików, Poland.

Owonubi, J. J., Abdulmumin, S., Malgwi, W. B. and Mu'azu, S. 1991. Review of soil water balance studies of the Sudano-Sahelian zone of Niger. In: Soil water balance in the Sudano-Sahelian zone. Proc. Of Niamey workshop. Feb. 1991. M. V. K. Siva kumar, J. S. Wallance, C. Renord and C. Grivoux 329-388. JAHS publ. No. 199.

Pal, D. and Broadbent, F. E. 1974. Kinetics of rice straw decomposition in soils. J. Environ. Qual. 4: 256-260.

Palm, C. A., Gachengo, C. N., Delve, R. J., Cadish, G. and Giller, K. E. 2001. Organic inputs for soil fertility management in tropical agroecosystems: applications of an organic resource database. Agric. Ecosystems and Environment 83: 27-42.

Palm, S. A., Myers, R. J. K. and Nandwa, S. M. 1997. Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. Pp. 193-217. In: Replenishing soil fertility in Africa. SSSA Special publ. no. 51. SSSA, ASA. Madison, Wisconsin.

Palm, C. A. 1995. Contributions of agroforestry trees to nutrient requirements of inter cropped plants. Agroforestry systems 30: 105-124.

Palm, C. A. and Sanchez, P. A. 1991. Nitrogen release from the leaves of tropical legumes as affected by their lignin and polyphenol contents. Soil Biochem. 23: 83-88.

Palmer, G. H. 1991. Sorghum – Food Beverage and Brewing Potentials. Review Process Biochemistry 27(1992): 145-153.

Papendick, R. I. 1994. Maintaining soil physical conditions. In: soil resilience and sustainable land use. Wallenford:AB Int. pp. 215-234.

Parashar, K. S., Prasad, R., Sharma, R. P. and Singh, S. 1980. Efficiency of urea, nitrification inhibitors treated urea and slow release nitrogen fertilizers for sugarcane. Z Pflanzenernaehr Bodenkd 143: 262-267.

Parr, J. F. and Papendick, R. I. 1978. Factors affecting the decomposition of crop residues by micro-organisms. In: Crop residue management systems (ed. W. R. Oschwald), pp 101-129. ASA-CSSA-SSSA, Madison, WI.

Patrao, M. R. 1985. Rare neem tree with sweet leaves. Neem Newsletter 2 (3): 34.

Penga, S., Lazaa, R. C., Visperasa, R. M., Sanicoa, A. L., Cassman, K. G. and Khush, G. S. 2000. Grain yield of rice genotypes and lines developed in the Philippines since 1966.

Crop Sci. 40: 307-314.

Pestov, N. 1994. The physico-chemical properties of granular and powdered fertilizers. Nauka, Moscow, p.175

Phiri, S. A., Rao, E. and Singh, B. R. 2001a. Disc harrowing intensity and its impact on soil properties and plant growth of agropastoralism systems in the Lanos of Colombia Soil. Tillage Research 62: 131-143.

Phiri, S., Barrios, E., Rao, J. M. and Singh, B. R. 2001b. Changes in soil organic matter and phosphorus fractions under plant fallows and crop rotation on Colombian volcanic ash soil. Plant and Soil 211-223.

Powell, J. M. and Williams, T. O. 1995. An overview of mixed farming systems in sub-Saharan Africa. In: Powell, J. M, Fernandez-Rivera, S., Williams, T. O. and Renard, C. (eds.), Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa. Proceedings of an International conference held at ILCA, Addis Ababa, Ethiopia, 22-26 November, 1993. Volume II. Technical papers. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethipia, pp 21-36.

Prasad, R., Singh, S., Saxena, V. S. and DevKumar, C. 1999. Coating of prilled urea with neem (Azadirachta indica J.) oil for efficient nitrogen use in rice. Short communication. Naturwissenschaften 86: 538-539.

Preston, C. M., Trofymow, J. A. and CIDET Worhing Group. 2000. Variability in litter quality and its relationship to litter decay in Canadian Forests. Can. J. Bot. 78: 1269-1287

Quintana, J. O., Pereira, J., Bouldin, D. R. and Lathwell, D. J. 1988. Screening legume green manures as nitrogen sources to succeeding non-legume crops. Plant and Soil 111: 1-85.

Radwanski, S. A. 1969. Improvement of acid soil by neem trees (Azadirachta indica) in Sokoto, north western state of Nigeria. J. of Applied Ecology 6: 507-511.

Radwanski, S. A. and Wickens, G. E. 1981. Vegetative fallows and potential value of the neem tree in the tropics.Econ. Botany 35: 398-414.

Raison, R. J., Connell, M. J. and Khanna, P. K. 1987. Application of sequential soil coring and in situ incubations to the study of N-cycling in plant communities. In Nitrogen cycling in agricultural systems of temperate Australia. Australian Society of Soil Science, Wagga Wagga.

Rajcan, I. and Tollenaar, M. 1999. Source-sink ratio and leaf senescence in maize. I. Dry matter accumulation and partitioning during the grain-filling period. Field Crops Res. 60: 245-253.

Rao, S. C. and Dao, T. H. 1992. Fertilizer placement and tillage effects of nitrogen assimilation by wheat. Agron. J. 84: 1028-1032.

Rao, S. C. and Dao, T. H. 1996. Nitrogen placement and tillage effects on dry matter and nitrogen accumulation and redistribution in winter wheat. Agron. J. 88: 365-371.

Rapp, M., Leclerc, M. C. and Lossaint, P. 1979. The nitrogen economy of a Pinus pinea L. stand. Forest Ecology and Management 2: 221-231.

Ravankar, H. N., Sarap, P. A., Topre, R. K., Rathod, V. B. and Deshmukh, P. W. 2001. Productivity, nutrient availability and their uptake in sorghum-wheat sequence under long term fertilization in vertisol. Agric. Sc. Digest 21 (3): 141-144

Rayburn, L., Repert, D. and Weiland, T. 1993. Wood decomposition: Nitrogen and phosphorus dynamics in relation to extracellular enzyme activity. Ecology 74: 1586-1593.

Read, D. J. 1983. The biology of mycorrhiza in the Ericales. Can. J. Botany 61: 985-1004.

Rehm, G. and Schmitt, M. 1993. understanding phosphorus in Minnesota soils. Minnesota: Communication and Educational Technology services, University of Minnesota Extension.

Reid, J. B. and Goss, M. J. 1982. Suppression of decomposition of ^{14}C-labelled plant roots in the presence of living roots of maize and perennial ryegrass. J. Soil Sci. 33: 387-395.

Reinertsen, S. A., Elliot, L. F., Cochran, V. L. and Campbell, G. S. 1984. Role of available carbon and nitrogen in determining the rate of straw decomposition. Soil Biol. Biochem. 16: 459-464.

Rengel, Z. 2003. Handbook of soil acidity. Australia: Marcel Dekker, Inc.

Rhoades, J. D. 1996. Salinity: Electrical conductivity and total dissolved solids. In. Methods of soil analysis, Part3. Chemical methods. Ed. D. L. Sparks. Pp. 417-435. SSSA, Madison, WI.

Richards, R. A. 2000. Selectable traits to increase crop photosynthesis and yield of grain crops. J. Exp. Bot. 51: 447-458.

Richardson, A. E., Hadobas, P. A. and Hayes, J. E. 2000. Acid phosphomonoesterase and phytase activities of wheat (Triticum aestivum L.) roots and utilization of organic phosphorus substrates by seedlings grown in sterile culture. Plant Cell Environ. 23:397-405.

Riggs, T. J., Hanson, P. R., Start, N. D., Miles, D. M., Morgan, C. L. and Ford, M. A. 1981. compariosm of spring barley varieties grown in England and Wales between 1880 and 1980. J. Agric. Sci. 97: 599-610.

Ritchie, G. S. P. and Dolling, P. J. 1985. The role of organic matter in soil acidification. Aust. J. Soil Res. 23: 569-576.

Rosenow, D. T. 1977. Breeding for lodging resistance in sorghum. p. 171-185. In: H. D. Loden and D. Wilkinson (ed.). Proceedings of the 32nd Annual Corn and Sorghum Research Conference. Am. Seed Trade Assoc. Washington, DC.

Rosenow, D. T. 1984. Breeding for resistance to root and stalk rots in Texas. p. 209-217. In: L. K. Mughogho (ed.). Sorghum root and stalk diseases, a critical review. Proc. Consultative group discussion of research needs and strategies for control of sorghum root and stalk diseases. Bellagio, Italy, 27 Nov.-2 Dec. 1983. ICRISAT, Patancheru, A. P., India.

Rosenow, D. T. and Clark, L. E. 1981. Drought tolerance in sorghum. p. 18-31. In: H. D. Loden and D. Wilkinson (ed.). Proc. 36th Annu. Corn and Sorghum Industry Res. Conf. Chicago, IL. 9-11 Dec. 1981. Am. Seed Trade Assoc., Washington, DC.

Rosenow, D. T., Quisenberry, J. E., Wendt, C. W. and Clark, L. E. 1983. Drought tolerant sorghum and cotton germplasm. Agric. Water Manage. 7: 207-222.

Rubins, E. J. and Bear, F. E. 1942. Carbon-to-nitrogen ratios in organic fertilizer materials in relation to the availability of their nitrogen. J. Soil Sci. 54: 411-423.

Runge, M. 1974. Die stickstoff-mineralization im boden eines sauerhumus-buchenwaldes. I. Mineralstickstoff-Gehalt und netto-mineralization. Oecologia Plantarum 9: 239-250.

Sanchez, P.A. 1994. Tropical soil fertility research, towards the second paradigm. Transactions, 15th World Congress of Soil Science, Vol. 1, Acapulco, Mexico, 65–88.

Sanginga, N. 2003. Role of biological nitrogen fixation in legume based cropping systems; a case study of West Africa farming systems. Plant and Soil 252 (1): 25-39.

Santhi, S. R., Palaniappan, S. P. and Purushothaman, D. 1986. Influence of neem leaf on nitrification in a lowland rice soil. Plant and Soil 93: 133-135.

Sateesh, M. K. 1998. Microbiological investigations on die-back disease of neem (Azadirachta indica A. Juss.). Ph. D. Thesis, University of Mysore. Mysore, India.

Sauerborn, J., Sprich, H. and Mercer-Quarshie, H. 2000. Crop rotation to improve agricultural production in sub-Saharan Africa. J Agron Crop Sci-Z Acker-Pflanzenb 184:67–72

Sawhney, S. K. and Naik, M. S. 1969. Amino acid composition of protein fractions of pearl millet and the effect of nitrogen fertilization on its proteins. Indian J. Genet. Plant Breed 29: 395-406.

Scharf, P. C. 1993. Development of field-specific spring nitrogen rate recommendations for winter wheat. Ph. D. dissertation. Virginia Polytechnic Institute and State University, Blacksburg, VA. 24061

Schimel, D. S. and Parton, W. J. 1986. Microclimate controls of N mineralization and

nitrification in shortgrass steppe soils. Plant Soil 93, 347–357.

Schmidt, E. L. 1982. Nitrification in soil. p. 253-288. In F. J. Stevenson (ed.) Nitrogen in agricultural soils. Agron. Monogr. 22. ASA, CSSA, and SSSA, Madison, WI.

Schmitt, M. A. and Randall, G. W. 1994. Developing a soil nitrate test for improved recommendations for corn. J. Prod. Agric. 7: 328-334.

Schmutterer, H. 2002. The neem tree, Azadirachta indica A. Juss and other meliaceous plant sources of unique natural products for integrated pest management, medicine and other purposes (2nd ed.). Neem foundation: Mumbai, India.

Schmutterer, H. and Singh, R. P. 1995. List of insects susceptible to neem products. In: The neem tree sources of unique natural products for integrated pest management, medicine, industry and other purposes. Schmutterer, H. (ed.). New York: VCH, Publishers

Schmutterer, H. 1990. Properties and potential of natural pesticides from the neem tree, *Azadirachta indica.* Ann. Rev. Entomol. 35: 271-297.

Seastedt, T. R. Jr. 1984. The role of microarthropods in decomposition and mineralization process. Ann. Entom. 29: 25-46.

Sedgley, R. H. 1991. An appraisal of the Donald ideotype after 21 years. Field Crops Res. 26: 93-112.

Seeling, B. and Zasoski, R. J. 1993. Microbial effects in maintaining organic and inorganic solution phosphorus concentrations in a grassland topsoil. Plant Soil 148: 277-284.

Sewanne, K. K. and Simmons, J. 2003. Leaf litter decomposition. West Virginia Wesleyan College. http:// www.sewanee.edu/forestry_Geology

Sharpley, A. N. and Moyer, B. 2000. Phosphorus forms in manure and compost and their release during simulated rainfall. J. Environ. Qual. 29: 1462-1469.

Sharpley, A. N. and Smith, S. J. 1989. Mineralization and leaching of phosphorus from soil incubated with surface-applied and incorporated crop residue. J. Environ. Qual. 18: 101-105.

Sher, A., Barbanti, L., Ansar, M., Manaf, A. and Kaleem, S. 2011. Late harvest associated with P and S fertilization enhances yield and quality of forage sorghum (Sorghum Bicolor (L.) Moench), grown as a rainfed crop in Pakistan. African J. Agric. Res. 6 (29): 6232-6239.

Shields, J. A. and Paul, E. A. 1973. Decomposition of ^{14}C-labelled plant material under field conditions. Can. J. Soil Sci. 53: 297-306.

Shiga, H. 1997. The decomposition of fresh and composted organic materials in soil. http:// www.agnet.org/library/eb/4447/.

Shiga, H., Ooyama, N., Suzuki, M., Maeda, K. and Suzuki, K. 1985. The effect of organic matter management in paddy fields on the accumulation of organic matter, or on the nitrogen sources in soils and growth of rice. Bulletin of the Nat. Agric. Res. Centre 5: 21-38.

Singh, B. B. and Jones, J. P. 1976. Phosphorus sorption and desorption characteristics of soil as affected by organic residues. Soil Sci. Soc. Am. Proc. 40: 389-394.

Singh, Y., Khind, C. S. and Singh, B. 1991a. Efficient management of leguminous green manures in wetland rice. Adv. Agron. 45: 136-189.

Singh, G. and Singh, O. P. 1994. Effect of slow release urea materials of rice and succeeding wheat. N. D. University of Agriculture and Technology, Centre Ghagharghat, Uttar Pradesh, India. Annals. Of Agric. Res. 15 (3): 260-263.

Singh, R. P., Singh, P. P. and Nair, K. P. P. 1991b. Studies on controlled release of N fertilizers and nitrification inhibitors. Indian J. Agric. Res. 25: 59-62.

Singh, U., Patil, S. K., Das, R. O., Padiila, J. L., Singh, V. P. and Pal, A. R. 1999. Nitrogen dynamics and crop growth on an alfisol and a vertisol under rain lowland rice based cropping system. Field Crops Research 61: 231-252.

Sinsabaugh, R. L., Antibus, R. K., Linkins, A. E., McClaugherty, C. A., Rayburn, L. and Repert, D. 1993. Wood decomposition: nitrogen and phosphorus dynamics in relation to extracellular enzyme activity. Ecology 74: 1586-1593.

Six, J., E.T.Elliott, and K.Paustian. 2000. Soil structure and soil organic matter. II. A Normalized stability index and the effect of mineralogy. *Soil Sci. Soc. Am. J.* 64:1042–1049.

Smith, S. J. and Power, J. F. 1985. Residual forms of fertilizer nitrogen in a grassland soil. Soil Sc. 140: 362-367.

Smith, S. J. and Sharpley, A. N. 1990. Soil nitrogen mineralization in the presence of surface and incorporated crop residues. Agron. J. 82: 112-116.

Smith, S. J., Young, L. B. and Miller, G. E. 1977. Evaluation of soil nitrogen mineralization potentials under modified field conditions. Soil Sci. Soc. Am. J. 41: 74-76.

Snapp, S. S. 1995. Improving fertilizer efficiency with small additions of high quality organic inputs. In S. R. Waddington (ed.), Report on the first meeting of the Network working group. Soil fertility research network for maize-based farming systems in selected countries of Southern Africa. Lilonge, Malawi, and Harare, Zimbabwe: The Rockefeller Foundation. Southern Africa Agricultural Sciences Programme and CIMMYT. Pp. 60-65.

Snedecor, G. W. and Cochran, W. G. 1978. Statistical methods. (6^{th} ed.). USA: Iowa State University press.

Sollins, P., Spycher, G. and Glassman, C. A. 1984. Net nitrogen mineralization from light- and heavy-fraction forest soil organic matter. Soil Biol. Biochem. 16: 31-37.

Solomon, M. G., Okon, P. B. and Umoetok, S. B. A. 2008. Effect of neem extracts on soil properties, microbial population and leaf area of fluted pumpkin (*Telfairia occidentalis*). Res. J. of Agron. 2 (1): 12-17.

Somda, Z. C., Powell, J. M., Fernandez-Rivera, S. and Reed, J. 1993. Feed factors affecting nutrient excretion by ruminanta and the fate of nutrients when applied to soil. In: Livestock and sustainable nutrient cycling in mixed farming system of sub-Saharan Africa. Powell, J. M., Fernandez-Rueria, Williams, T. O. and Renard, C. (eds.). Volume II, Addis Ababa, Ethiopia, pp 27-246

Soufizadeh, S. 2005. Physiology of yield, canopy structure and phenology of different rapeseed (*Brassica napus* L.) genotypes and determining the ideotype (thesis). (Tehran): University of Tehran, Iran.

Soufizadeh, S., Hejazi, A. Z. and Akbari, Gh Al, Allahdadi, I, Deihimfard, R. and Sheibany, K. 2006. Has hybridization improved biomass production, and the quantity and quality of winter oilseed rape (*Brassica napus* L.) yield successfully? Paper presented at: Proceedings IX Congress of European society for Agronomy: Warsaw, Poland.

Sparling, G. P., Cheshire, M. V, and Mundie, C. M. 1982. Effect of barley plants on the decomposition of 14C-labelled soil organic matter. J. Soil Sci. 33: 89-100.

Specht, J. E., Hume, D. J. And Kumudini, S. V. 1999. Soybean yield potential – A genetic and physiological perspective. Crop Sci. 39: 1560-1570.

Stanford, G. and Epstein, E. (1974). Nitrogen mineralization – water retention in soil. Soil Sci. Soc. Am. Proc. 38: 103-107.

Stanford, G., Frere, M. H. and Van der pol, R. A. 1975. Effect of fluctuating temperatures on soil nitrogen mineralization. Soil Sci. 119: 222-226.

Stanford, G., Frere, M. H. and Schwaninger, D. H. 1973. Temperature coefficient of soil nitrogen mineralization. Soil Sci. 115: 321-323.

Stanford, G. and Smith, S. J. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Am. Proc. 36: 465-472.

Stanford, G., Carter, J. N. and Smith, S. J. 1974. Estimates of potentially mineralizable soil nitrogen based on short-term incubations. Soil Sci. Soc. Am. Proc. 38: 99-102.

Stangel, P. J. 1995. Nutrient cycling and its importance in sustaining crop-livestock systems in sub-Saharan Africa: An overview. In: Powell, J. M., Fernandez-Rueria, S., Williams, T. O. and Renard, C. (Eds.). Livestock and sustainable nutrient cycling in mixed farming

system of sub-Saharan Africa. Vol. II. Technical papers proceedings of ILCA Conference, Addis-Ababa, Ethiopia pp. 37-62.

Steele, K. W. and Vallis, I. 1988. The nitrogen cycle in pastures. p. 274-291. In: J. Wilson (ed.). Advances in nitrogen cycling in agricultural ecosystems. Wallingford, U. K.: CAB Int.

Steele, K. W. and Vallis, I. 2001. Improving water use of annual crops and pastures – limitations and opportunities in Western Australia. Aust. In: Connor, D. J. et al. 2011 (ed.) 568p. Crop ecology: Productivity and management in Agricultural systems. http:// www.booksgoogle.com.ng/books ISBN 0521761271

Stevenson, F. J. 1986. Cycles of carbon, nitrogen, phosphorus, sulphur and micronutrients. New York: Wiley, 380pp.

Stevenson, F. J. 1982. Humus: Chemistry, genesis, composition and reactions. New York: J. Wiley 433pp.

Stewart, J. W. B. and Tiessen, H. 1987. Dynamics of soil organic phosphorus. Biogeochemistry 4: 41-60.

Stocking, M. and Murnaghan, N. 2001. Handbook for the field assessment of land degradation. London, Stering, UK: Earthscan Publication Limited.

Stribley, D. P. and Read, D. J. 1980. The biology of mycorrhiza in the Ericaceae VII. The relationship between mycorrhizal infection and the capacity to utilize simple and complex nitrogen sources. New Phytologist 86: 365-371.

Struthers, P. J. and Sieling, D. H. 1950. Effect of organic anions in phosphate precipitation by iron and aluminium as influenced by pH. Soil Sci. 69: 205-213.

Swift, M. J., Heal, O.W. and Anderson, J. M. 1979. Decomposition in terrestrial ecosystems. Studies in ecology. Vol. 5. England, Oxford: Blackwell scientific.

Swift, M. J. and Sanchez,P. A. 1984. Biological management of tropical soil fertility for sustained productivity. Nature and Resources 10: 1-8.

Syers, J. K. and Craswell, E. T. 1995. Role of organic matter in sustainable agricultural systems.In: Soil organic matter for sustainable agriculture, Legroy, R. D. B., Blair,G. J. and Craswell, E. T. (Eds.).ACIAR workshop proceedings No 5: 7-14.

Sylvester-Bradley, R., Mosquera, D. and Mèndez, J. E. 1988. Inhibition of nitrate accumulation in tropical grassland soils: Effect of nitrogen fertilization and soil disturbance. J. Soil Sci. 39: 407-416.

Talpaz, H., Fine, P. and Bar-Yosef, B. 1981. On the estimation of nitrogen mineralization parameters from incubation experiments. Soil Sci. Soc. Am. J. 45: 993-996.

Tang, C., Sparling, G. P., McLay, C. D. A., Raphael, C. 1999. Effect of short term legume

residue decomposition on soil acidity. Aust. J. Soil Res. 37: 561-573.

Tarfa, B. D. 2001. Effect of some selected indigenous tree foliage on soil fertility and productivity of a savanna soil. Unpublished Ph. D. thesis, Department of soil science, faculty of agriculture, Ahmadu Bello University, Samaru, Zaria 164pp.

Tarfa, B. D., Uyovbisere, E. O., Chude, V. O., Raji, B. A. and Yaro, D. J. 2001. Effect of the complementary use of foliage Azadirachta indica, Parkia biglobossa and NPK on yield and nutrients uptake of maize in a savannah soil. Nig. J. Soil Res. 2: 43-50.

Terrell, T. B., Lockaby, B. G., Conner, W. H., Meier, C. E., Stanturf, J. A. and Burke, M. K. 2001. Leaf litter decomposition and nutrient dynamics in four southern forested flood plain communities. Soil Sci. Soc. Am. J. 65: 1334-1347.

Theng, B. K. G., Tate, K. R. and Sollins, 1989. Constituents of organic matter in temperate and tropical soils. In Coleman, D. C., Oades, J. M. and Ueraha, G. (eds). Dynamics of soil organic matter in tropical ecosystems. Honolulu, Hawaii, USA: University of Hawaii press.

Thibaud, M. C., Moret, C. and Fardeau, J. C. 1988. Contribution of phosphorus issued from crop residues to plant nutrition. Soil Sci. Plant Nutr. 34: 481-491.

Thomas, H. and smart, C. M. 1993. Crops that stays green. Ann. Applied Biol. 123: 193-219.

Thompson, L. M. and Black, C. A. 1950. The mineralization of organic phosphorus, nitrogen and carbon in Clarion and Webster soils. Soil Sci. Soc. Am. Proc. 14: 147-151.

Thompson, L. M., Black, C. A. and Zoellner, J. A. 1954. Occurrence and mineralization of organic phosphorus in soils, with particular reference to associations with nitrogen, carbon, and pH. Soil Sci. 77: 185-196.

Thonnissen, C., Midmore, D. D., Ladha, J. K., Oik, D. C. and Schmidhalter, U. 2000. Legume decomposition and nitrogen release when applied as green manures to tropical vegetable production systems. Agron. J. 92: 253-260.

Tian, G., Kang, B. T. and Brussard, L. 1993. Mulching effect of plant residues with chemically contrasting composition on maize growth and nutrients accumulation. Plant soil 153: 179-187.

Tian, G., Kang, B. T. and Brussard, L. 1992. Biological effect of plant residues with contrasting chemical composition under humid tropical conditions- Decomposition and nutrient release. Soil Biol. Biochem. 24: 1051-1060.

Tiersen, H. 1991. Characterization of soil phosphorus and its availability in different ecosystems. Trends in soil science. Counc. Sci. Res. Integration, Trivendrum, India pp.83-99. www.toprak.org.tr/isd/can_35.htm.

Tiessen, H. J., Stewort, W. B. and Cole, V. C. 1984. Pathways of phosphorus transformations in soil differing pedogenesis. Soil Sci. Soc. Am. J. 48: 853-858.

Till, A. R. and Blair, G. J. 1978. The utilization by grass of sulphur and phosphorus from clover litter. Aust. J. Soil Res. 29: 235-242.

Tisdale,S. L., Nelson, W. L., Beaton, J. D. and Havlin, J. L. 2003. Soil fertility and fertilizers (5th ed.). New Delhi: Prentice-Hall of India private limited.

Tisdall, J. M. and Oades, J. M. 1982. Organic matter and water-stable aggregates in soils. J. Soil Sci. 33: 141-163

Touchton, J. T. and Hargrove, W. L. 1982. Nitrogen sources and method of application for no-tillage corn production. Agron. J. 74: 823-826.

Trofymow, J. A., Moore, T. R. and Titus, B. 2002. Rates of litter decomposition over 6 years in Canadian forests: influence of litter quality and climate. Canadian J. forestry Res. 32: 789-804.

Turner, C. L. 1997. Soil nitrogen and plant responses to fire, topography, and supplemental nitrogen in tall grass praire. Ecology 78: 433-444.

Uko, O. J. and Kamalu, T. N. 2001. The neem tree – uses and potentials. Nig. J. Exptal. Applied Biol. 2:223-229.

United State Agency International Development. 2008. Package of practices for sorghum production. Nigeria: USAID Markets.

USDA (Soil Survey Staff) 1975. Soil taxononmy: A basic system of soil classification for making and interpreting soil survey (1st ed.). 754p. USDA Handbook 436. Washington DC: US Govt. Printing Office,

Uyovbisere, E. O.1979. Influence of inorganic phosphate fractions on tractable phosphorus in the Northern Guinea savanna ecological zone. M. Sc. Thesis, ABU, Zaria, Nigeria.

Uyovbisere, E. O. and Lombin, G. 1991. Efficient fertilizer use for increased production: The subhumid savanna experience. Fertilizer Research 29: 81-94.

Uyovbisere, E. O. and Elemo, K. A. 2000. Effect of inorganic fertilizer and foliage of Azadirachta and Parkia species on the productivity of early maize.Nig. J. Soil Res..1: 17-22.

Uyovbisere, E. O., Elemo, K. A. and Tarfa, B. D. 1999. Effect of foliage of locust bean and neem on soil fetility and productivity of early maize in a savanna Alfisol. In: Impact, challenges and prospects of maize research and development in West and Central Africa. WECAMAN/ IITA workshop proceedings pp. 185-194.

Valette, J. A. and Ibanga, I. J. 1984. The detailed soil survey of the experimental farm of the Institute for Agricultural Research Farm, Samaru, Zaria, Nigeria. Soil survey bull. Ahmadu Bello University, Zaria, Nigeria.

Vallis, I. and Jones, R. J. 1973. Net mineralization of nitrogen in leaves and litter of

D.intortom and P. artropurpureus mixed with soil. SBB 5: 391-398.

Vance, E. D. , Brookes, P. C. and Jenkinson, D. S. 1987. An extraction method for measuring soil biomass C. Soil Biol. Biochem. 19: 703-707.

Van der Krift, T. A. J., Gioacchini, P., Kuikman, P. J. and Berendse, F. 2001. Effects of high and low fertility plant species on dead root decomposition and nitrogen mineralization. Soil Biol. Biochem 33: 2115-2124.

Vanderlip, R. L. 1993. How a sorghum plant develops. Cooperative extension service contribution No. 1203, Kansas Agricultural Experiment Station, Manhattan, Kansas.

Van der Meersh, M. K., Mulungoy, K. and Merckx, R. 1993. Evolution of plant biomass and nutrient content alley relation to soil fertility changes in two alley cropping systems. In: Soil matter dynamics and sustainability of tropical agriculture, Mulungoy, K. and Merckx, R. (Ed.). John Wiley U. K. pp.143-154.

Vanderpitte, V., Quartaert, P., DeRore, H. and Verstraete, W. 1995. Evaluation of the Gompertz function to model survival of bacteria introduced into soils. Soil Biol. Biochem. 27: 365-372.

Vanlauwe, B. 2001. Integrated soil fertility management research at TSBF: the framework, the principles, and their application. P. 25-42. In: Integrated soil fertility management in Africa. http:// www.books. google.com.ng/books

Vanlauwe, B., Wendt, J. and Diels, J. 2001. Combined application of organic matter and fertilization. SSSA special publication 58: 247-279.

Vanlauwe, B., Diels, J., Sanginga, N., Carsky, R. J., Deckers, J. and Merckx, R. 2000. Utilization of rock phosphate by crops on a representative toposequence in the Northern Guinea savanna zone of Nigeria: Response by maize to previous herbaceous legume cropping and rock phosphate treatments. Soil Biol. Biochem. 32: 2079-2090.

Vanlaume, B., Diels, J., Sanginga, N. and Merckx, R. 1997. Residue quality and decomposition: an unsteady relationship. In: Driven by nature: plant litter quality and decomposition. CAB Int. Pp 157-166. International, pp. 113-122.

Vanlauwe, B. and Sanginga, N. 1995. Efficiency of the use of nitrogen from pruning and soil organic matter dynamics in *Leucaena leucocephala* alley cropping in south western Nigeria. P. 279-292. In: R. Dudal and R. N. Roy (ed.). Integrated plant nutrition systems. FAO, Rome, Italy.

Van Noordwijk, M., Cadisch, G. and Ong, K. 2004. Below ground interactions in tropical agroecosystems. 580p. Wallingford: CABI.

Velthof, G. L., van Beusichen, M. L., Raijmakers, W. M. F. and Jassen, B. H. 1998. Relationship between availability indices and plant uptake of nitrogen and phosphorus from organic products. Plant Soil 200: 215-226.

Verhoeven, J. T. A., Maltby, E. and Schmitz, M. B. 1990. Nitrogen and phosphorus mineralization in fens and bogs. J. Ecol. 78: 713-726.

Vietmeyer, N. D. 1992. Neem: A tree for solving global problems. Washington, DC: National Academy press.

Virzo De Santo, A., Alfani, A. and Fioretto, A. 1982. Nitrogen mineralization in southern beech forests. Pedobiologia 23: 348-357.

Vitousek, P. M. and Matson, P. A. 1985. Disturbance, nitrogen availability and nitrogen losses in an intensively managed loblolly pine plantation. Ecology 66: 1360-1376.

Waggle, D. H., Deyoe, C. W. and Smith, F. W. 1967. Effect of nitrogen fertilization on the amino acid composition and distribution in sorghum grain. Crop Sci. 7: 367-368.

Walbridge, M. R. and Vitousek, P. M. 1987. Phosphorus mineralization potentials in acid organic soils: Processes affecting $^{32}PO^{3-}_{4}$ isotope dilution measurements. Soil Biol. Biochem. 19: 709-717.

Wallace, J. S. 1996. The water balance of mixed tree-crop systems. In: Ong, C. K. and Huxley (eds.) Tree-crop interactions: a physiological approach. Wallingford, UK: CAB International pp.73-158.

Wander, M. 2004. Soil organic matter fractions and their relevance to soil functions. In: F. Magdoff and R. R. Weil (eds.). Soil organic matter in sustainable agriculture. Washington D. C.: CRC press.

Wander, M. M. and Bidert, M. G. 2000. Tillage practice influences on the physical protection, bioavailability and composition of particulate organic matter. Biol. Fertil. Soils 32: 360-367.

Waniska, R. D. 2000. Structure, phenolic compounds and antifungal proteins of sorghum caryopses. In Chandrashekas, A. , Bandyopadhyay, R. and Hall, A. J. (eds.). Technical and institutional options for sorghum grain mold management: proceedings of an International consultation. ICRISAT. Pp. 72-106.

Wardle, D. A. 1992. A comparative assessment of factors which influence microbial biomass carbon and nitrogen levels in soil. Biol. Rev. 67: 321-358.

Warsi, A. S. and Wright, B. C. 1973. Effects of rates and methods of nitrogen application on the quality of sorghum grain. Indian J. Agric. Sci. 43: 722-726.

Waterman, P. G. and Mole, S. 1994. Analysis of phenolic plant metabolites. Ecology in ecology Oxford: Blackwell Scientific Publications

Watsman, S. A. 1938. The method of proximate analysis and its application to the study of plant residues, composts and humus formations. Trans. Int. Soil Sci. Comm. III, A, 101-119.

Wedin, D. A. and Tilman, D. 1990. Species effects on nitrogen cycling: A test with perennial grasses. Oecologia 84: 433-444.

Weider, R. K., Carrel, J. E., Rapp, J. K. and Kucera, C. L. 1983. Decomposition of tall festue (Festuca elatior var. arundinacea) and cellulose litter on surface mines and a tall grass praire in central Missouri, USA. Journal Applied Ecology

Weider, R. K. and Lang, G. E. 1982. A critique of the analytical methods used in examining decomposition data obtained from litter bags. Ecology 63 (6): 1636-1642.

Weier, K. L. and MacRae, I. C. 1993. Net mineralization, net nitrification and potentially available N in the subsoil beneath a cultivated pasture. J. Soil Sci. 44: 451-458.

Weil, R. R. and Magdoff, F. 2004. Significance of soil organic matter to soil quality and health. In Magdoff, F. and Weil, R. R. (eds.). Soil organic matter in sustainable agriculture. Boca Raton London New York Washington, D. C.: CRC press.

Westermann, D.T. and Crothers, S. E. 1980. Measuring soil nitrogen mineralization under field conditions. Agron. J. 72: 1009-1012. Murphy, R. P. (1958). J. Sci. Fd. Agric. 9: 714

White, R. E. and Ayoub, A. T. 1983. Decomposition of plant residues of variable C/P ratio and the effect on soil phosphate availability. Plant and Soil 74: 163-173.

Wikipedia, 2009. http://enwikipedia.org/wiki/neem_cake.

Wild, A. 2003. Soils, land and food: managing the land during the twenty-first century. Cambridge, UK: Cambridge University Press p. 246.

Williams, C. H. 1967. Some factors affecting the mineralization of organic sulphur in soils. Plant Soil 26: 205-223.

Winding, A., Hund-Rinke, K. and Rutgers, M. 2005. The use of micro-organisms in ecological soil classification and assessment concepts. Ecotoxicol. Environ. Saf. 62: 230-248

Wong, M. T. F. and Notcliff, S. (1995). Seasonal fluctuations of native available N and characterization of rice-growing environments. The Netherlands, Wageningen: ILRI (Publication No 52).

Woodfin, C. A., Rosenow, D. T. and Clark, L. E. 1988. Association between the stay-green trait and lodging resistance in sorghum. p. 102. In: Agron. Abstracts, ASA, Madison, WI.

Woomer, P. L. and Swift, M. J. 1994. The biological management of Tropical soil fertility. Chichester, UK: John Wiley and Sons.

Yadvinder-Singh, Bijay-Singh. and Khind, C. S. 1992. Nutrient transformations in soils amended with green manures. Adv. Soil Sci. 20: 237-309.

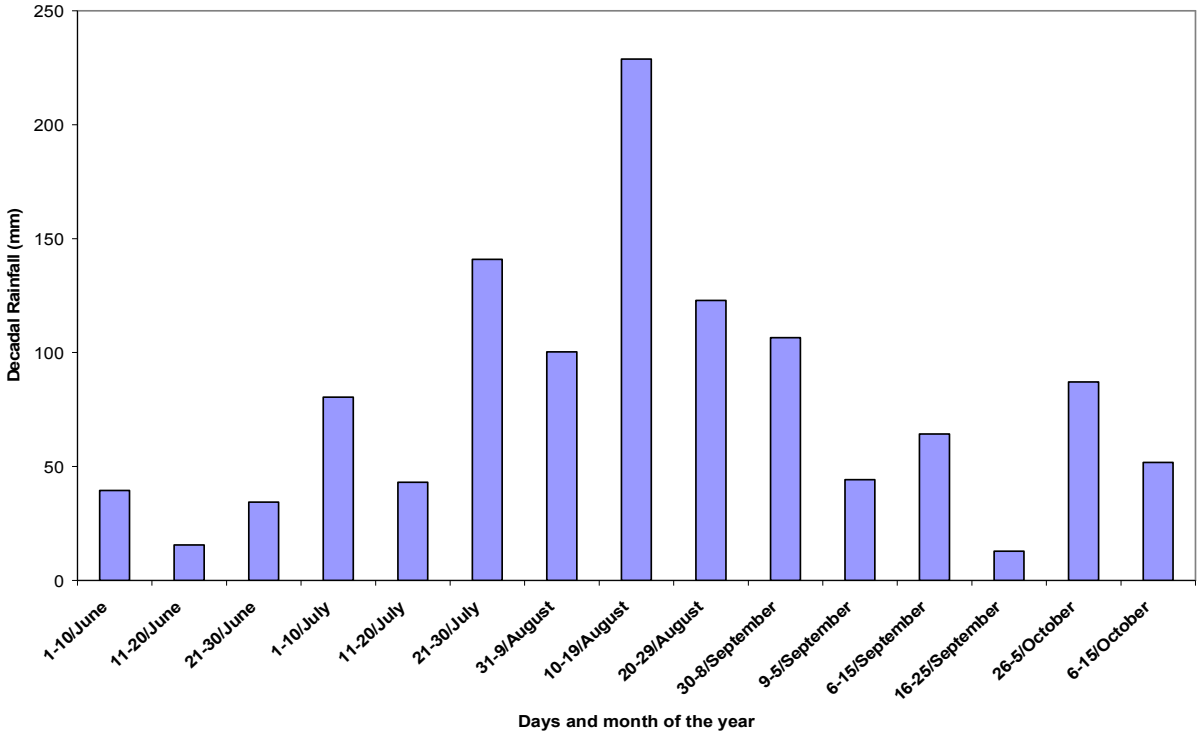
Yar'adua, A. A. 2007. Short term effect of neem residues on soil physico-chemical properties

and its implication for Striga management in a semi-arid agro-ecology. Proceedings of the 41st Conference of Agric. Soc. Of Nig. P.234-238.

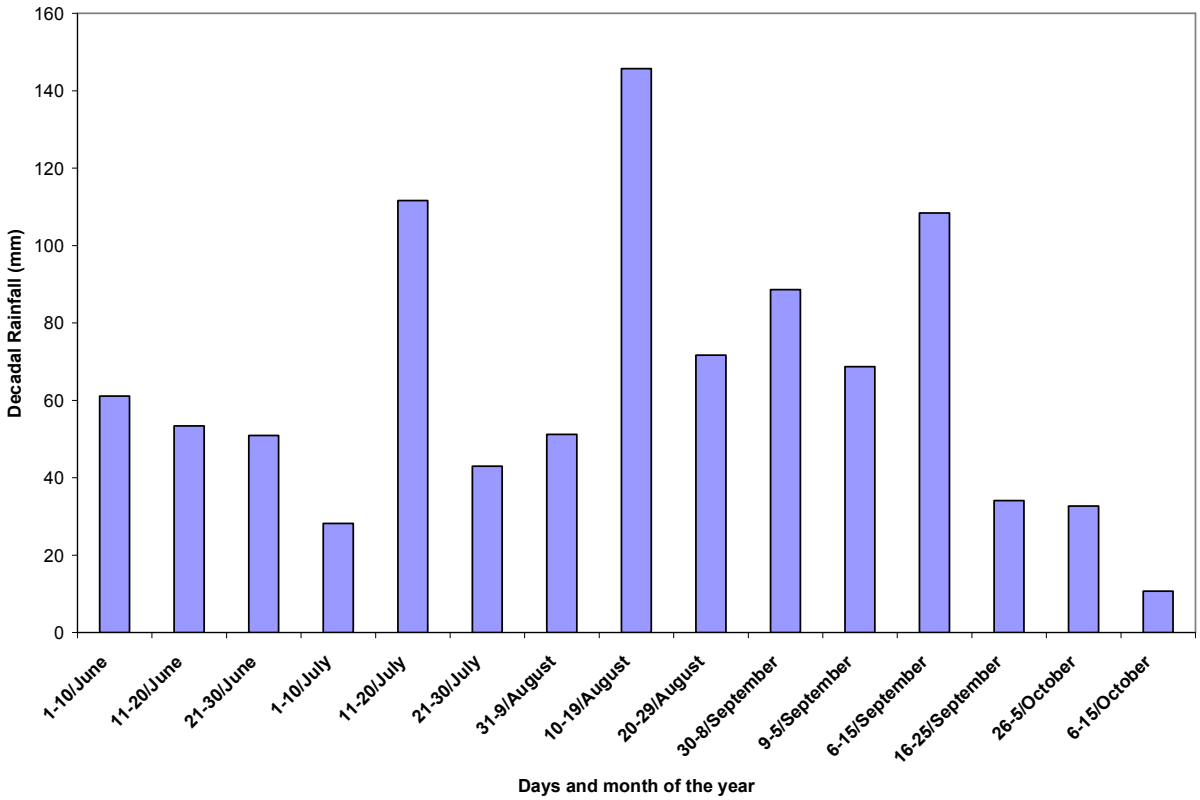
Zagal, E. 1994. Influence of light intensity on the distribution of carbon and consequent effects on mineralization of soil nitrogen in a barley (Hordeum vulgare L.) soil system. Plant Soil 160: 21-31.

Zou, X., Binkley, D. and Doxtader, K. G. 1992. A new method for extracting gross phosphorus mineralization and immobilization rates in soil.Plant and Soil 147: 243-250.

Zvomuya, F., Helgason, B. L., Larney, F. J., Janzen, H. H., Akinremi, O. O. and Olson, B. M. 2006. Predicting phosphorus availability from soil-applied composted and non-composted cattle feedlot manure. J. Environ. Qual. 35: 928-937.



Appendix 1: Rainfall Decadal Analysis for 2009 at Samaru



Appendix 2: Rainfall Decadal Analysis for 2010 at Samaru

APPENDIX 3

TWO-WAY ANOVA FOR THE GREENHOUSE GROWTH PARAMETERS OF SORGHUM

Variables	Source	Degree of freedom	Sum of squares	Mean square	F - value	Pr > F
Leaf number	Replicate	2	0.1155	0.0577	0.33	0.7249
	NPK	3	0.4479	0.1493	0.84	0.4821
	NSC	3	0.3889	0.1296	0.73	0.5420
	NPK*NSC	9	3.3067	0.3674	2.07	0.0655
	Error	30	5.3244	0.1775		
	TOTAL	47	9.5834			
Plant height	Replicate	2	176.5590	88.2795	4.33	0.0222*
	NPK	3	22.2570	7.4190	0.36	0.7794
	NSC	3	35.5723	11.8574	0.58	0.6315
	NPK*NSC	9	335.4438	37.2715	1.83	0.1039
	Error	30	611.3824	20.3794		
	TOTAL	47	1811.2145			
Stem girth	Replicate	2	0.0142	0.0071	0.27	0.7670
	NPK	3	0.0894	0.0298	1.12	0.3547
	NSC	3	0.1059	0.0353	1.33	0.2822
	NPK*NSC	9	0.1611	0.0179	0.68	0.7242
	Error	30	0.7944	0.0265		
	TOTAL	47	1.1649			
Dry matter yield at eight weeks	Replicate	2	3.5762	1.7881	0.50	0.6093
	NPK	3	17.2768	5.7589	1.62	0.2049
	NSC	3	7.9839	2.6613	0.75	0.5310
	NPK*NSC	9	57.6888	6.4099	1.81	0.1085
	Error	30	106.4760	3.5492		
	TOTAL	47	193.0017			

LEGEND: * Significant at 0.05 level of probability

APPENDIX 4

TWO-WAY ANOVA FOR GREENHOUSE NUTRIENT UPTAKE

Variables	source	Degree of freedom	sum of squares	mean square	F-value	Pr > F
Total nitrogen	Replicate	2	21.6586	10.8293	3.31	0.0504
	NPK	3	5.3594	1.7865	0.55	0.6551
	NSC	3	14.7095	4.9032	1.5	0.2355
	NPK*NSC	9	37.4056	4.1562	1.27	0.2938
	Error	30	98.2895	3.2763		
	Total	47	177.4226			
Total phosphorus	Replicate	2	0.4457	0.2229	6.07	0.0061**
	NPK	3	0.234	0.078	2.13	0.1178
	NSC	3	0.164	0.0547	1.49	0.2372
	NPK*NSC	9	0.5815	0.0646	1.76	0.1182
	Error	30	1.1006	0.0367		
	Total	47	2.5258			
Total potassium	Replicate	2	709.1567	354.5784	2.93	0.0690
	NPK	3	744.4074	248.1358	2.05	0.1282
	NSC	3	138.2537	46.0846	0.38	0.7678
	NPK*NSC	9	899.5213	99.9468	0.83	0.5983
	Error	30	3633.791	121.1264		
	Total	47	6125.131			

LEGEND: ** Significant at 0.01 level of probability

APPENDIX 5

TWO-WAY ANOVA FOR GREENHOUSE SOIL PROPERTIES AFTER CROPPING

Variables	Sources	Degree of freedom	Sum of square	Mean square	F-value	Pr > F
pH_{water}	Replicate	2	0.007	0.0035	0.56	0.5782
	NPK	3	0.1377	0.0459	7.37	0.0008**
	NSC	3	0.9674	0.3225	51.74	<0.0001***
	NPK*NSC	9	0.1165	0.0129	2.08	0.0646
	Error	30	0.187	0.0062		
	Total	47	1.4155			
pH_{CaCl2}	Replicate	2	0.0013	0.0006	0.08	0.9204
	NPK	3	0.0308	0.0103	1.37	0.2715
	NSC	3	0.2208	0.0736	9.8	0.0001**
	NPK*NSC	9	0.1942	0.0216	2.87	0.0143*
	Error	30	0.2254	0.0075		
	Total	47	0.6725			
Exchangeable Acidity	Replicate	2	0.0079	0.004	1.65	0.2095
	NPK	3	0.0225	0.0075	3.12	0.0406*
	NSC	3	0.0292	0.0097	4.05	0.0158*
	NPK*NSC	9	0.0475	0.0053	2.2	0.0514
	Error	30	0.0721	0.0024		
	Total	47	0.1792			
Organic carbon	Replicate	2	0.1575	0.0787	1.86	0.173
	NPK	3	0.0893	0.0298	0.7	0.5573
	NSC	3	0.1483	0.0494	1.17	0.3381
	NPK*NSC	9	0.1266	0.0141	0.33	0.9571
	Error	30	1.2692	0.0423		
	Total	47	1.7909			

APPENDIX 5 (C0NTD.)

Variables	Sources	Degree of freedom	Sum of square	Mean square	F-value	Pr > F
Exchangeable calcium	Replicate	2	2.1217	1.0608	1.06	0.3577
	NPK	3	2.5	0.8333	0.84	0.4848
	NSC	3	12.82	4.2733	4.29	0.0124*
	NPK*NSC	9	4.84	0.5378	0.54	0.8339
	Error	30	29.905	0.9968		
	Total	47	52.1867			
Exchangeable magnesium	Replicate	2	0.0002	0.0001	0.02	0.9839
	NPK	3	0.003	0.001	0.19	0.9023
	NSC	3	0.0247	0.0082	1.58	0.2159
	NPK*NSC	9	0.0645	0.0072	1.37	0.246
	Error	30	0.1571	0.0052		
	Total	47	0.2494			
Exchangeable potassium	Replicate	2	0.1438	0.0719	24.99	<0.0001***
	NPK	3	0.0217	0.0072	2.51	0.0774
	NSC	3	0.0204	0.0068	2.37	0.0907
	NPK*NSC	9	0.0385	0.0043	1.49	0.1974
	Error	30	0.0863	0.0029		
	Total	47	0.3108			
Exchangeable sodium	Replicate	2	0.1611	0.0805	10.22	0.0007**
	NPK	3	0.0024	0.0008	0.1	0.9584
	NSC	3	0.0313	0.0104	1.32	0.2857
	NPK*NSC	9	0.0471	0.0052	0.66	0.7338
	Error	30	0.2365	0.0079		
	Total	47	0.4784			

APPENDIX 5 (CONTD.)

Variables	Sources	Degree of freedom	Sum of square	Mean square	F-value	Pr > F
Available phosphorus	Replicate	2	3.4453	1.7227	0.33	0.7203
	NPK	3	10.9102	3.6367	0.7	0.5593
	NSC	3	36.9414	12.3138	2.37	0.0902
	NPK*NSC	9	25.0742	2.786	0.54	0.8362
	Error	30	155.8047	5.1935		
	Total	47	232.1758			
Total Kjeldahl Nitrogen	Replicate	2	0.024	0.012	0.43	0.6527
	NPK	3	0.4252	0.1417	5.12	0.0056**
	NSC	3	0.4818	0.1606	5.8	0.0030**
	NPK*NSC	9	0.3512	0.039	1.41	0.2278
	Error	30	0.8302	0.0277		
	Total	47	2.1123			

LEGEND: * Significant at 0.05 level of probability
** Significant at 0.01 level of probability
*** Significant at <0.0001 level of probability

APPENDIX 6

TWO-WAY ANOVA FOR 2009 AND 2010 GROWTH PARAMETERS OF SORGHUM AT SAMARU, ZARIA

			2009				2010			
variables	Source	Degree of freedom	Sum of squares	Mean square	F – value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
Leaf number	Replicate	2	0.6913	0.3457	0.86	0.4333	3.5660	1.7830	2.05	0.1465
	NPK	3	3.5999	1.2000	2.99	0.0468*	10.4925	3.4975	4.02	0.0162*
	NSC	3	5.2734	1.7578	4.37	0.0114**	11.3675	3.7892	4.36	0.0116**
	NPK*NSC	9	3.5480	0.3942	0.98	0.4753	3.8293	0.4255	0.49	0.8703
	Error	30	12.0570	0.4019			26.1007	0.8700		
	TOTAL	47	25.1696				55.3559			
Dry matter yield	Replicate	2	69.28	34.6381	0.46	0.6365	57.5184	28.7592	0.48	0.6245
	NPK	3	836.70	278.9007	3.69	0.0225*	1261.5497	420.5166	6.99	0.0011**
	NSC	3	648.79	216.2645	2.86	0.0532	2179.0036	726.3345	12.08	<0.0001***
	NPK*NSC	9	773.40	85.9330	1.14	0.3682	293.0698	32.5633	0.54	0.8324
	Error	30	2265.88	75.5296			1803.8656	60.1289		
	TOTAL	47	4594.05				5595.0072			
Leaf area index	Replicate	2	0.5067	0.2534	0.71	0.4989	1.3961	0.6980	3.02	0.0640
	NPK	3	1.4061	0.4687	1.32	0.2873	6.4761	2.1587	9.33	0.0002**
	NSC	3	1.7762	0.5921	1.66	0.1959	8.1219	2.7073	11.70	<0.0001***
	NPK*NSC	9	1.7835	0.1982	0.56	0.8209	1.0860	0.1207	0.52	0.8472
	Error	30	10.6800	0.3560			6.9410	0.2314		
	TOTAL	47	16.1525				24.0210			
Stem girth	Replicate	2	0.0802	0.0401	0.61	0.5493	0.1770	0.0885	3.15	0.0571
	NPK	3	0.2135	0.0712	1.09	0.3703	1.3451	0.4484	15.98	<0.0001***
	NSC	3	0.2004	0.0668	1.02	0.3981	2.2161	0.7387	26.33	<0.0001***
	NPK*NSC	9	0.3515	0.0391	0.60	0.7902	0.0929	0.0103	0.37	0.9414
	Error	30	1.9668	0.0656			0.8416	0.0281		
	TOTAL	47	2.8124				4.6728			
Plant height	Replicate		56.7926	28.3963	0.31	0.7334	589.4580	294.7290	4.10	0.0267
	NPK		816.2106	272.0702	3.00	0.0460*	3302.2154	1100.7385	15.31	<0.0001***
	NSC		605.4878	201.8293	2.23	0.1055	4064.1740	1354.7247	18.84	<0.0001***
	NPK*NSC		354.5415	39.3935	0.43	0.0954	350.0564	38.8952	0.54	0.8328
	Error		2718.98	90.6326			2156.8977	71.8966		
	TOTAL		4552.01				10462.8015			

APPENDIX 6 (continued)

TWO-WAY ANOVA FOR THE TWO YEARS COMBINED GROWTH PARAMETERS OF SORGHUM AT SAMARU, ZARIA

variables	source	Degree of freedom	Sum of squares	Mean square	F - value	Pr > F	
Leaf number	Replicate	2	1.4069	0.7035	0.44	0.6440	R^2 = 0.2047
	NPK	3	11.8661	3.9554	2.49	0.0666	CV = 11.23
	NSC	3	14.9301	4.9767	3.13	0.0303*	SE± =
	NPK*NSC	9	3.7090	0.4121	0.26	0.9834	RMSE = 1.2609
	Error	78	124.0004	1.5897			μ = 11.23
	TOTAL	95	155.9125				
Dry matter yield	Replicate	2	91.4233	45.7117	0.33	0.7234	R^2 = 0.3295
	NPK	3	2800.6939	933.5646	6.64	0.0005**	CV = 26.55
	NSC	3	1784.3446	594.7815	4.23	0.0080**	SE± =
	NPK*NSC	9	713.5933	79.2881	0.56	0.8225	RMSE = 11.8582
	Error	78	10968.0556	140.6161			μ = 44.66
	TOTAL	95	16358.1108				
Leaf area index	Replicate	2	0.1994	0.0997	0.22	0.8051	R^2 = 0.3143
	NPK	3	7.8925	2.6308	5.74	0.0013**	CV = 20.43
	NSC	3	7.2837	2.4279	5.30	0.0022*	SE± =
	NPK*NSC	9	1.0164	0.1129	0.25	0.9862	RMSE = 0.6771
	Error	78	35.7602	0.4585			μ = 3.31
	TOTAL	95	52.1521				
Stem girth	Replicate	2	0.2383	0.1192	1.79	0.1742	R^2 = 0.4157
	NPK	3	1.9026	0.6342	9.51	<0.0001***	CV = 10.57
	NSC	3	1.2919	0.4306	6.46	0.0006**	SE± =
	NPK*NSC	9	0.2671	0.0297	0.45	0.9061	RMSE = 0.2582
	Error	78	5.1998	0.0667			μ = 2.44
	TOTAL	95	8.8997				
Plant height	Replicate	2	422.0595	211.0297	1.86	0.1629	R^2 = 0.4859
	NPK	3	4233.5517	1411.1839	12.42	<0.0001***	CV = 8.9591
	NSC	3	3330.7197	1110.2399	9.77	<0.0001***	SE± =
	NPK*NSC	9	390.2503	43.3611	0.38	0.9406	RMSE = 10.6596
	Error	78	8862.8816	113.6267			μ = 118.98
	TOTAL	95	17239.4627				

APPENDIX 7

TWO-WAY ANOVA FOR 2009 AND 2010 YIELD AND NUTRITION PERFORMANCE OF SORGHUM AT SAMARU, ZARIA

			2009				2010			
variables	source	Degree of freedom	Sum of squares	Mean square	F – value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
Grain yield	Replicate	2	1087110.96	543555.48	1.30	0.2871	65973.65	32986.83	0.70	0.5028
	NPK	3	1837103.09	612367.70	1.47	0.2436	913041.31	304347.10	6.49	0.0016*
	NSC	3	573524.29	191174.76	0.46	0.7139	427893.90	142631.30	3.04	0.0441*
	NPK*NSC	9	1822872.55	202541.39	0.48	0.8731	558395.00	62043.92	1.32	0.2666
	Error	30	12531714.46	417723.82			1406594.92	46886.50		
	TOTAL	47	17852325.35				3371899.04			
Stover yield	Replicate	2	13570610.30	6785305.15	0.74	0.4848	11335334.4	5667667.2	2.07	0.1443
	NPK	3	59765529.86	19921843.29	2.18	0.1113	19603583.2	6534527.7	2.38	0.0891
	NSC	3	74001647.92	24667215.97	2.70	0.0635	103168323.3	34389441.1	12.54	<0.0001***
	NPK*NSC	9	33810743.75	3756749.31	0.41	0.9193	9620929.7	1068992.2	0.39	0.9306
	Error	30	274392126.70	914604.20			82298898.0	2743296.6		
	TOTAL	47	455540658.50				226027068.6			
Tannin	Replicate	2	0.0090	0.0045	0.26	0.7753	0.0116	0.0058	0.06	0.9452
	NPK	3	0.0186	0.0062	0.35	0.7872	0.4071	0.1357	1.32	0.2857
	NSC	3	0.0472	0.0157	0.90	0.4544	0.2834	0.0945	0.92	0.4430
	NPK*NSC	9	0.0759	0.0084	0.48	0.8765	1.1336	0.1260	1.23	0.3161
	Error	30	0.5269	0.0176			3.0803	0.1027		
	TOTAL	47	0.6776				4.9159			
Crude protein	Replicate	2	43.1773	21.5886	7.44	0.0024*	0.6985	0.3492	0.34	0.7167
	NPK	3	18.9804	6.3268	2.18	0.1108	0.5759	0.1920	0.19	0.9056
	NSC	3	7.3302	2.4434	0.84	0.4814	0.6663	0.2221	0.21	0.8857
	NPK*NSC	9	10.3107	1.1456	0.40	0.9278	5.0699	0.5633	0.54	0.8310
	Error	30	87.0006				31.0995	1.0367		
	TOTAL	47	166.7988				38.1101			

APPENDIX 7 (continued)

TWO-WAY ANOVA FOR THE TWO YEARS COMBINED YIELD AND NUTRITION PERFORMANCE OF SORGHUM AT SAMARU, ZARIA

variables	source	Degree of freedom	Sum of squares	Mean square	F - value	Pr > F	$R^2 = 0.0640$ CV = 51.09 SE± = RMSE = 1029.71 μ = 2015.43
Grain yield	Replicate	2	594182.945	297091.473	0.28	0.7564	
	NPK	3	2009921.726	669973.909	0.63	0.5966	
	NSC	3	1355445.438	451815.146	0.43	0.7348	
	NPK*NSC	9	1694567.928	188285.325	0.18	0.9959	
	Error	78	82704139.28	1060309.48			
	TOTAL	95	88358257.32				
Stover yield	Replicate	2	1985683.6	992841.8	0.03	0.9672	$R^2 = 0.0993$ CV = 44.20 SE± = RMSE = 5456.09 μ = 12343.75
	NPK	3	153963951.5	51321317.2	1.72	0.1689	
	NSC	3	84085581.7	28028527.2	0.94	0.4248	
	NPK*NSC	9	15856503.2	1761833.7	0.06	1.0000	
	Error	78	2321972333	29768876			
	TOTAL	95	2577864053				
Tannin	Replicate	2	0.0122	0.0061	0.05*	0.9514	$R^2 = 0.1048$ CV = 55.98 SE± = RMSE = 0.3504 μ = 0.6259
	NPK	3	0.2206	0.0735	0.60	0.6176	
	NSC	3	0.3096	0.1032	0.84	0.4757	
	NPK*NSC	9	0.5781	0.06423	0.52	0.8535	
	Error	78	9.5753	0.1228			
	TOTAL	95	10.6958				
Crude protein	Replicate	2	18.7491	9.3745	4.09	0.0205*	$R^2 = 0.1880$ CV = 18.89 SE± = RMSE = 1.5146 μ = 8.0175
	NPK	3	9.1223	3.0408	1.33	0.2721	
	NSC	3	3.6299	1.2100	0.53	0.6647	
	NPK*NSC	9	9.9157	1.1017	0.48	0.8837	
	Error	78	178.9291	2.2940			
	TOTAL	95	220.3462				

APPENDIX 8

TWO-WAY ANOVA FOR 2009 AND 2010 YIELD PARAMETERS OF SORGHUM AT SAMARU, ZARIA

			2009				2010			
variables	source	Degree of freedom	Sum of squares	Mean square	F - value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
Days to 50% panicle emergence	Replicate	2	3.2917	1.6458	1.30	0.2880	68.1667	34.0833	7.96	0.0017*
	NPK	3	20.2292	6.7431	5.32	0.0046*	91.2292	30.4097	7.10	0.0010**
	NSC	3	15.7292	5.2431	4.13	0.0144*	153.5625	51.1875	11.95	<0.0001***
	NPK*NSC	9	15.6875	1.7431	1.37	0.2431	43.5208	4.8356	1.13	0.3737
	Error	30	38.0417	1.2681			128.5000	4.2833		
	TOTAL	47	92.9792				484.9792			
Days to 50% flowering	Replicate	2	5.1667	2.5833	2.10	0.1396	87.1667	43.5833	9.11	0.0008**
	NPK	3	19.3958	6.4653	5.27	0.0049**	104.7292	34.9097	7.30	0.0008**
	NSC	3	16.7292	5.5764	4.54	0.0097**	229.0625	76.3542	15.96	<0.0001***
	NPK*NSC	9	15.3542	1.7060	1.39	0.2366	54.5208	6.0579	1.27	0.2949
	Error	30	36.8333	1.2278			143.5000	4.7833		
	TOTAL	47	93.4792				618.9792			
Weight per panicle	Replicate	2	0.0005	0.0002	1.13	0.3351	2.279×10^{-5}	1.140×10^{-5}	0.32	0.7038
	NPK	3	0.0013	0.0004	2.09	0.1223	5.242×10^{-4}	1.747×10^{-4}	4.86	0.0071**
	NSC	3	0.0003	0.0001	0.52	0.6718	8.726×10^{-4}	2.909×10^{-4}	8.09	0.0004**
	NPK*NSC	9	0.0010	0.0001	0.54	0.8341	5.479×10^{4}	6.087×10^{-5}	1.69	0.1345
	Error	30	0.0064	0.0002			0.0011	3.595×10^{-5}		
	TOTAL	47	0.0095				0.0030			
Grain weight per panicle	Replicate	2	0.0004	0.0002	1.27	0.2966	2.529×10^{-5}	1.265×10^{-5}	0.78	0.4682
	NPK	3	0.0006	0.0002	1.40	0.2624	3.208×10^{-4}	1.069×10^{-4}	6.58	0.0015**
	NSC	3	0.0002	0.0001	0.46	0.7145	$1.512\times10\text{-}^{4}$	5.039×10^{-5}	3.10	0.0414*
	NPK*NSC	9	0.0006	0.0001	0.46	0.8864	2.020×10^{-4}	2.244×10^{-5}	1.38	0.2400
	Error	30	0.0045				4.874×10^{-4}	1.625×10^{-5}		
	TOTAL	47	0.0063				0.0012			

APPENDIX 8 (continued)

TWO-WAY ANOVA FOR THE TWO YEARS COMBINED YIELD PARAMETERS OF SORGHUM AT SAMARU, ZARIA

variables	source	Degree of freedom	Sum of squares	Mean square	F - value	Pr > F	$R^2 = 0.3745$ CV = 2.4963 SE± = RMSE = 2.6128 μ = 104.67
Days to 50% panicle emergence	Replicate	2	49.5208	24.7604	3.63	0.0312*	
	NPK	3	135.6667	45.2222	6.62	0.0005**	
	NSC	3	90.8333	30.2778	4.44	0.0062**	
	NPK*NSC	9	42.8333	4.7593	0.70	0.7095	
	Error	78	532.4792	6.8267			
	TOTAL	95	851.3333				
Days to 50% flowering	Replicate	2	64.3333	32.1667	6.91	0.0017*	$R^2 = 0.5210$ CV = 1.9845 SE± = RMSE = 2.1573 μ = 108.71
	NPK	3	182.2500	60.7500	13.05	<0.0001***	
	NSC	3	102.3333	34.1111	7.33	0.0002**	
	NPK*NSC	9	45.9167	5.1019	1.10	0.3754	
	Error	78	363.0000	4.6538			
	TOTAL	95	757.8333				
Weight per panicle	Replicate	2	0.0002	0.0001	0.14	0.8692	$R^2 = 0.0911$ CV = 41.52 SE± = RMSE = 0.0232 μ = 0.0558
	NPK	3	0.0021	0.0007	1.32	0.2735	
	NSC	3	0.0007	0.0002	0.46	0.7136	
	NPK*NSC	9	0.0012	0.0001	0.25	0.9864	
	Error	78	0.0419	0.0005			
	TOTAL	95	0.0461				
Grain weight per panicle	Replicate	2	0.0002	0.0001	0.29	0.7507	$R^2 = 0.0631$ CV = 51.29 SE± = RMSE = 0.0195 μ = 0.0380
	NPK	3	0.0007	0.0002	0.61	0.6119	
	NSC	3	0.0005	0.0002	0.42	0.7368	
	NPK*NSC	9	0.0006	0.0001	0.18	0.9960	
	Error	78	0.0297	0.0004			
	TOTAL	95	0.0317				

APPENDIX 8 (continued)

TWO-WAY ANOVA FOR 2009 AND 2010 YIELD PARAMETERS OF SORGHUM AT SAMARU, ZARIA

			2009				2010			
variables	source	Degree of freedom	Sum of squares	Mean square	F – value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
One thousand seed weight	Replicate	2	7.5254	3.7627	1.05	0.3611	17.8079	8.9040	2.36	0.1114
	NPK	3	14.9308	4.9769	1.39	0.2638	20.5823	6.8608	1.82	0.1647
	NSC	3	1.8717	0.6239	0.17	0.9126	49.6223	16.5408	4.39	0.0112**
	NPK*NSC	9	18.6294	2.0699	0.58	0.8029	24.7902	2.7545	0.73	0.6775
	Error	30	107.1121	3.5704			113.0521	3.7684		
	TOTAL	47	150.0694				225.8548			
Biomass yield	Replicate	2	18671481.92	9335740.96	0.80	0.4576	9677619.1	4838809.5	1.66	0.2071
	NPK	3	77381117.05	25793705.68	2.22	0.1066	23287103.1	7762367.7	2.66	0.0658
	NSC	3	82701748.73	27567249.58	2.37	0.0904	112813566.2	37604522.1	12.90	<0.0001***
	NPK*NSC	9	40471133.17	4496792.57	0.39	0.9323	10228262.3	1136473.6	0.39	0.9305
	Error	30	349025607.70	11634186.90			87428493.0	2914283.1		
	TOTAL	47	568251088.60				243435043.7			
Harvest index	Replicate	2	0.0013	0.0006	1.10	0.3470	0.0043	0.0022	2.53	0.0965
	NPK	3	0.0013	0.0004	0.76	0.5276	0.0089	0.0030	3.48	0.0279*
	NSC	3	0.0019	0.0006	1.08	0.3707	0.0117	0.0039	4.56	0.0096**
	NPK*NSC	9	0.0032	0.0004	0.62	0.7741	0.0081	0.0009	1.06	0.4211
	Error	30	0.0175	0.0006			0.0257	0.0009		
	TOTAL	47	0.0252				0.0588			
Threshing percentage	Replicate	2	16.7929	8.3965	0.67	0.5204	289.69	144.8430	2.53	0.0963
	NPK	3	168.3398	56.1133	4.46	0.0105*	384.59	128.1982	2.24	0.1038
	NSC	3	36.0391	12.0130	0.96	0.4266	189.61	63.2034	1.11	0.3624
	NPK*NSC	9	103.9213	11.5468	0.92	0.5232	287.44	31.9378	0.56	0.8195
	Error	30	377.3134	12.5771			1715.61	57.1869		
	TOTAL	47	702.4065				2866.94			

APPENDIX 8 (continued)

TWO-WAY ANOVA FOR THE TWO YEARS COMBINED YIELD PARAMETERS OF SORGHUM AT SAMARU, ZARIA

variables	source	Degree of freedom	Sum of squares	Mean square	F - value	Pr > F	
One thousand seed weight	Replicate	2	19.7208	9.8604	0.89	0.4165	R^2 = 0.0863
	NPK	3	24.7237	8.2412	0.74	0.5312	CV = 10.29
	NSC	3	12.1052	4.0351	0.36	0.7803	SE± =
	NPK*NSC	9	25.4976	2.8331	0.25	0.9845	RMSE = 3.3364
	Error	78	868.2564	11.1315			μ = 32.42
	TOTAL	95	950.3037				
Biomass yield	Replicate	2	4620094.2	2310047.1	0.06	0.9450	R^2 = 0.0875
	NPK	3	180745559.7	60248519.9	1.48	0.2275	CV = 44.49
	NSC	3	96796240.0	32265413.3	0.79	0.5028	SE± =
	NPK*NSC	9	23179247.0	2575471.9	0.06	0.9999	RMSE = 6388.47
	Error	78	3183374734	40812497			μ = 14359.17
	TOTAL	95	3488715875				
Harvest index	Replicate	2	0.0014	0.0007	0.86	0.4275	R^2 = 0.2765
	NPK	3	0.0093	0.0031	3.84	0.0128**	CV = 20.22
	NSC	3	0.0076	0.0025	3.12	0.0306*	SE± =
	NPK*NSC	9	0.0058	0.0006	0.80	0.6159	RMSE = 0.0284
	Error	78	0.0629	0.0008			μ = 0.1405
	TOTAL	95	0.0870				
Threshing percentage	Replicate	2	84.3137	42.1569	0.55	0.5805	R^2 = 0.1090
	NPK	3	227.8150	75.9383	0.99	0.4036	CV = 13.29
	NSC	3	211.7605	70.5868	0.92	0.4367	SE± =
	NPK*NSC	9	210.2802	23.3645	0.30	0.9716	RMSE = 8.7733
	Error	78	6003.7723	76.9714			μ = 66.04
	TOTAL	95	6737.9417				

APPENDIX 9

TWO-WAY ANOVA FOR 2009 AND 2010 MINERAL-N AT VARIOUS STAGES OF SORGHUM GROWTH AT SAMARU, ZARIA

			2009				2010			
variables	source	Degree of freedom	Sum of squares	Mean square	F - value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
2 weeks before planting	Replicate	2	0	0	0	1.0000	0.0000476	0.0000238	3.34	0.0490*
	NPK	3	0	0	0	1.0000	0.0000054	0.0000018	0.25	0.8602
	NSC	3	0	0	0	1.0000	0.0000151	0.0000050	0.70	0.5568
	NPK*NSC	9	2.5679E-34	2.8532E-35	3.3	0.0062	0.0000549	0.0000061	0.86	0.5731
	Error	30	2.5679E-34	8.5597E-36			0.0002137	0.0000071		
	TOTAL	47	0				0.0003367			
At planting	Replicate	2	0.000175	0.0000876	0.36	0.6989	0.00015963	0.00007982	2.19	0.1292
	NPK	3	0.000234	0.0000781	0.32	0.8084	0.00003388	0.00001129	0.31	0.8178
	NSC	3	0.000905	0.0003018	1.25	0.3095	0.00012116	0.00004039	1.11	0.3606
	NPK*NSC	9	0.000963	0.0001070	0.44	0.9005	0.00019147	0.00002127	0.58	0.7991
	Error	30	0.007249	0.0002416			0.00109191	0.00003640		
	TOTAL	47	0.009526				0.00159805			
Side-dressing	Replicate	2	0.0003651	0.0001826	18.03	<0.0001***	0.00000153	0.00000077	0.12	0.8901
	NPK	3	0.0000346	0.0000115	1.14	0.3487	0.00001027	0.00000342	0.52	0.6700
	NSC	3	0.0000653	0.0002177	2.15	0.1146	0.00002163	0.00000721	1.10	0.3642
	NPK*NSC	9	0.0000487	0.0000054	0.53	0.8376	0.00006348	0.00000705	1.08	0.4075
	Error	30	0.0003037	0.0000101			0.00019651	0.00000655		
	TOTAL	47	0.0008174				0.00029343			

APPENDIX 10

TWO-WAY ANOVA FOR SOIL PHYSICOCHEMICAL PROPERTIES IN 2009 AND 2010 AT SAMARU, ZARIA FOLLOWING THE INCORPORATION OF NEEM SEED CAKE AND/ INORGANIC FERTILIZER USING SORGHUM AS A BIO-INDICATOR.

BEFORE NEEM SEED CAKE INCORPORATION

			2009				2010			
variables	source	Degree of freedom	Sum of squares	Mean square	F - value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
Total Kjeldahl Nitrogen (TKN)	Replicate NSC NPK NPK*NSC Error	2 3 3 9 30					0.0006 0.0009 0.0008 0.0046 0.0082	0.0003 0.0003 0.0003 0.0005 0.0003	1.12 1.08 1.03 1.88	0.3381 0.3727 0.3929 0.0949
	TOTAL	47					0.0151			
Available Phosphorus	Replicate NSC NPK NPK*NSC Error	2 3 3 9 30					2779.8110 1250.5269 1259.0990 3517.7342 12547.4153	1389.9055 416.8423 419.6997 390.8594 418.2472	3.32 1.00 1.00 0.93	0.0497* 0.4078 0.4048 0.5104
	TOTAL	47					21354.5864			
Exchangeable Potassium	Replicate NSC NPK NPK*NSC Error	2 3 3 9 30					0.0034 0.0004 0.0002 0.0044 0.0223	0.0017 0.0001 0.0001 0.0005 0.0007	2.31 0.17 0.08 0.65	0.1170 0.9146 0.9692 0.7436
	TOTAL	47					0.0307			
Exchangeable Calcium	Replicate NSC NPK NPK*NSC Error	2 3 3 9 30					0.6654 0.2690 0.3223 1.2385 4.1346	0.3327 0.0897 0.1074 0.1376 0.1378	2.41 0.65 0.78 1.00	0.1066 0.5888 0.5147 0.4623
	TOTAL	47					6.6298			

APPENDIX 10 (continued)

BEFORE NEEM SEED CAKE INCORPORATION

			2009				2010			
variables	source	Degree of freedom	Sum of squares	Mean square	F – value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
Exchangeable Magnesium	Replicate	2					0.0368	0.0184	4.02	0.0285
	NSC	3					0.0026	0.0009	0.19	0.9007
	NPK	3					0.0165	0.0055	1.21	0.3248
	NPK*NSC	9					0.0290	0.0032	0.70	0.7011
	Error	30					0.1373	0.0046		
	TOTAL	47					0.2222			
Exchangeable Sodium	Replicate	2					0.0022	0.0011	1.02	0.3716
	NSC	3					0.0077	0.0026	2.44	0.0842
	NPK	3					0.0006	0.0002	0.20	0.8931
	NPK*NSC	9					0.0105	0.0012	1.11	0.3826
	Error	30					0.0315	0.0011		
	TOTAL	47					0.0525			
Organic Carbon	Replicate	2					0.0621	0.0310	2.62	0.0892
	NSC	3					0.0019	0.0006	0.05	0.9839
	NPK	3					0.0117	0.0039	0.33	0.8034
	NPK*NSC	9					0.0647	0.0072	0.61	0.7809
	Error	30					0.3550	0.0118		
	TOTAL	47					0.4953			
pH_{water}	Replicate	2					0.8866	0.4433	10.52	0.0003
	NSC	3					0.0934	0.0311	0.74	0.5374
	NPK	3					0.0218	0.0073	0.17	0.9140
	NPK*NSC	9					0.6752	0.0750	1.78	0.1141
	Error	30					1.2645	0.0422		
	TOTAL	47					2.9416			

APPENDIX 10 (continued)

BEFORE NEEM SEED CAKE INCORPORATION

			2009				2010			
variables	source	Degree of freedom	Sum of squares	Mean square	F – value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
pH_{CaCl2}	Replicate	2					0.1782	0.0891	8.03	0.0016
	NSC	3					0.0124	0.0041	0.37	0.7734
	NPK	3					0.0488	0.0163	1.46	0.2440
	NPK*NSC	9					0.1307	0.0145	1.31	0.2742
	Error	30					0.3331	0.0111		
	TOTAL	47					0.7031			
Exchangeable Acidity	Replicate	2					0.2150	0.1075	9.92	0.0005
	NSC	3					0.0167	0.0056	0.51	0.6765
	NPK	3					0.0117	0.0039	0.36	0.7830
	NPK*NSC	9					0.2417	0.0269	2.48	0.0300
	Error	30					0.3250	0.0108		
	TOTAL	47					0.8100			
Cation Exchange Capacity	Replicate	2					59.7291	29.8645	10.16	0.0004
	NSC	3					11.7234	3.9078	1.33	0.2832
	NPK	3					2.0239	0.6746	0.23	0.8751
	NPK*NSC	9					22.7447	2.5272	0.86	0.5697
	Error	30					88.1669	2.9389		
	TOTAL	47					184.3880			
Effective Cation Exchange Capacity	Replicate	2					1.1421	0.5711	3.43	0.0457
	NSC	3					6.3765	0.1255	0.75	0.5292
	NPK	3					0.3856	0.1285	0.77	0.5192
	NPK*NSC	9					1.2015	0.1335	0.80	0.6183
	Error	30					4.9990	0.1666		
	TOTAL	47					8.1047			

APPENDIX 10 (continued)

AT PLANTING

			2009				2010			
variables	source	Degree of freedom	Sum of squares	Mean square	F – value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
Total Kjeldahl Nitrogen (TKN)	Replicate	2	0.0033	0.0017	1.80	0.1829	0.0971	0.0485	20.25	<0.0001***
	NSC	3	0.0009	0.0003	0.32	0.8097	0.0061	0.0020	0.85	0.4770
	NPK	3	0.0014	0.0005	0.50	0.6837	0.0007	0.0002	0.10	0.9608
	NPK*NSC	9	0.0088	0.0010	1.07	0.4154	0.0233	0.0026	1.08	0.4056
	Error	30	0.0276	0.0009			0.0719	0.0024		
	TOTAL	47	0.0420				0.1991			
Available Phosphorus	Replicate	2	1227.0417	613.5208	3.65	0.0382	21.0837	10.5418	1.11	0.3424
	NSC	3	1044.0573	348.0191	2.07	0.1253	21.2221	7.0740	0.75	0.5335
	NPK	3	276.9010	92.3003	0.55	0.6528	30.7377	10.2459	1.08	0.3726
	NPK*NSC	9	889.9115	98.8791	0.59	0.7964	101.5413	11.2824	1.19	0.3375
	Error	30	5044.9583	168.1653			284.6735	9.4891		
	TOTAL	47	8482.8698				459.2583			
Exchangeable Potassium	Replicate	2	0.0253	0.0127	0.10	0.9088	0.0936	0.0468	3.77	0.0345*
	NSC	3	1.4013	0.4671	3.54	0.0264*	0.0936	0.0312	2.51	0.0773
	NPK	3	0.0444	0.0148	0.11	0.9524	0.0217	0.0072	0.58	0.6306
	NPK*NSC	9	0.5923	0.0658	0.50	0.8638	0.0650	0.0072	0.58	0.8011
	Error	30	3.9621	0.1321			0.3721	0.0124		
	TOTAL	47	6.0254				0.6460			
Exchangeable Calcium	Replicate	2	1.3854	0.6927	4.92	0.0142*	14.5829	7.2915	8.41	0.0013*
	NSC	3	0.2017	0.0672	0.48	0.7007	0.7033	0.2344	0.27	0.8463
	NPK	3	0.2583	0.0861	0.61	0.6131	5.3550	1.7850	2.06	0.1268
	NPK*NSC	9	0.7433	0.0826	0.59	0.7979	11.3583	1.2620	1.46	0.2098
	Error	30	4.2279				26.0171	0.8672		
	TOTAL	47	6.8167				58.0167			

APPENDIX 10 (continued)

AT PLANTING

			2009				2010			
variables	source	Degree of freedom	Sum of squares	Mean square	F – value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
Exchangeable Magnesium	Replicate	2	0.2595	0.1297	13.82	<0.0001***	0.1406	0.0703	6.01	0.0064
	NSC	3	0.0833	0.0278	2.96	0.0481*	0.0359	0.0120	1.02	0.3966
	NPK	3	0.0992	0.0331	3.52	0.0267*	0.0552	0.0184	1.57	0.2166
	NPK*NSC	9	0.0489	0.0054	0.58	0.8036	0.0645	0.0072	0.61	0.7769
	Error	30	0.2816	0.0094			0.3512	0.0117		
	TOTAL	47	0.7725				0.6475			
Exchangeable Sodium	Replicate	2	0.0385	0.0193	4.74	0.0163*	0.0149	0.0075	1.67	0.2053
	NSC	3	0.0633	0.0211	5.19	0.0052*	0.0085	0.0028	0.63	0.6007
	NPK	3	0.0132	0.0044	1.09	0.3701	0.0089	0.0030	0.67	0.5795
	NPK*NSC	9	0.0195	0.0022	0.53	0.8383	0.0296	0.0033	0.74	0.6725
	Error	30	0.1220	0.0041			0.1339	0.0045		
	TOTAL	47	0.2565				0.1958			
Organic Carbon	Replicate	2	0.1482	0.0741	1.61	0.2162	0.1216	0.0608	9.28	0.0007*
	NSC	3	0.2404	0.0801	1.74	0.1791	0.1155	0.0385	5.88	0.0028*
	NPK	3	0.1410	0.0470	1.02	0.3963	0.0378	0.0126	1.93	0.1468
	NPK*NSC	9	0.5113	0.0568	1.24	0.3107	0.0443	0.0049	0.75	0.6609
	Error	30	1.3781	0.0459			0.1966	0.0066		
	TOTAL	47	2.4189				0.5158			
pH_{water}	Replicate	2	0.2188	0.1094	2.94	0.0680	0.2363	0.1181	12.20	0.0001*
	NSC	3	0.4573	0.1524	4.10	0.0149*	0.1683	0.0561	5.80	0.0030*
	NPK	3	0.0740	0.0247	0.66	0.5810	0.0083	0.0028	0.29	0.8344
	NPK*NSC	9	0.6135	0.0682	1.83	0.1027	0.1467	0.0163	1.68	0.1370
	Error	30	1.1146	0.0372			0.2904	0.0097		
	TOTAL	47	2.4781				0.8500			

APPENDIX 10 (continued)

AT PLANTING

			2009				2010			
variables	source	Degree of freedom	Sum of squares	Mean square	F – value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
pH_{CaCl2}	Replicate	2	1.6404	0.8202	9.39	0.0007*	0.2817	0.1408	14.49	<0.0001***
	NSC	3	0.3025	0.1008	1.15	0.3432	0.0590	0.0197	2.02	0.1321
	NPK	3	0.1092	0.0364	0.42	0.7423	0.0623	0.0208	2.14	0.1165
	NPK*NSC	9	1.1675	0.1297	1.49	0.1984	0.0502	0.0056	0.57	0.8076
	Error	30	2.6196	0.0873			0.2917	0.0097		
	TOTAL	47	5.8392				0.7448			
Exchangeable Acidity	Replicate	2	0.1117	0.0558	5.32	0.0106	0.0450	0.0225	1.09	0.3505
	NSC	3	0.0433	0.0144	1.38	0.2692	0.1406	0.0469	2.26	0.1015
	NPK	3	0.0167	0.0056	0.53	0.6657	0.0523	0.0174	0.84	0.4821
	NPK*NSC	9	0.0700	0.0078	0.74	0.6692	0.1835	0.0204	0.98	0.4729
	Error	30	0.3150	0.0105			0.6217	0.0207		
	TOTAL	47	0.5567				1.0431			
Cation Exchange Capacity	Replicate	2	1.9723	0.9862	1.30	0.2866	54.9368	27.4684		
	NSC	3	0.5957	0.1986	0.26	0.8519	136.2892	45.4297		
	NPK	3	1.4548	0.4849	0.64	0.5947	96.9584	32.3195		
	NPK*NSC	9	4.5866	0.5096	0.67	0.7261	307.3235	34.1471		
	Error	30	22.7016	0.7567			502.0385	16.7346		
	TOTAL	47	31.3110				1097.5463			
Effective Cation Exchange Capacity	Replicate	2	0.3775	0.1887	0.50	0.6036	17.2185	8.6092	10.38	0.0004**
	NSC	3	3.9245	1.3082	3.50	0.0274*	1.3943	0.4648	0.56	0.6453
	NPK	3	0.1067	0.0356	0.10	0.9621	4.6536	1.5512	1.87	0.1559
	NPK*NSC	9	1.2600	0.1400	0.37	0.9383	11.7273	1.3030	1.57	0.1691
	Error	30	11.2157	0.3739			24.8770	0.8292		
	TOTAL	47	16.8844				59.8707			

APPENDIX 10 (continued)

AT HEADING

			2009				2010			
variables	source	Degree of freedom	Sum of squares	Mean square	F – value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
Total Kjeldahl Nitrogen (TKN)	Replicate	2	0.0036	0.0018	0.82	0.4507	0.0001	0.00004	0.32	0.7306
	NSC	3	0.0066	0.0022	1.00	0.4045	0.0004	0.00012	0.87	0.4655
	NPK	3	0.0055	0.0018	0.85	0.4787	0.0003	0.00011	0.77	0.5188
	NPK*NSC	9	0.0164	0.0018	0.84	0.5860	0.0017	0.00019	1.35	0.2533
	Error	30	0.0652	0.0022			0.0042	0.00010		
	TOTAL	47	0.0973				0.0066			
Available Phosphorus	Replicate	2	93.5729	46.7865	3.55	0.0413*	6.5661	3.2831	2.13	0.1361
	NSC	3	52.0573	17.3524	1.32	0.2872	1.1681	0.3894	0.25	0.8586
	NPK	3	2.5469	0.8490	0.06	0.9783	9.5040	3.1680	2.06	0.1268
	NPK*NSC	9	184.3906	20.4878	1.55	0.1744	16.6105	1.8456	1.20	0.3315
	Error	30	395.3021	13.1767			46.1674	1.5389		
	TOTAL	47	727.8698				80.0160			
Exchangeable Potassium	Replicate	2	0.0053	0.0026	0.75	0.4830	0.0001	0.00003	0.06	0.9458
	NSC	3	0.0054	0.0018	0.51	0.6796	0.0018	0.00060	1.24	0.3120
	NPK	3	0.0062	0.0021	0.58	0.6323	0.0018	0.00059	1.22	0.3199
	NPK*NSC	9	0.0262	0.0029	0.83	0.5980	0.0027	0.00030	0.61	0.7774
	Error	30	0.1059	0.0035			0.0145	0.00050		
	TOTAL	47	0.1490				0.0208			
Exchangeable Calcium	Replicate	2	17.0817	8.5408	8.92	0.0009***	5.8329	2.9165	1.18	0.3226
	NSC	3	1.4867	0.4956	0.52	0.6735	4.4690	1.4897	0.60	0.6198
	NPK	3	1.8267	0.6089	0.64	0.5978	9.3256	3.1085	1.25	0.3082
	NPK*NSC	9	3.4200	0.3800	0.40	0.9269	40.6402	4.5156	1.82	0.1058
	Error	30	28.7317	0.9577			74.4471	2.4816		
	TOTAL	47	52.5467				134.7148			

APPENDIX 10 (continued)

AT HEADING

			2009				2010			
variables	source	Degree of freedom	Sum of squares	Mean square	F – value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
Exchangeable Magnesium	Replicate	2	0.0063	0.0032	0.87	0.4278				
	NSC	3	0.0065	0.0022	0.60	0.6192				
	NPK	3	0.0664	0.0221	6.10	0.0023**				
	NPK*NSC	9	0.0364	0.0040	1.11	0.3827				
	Error	30	0.1088	0.0036						
	TOTAL	47	0.2245							
Exchangeable Sodium	Replicate	2	0.3503	0.1752	29.16	<0.0001***	0.0009	0.0005	0.46	0.6383
	NSC	3	0.0145	0.0048	0.80	0.5020	0.0041	0.0014	1.36	0.2730
	NPK	3	0.0125	0.0042	0.69	0.5630	0.0022	0.0007	0.75	0.5296
	NPK*NSC	9	0.0480	0.0053	0.89	0.5474	0.0047	0.0005	0.53	0.8407
	Error	30	0.1802	0.0060			0.0298	0.0010		
	TOTAL	47	0.6055				0.0417			
Organic Carbon	Replicate	2	0.4990	0.2495	14.43	<0.0001***	0.0246	0.0123	0.63	0.5393
	NSC	3	0.0005	0.0002	0.01	0.9986	0.1215	0.0405	2.08	0.1243
	NPK	3	0.0384	0.0128	0.74	0.5361	0.0113	0.0038	0.19	0.9002
	NPK*NSC	9	0.1975	0.0219	1.27	0.2934	0.1654	0.0184	0.94	0.5046
	Error	30	0.5187	0.0173			0.5853	0.0195		
	TOTAL	47	1.2542				0.9081			
pH_{water}	Replicate	2	0.3304	0.1652	20.40	<0.0001***	0.8600	0.4300	27.64	<0.0001***
	NSC	3	0.0273	0.0091	1.12	0.3552	0.0842	0.0281	1.80	0.1678
	NPK	3	0.0506	0.0169	2.08	0.1233	0.0425	0.0142	0.91	0.4475
	NPK*NSC	9	0.0985	0.0109	1.35	0.2531	0.1392	0.0155	0.99	0.4656
	Error	30	0.2429	0.0081			0.4667	0.0156		
	TOTAL	47	0.7498				1.5925			

APPENDIX 10 (continued)

AT HEADING

			2009				2010			
variables	source	Degree of freedom	Sum of squares	Mean square	F – value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
pH_{CaCl2}	Replicate	2	0.0329	0.0165	2.84	0.0741	0.3463	0.1731	28.79	<0.0001***
	NSC	3	0.0190	0.0063	1.09	0.3680	0.0373	0.0124	2.07	0.1256
	NPK	3	0.0290	0.0097	1.67	0.1952	0.0240	0.0080	1.33	0.2837
	NPK*NSC	9	0.0652	0.0072	1.25	0.3030	0.0352	0.0039	0.65	0.7453
	Error	30	0.1738	0.0058			0.1804	0.0060		
	TOTAL	47	0.3198				0.6231			
Exchangeable Acidity	Replicate	2	0.0117	0.0058	0.81	0.4526	0.2304	0.1152	1.98	0.1563
	NSC	3	0.0300	0.0100	1.40	0.2634	0.0467	0.0156	0.27	0.8488
	NPK	3	0.0217	0.0072	1.01	0.4030	0.4017	0.1339	2.30	0.0979
	NPK*NSC	9	0.0883	0.0098	1.37	0.2453	0.2183	0.0242	0.42	0.9163
	Error	30	0.2150	0.0072			1.7496	0.0583		
	TOTAL	47	0.3667				2.6467			

APPENDIX 10 (continued)

AT HARVEST

			2009				2010			
variables	source	Degree of freedom	Sum of squares	Mean square	F – value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
Total Kjeldahl Nitrogen (TKN)	Replicate	2	0.4370	0.2185	1.67	0.2060	0.0016	0.0008	2.57	0.0936
	NPK	3	0.4240	0.1413	1.08	0.3733	0.0003	0.0001	0.38	0.7683
	NSC	3	0.2448	0.0816	0.62	0.6061	0.0011	0.0004	1.17	0.3362
	NPK*NSC	9	1.9989	0.2221	1.69	0.1343	0.0020	0.0002	0.74	0.6679
	Error	30	3.9336	0.1311			0.0092	0.0003		
	TOTAL	47	7.0382				0.0142			
Available Phosphorus	Replicate	2	193.4479	96.7240	7.84	0.0018**	149.9030	74.9515	5.40	0.0100*
	NPK	3	70.4375	23.4792	1.90	0.1503	60.1494	20.0498	1.44	0.2497
	NSC	3	15.8229	5.2743	0.43	0.7347	96.2613	32.0871	2.31	0.0963
	NPK*NSC	9	75.0313	8.3368	0.68	0.7241	99.2920	11.0324	0.79	0.6239
	Error	30	370.0521	12.3351			416.6595	13.8887		
	TOTAL	47	724.7917				822.2653			
Exchangeable Potassium	Replicate	2	0.0491	0.0245	1.71	0.1979	0.0010	0.0005	0.83	0.4440
	NPK	3	0.0418	0.0139	0.97	0.4192	0.0082	0.0027	4.42	0.0109*
	NSC	3	0.0438	0.0146	1.02	0.3986	0.0067	0.0022	3.59	0.0249
	NPK*NSC	9	0.1342	0.0149	1.04	0.4332	0.0095	0.0011	1.71	0.1299
	Error	30	0.4303	0.0143			0.0185	0.0006		
	TOTAL	47	0.6992				0.0439			
Exchangeable Calcium	Replicate	2	0.1838	0.0919	0.52	0.5984	3.0150	1.5075	2.69	0.0839
	NPK	3	0.3217	0.1072	0.61	0.6140	1.3706	0.4569	0.82	0.4949
	NSC	3	0.2217	0.0739	0.42	0.7399	3.7373	1.2458	2.23	0.1055
	NPK*NSC	9	0.5467	0.0607	0.35	0.9517	3.7252	0.4139	0.74	0.6700
	Error	30	5.2763	0.1759			16.7850	0.5595		
	TOTAL	47	6.5500				28.6331			

APPENDIX 10 (continued)

AT HARVEST

			2009				2010			
variables	source	Degree of freedom	Sum of squares	Mean square	F – value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
Exchangeable Magnesium	Replicate	2	0.0067	0.0033	0.69	0.5080	2.1722	1.0861	3.67	0.0375
	NPK	3	0.0122	0.0041	0.84	0.4806	1.4710	0.4903	1.66	0.1972
	NSC	3	0.0004	0.0001	0.03	0.9925	0.4802	0.1601	0.54	0.6579
	NPK*NSC	9	0.0465	0.0052	1.07	0.4119	4.0585	0.4509	1.52	0.1847
	Error	30	0.1449	0.0048			8.8761	0.2959		
	TOTAL	47	0.2108				17.0580			
Exchangeable Sodium	Replicate	2	0.0203	0.0102	1.74	0.1929	0.0242	0.0121	6.01	0.0064*
	NPK	3	0.0034	0.0011	0.19	0.9015	0.0089	0.0030	1.48	0.2409
	NSC	3	0.0160	0.0053	0.91	0.4466	0.0041	0.0014	0.68	0.5700
	NPK*NSC	9	0.0276	0.0031	0.53	0.8445	0.0271	0.0030	1.49	0.1955
	Error	30	0.1754	0.0058			0.0605	0.0020		
	TOTAL	47	0.2427				0.1248			
Organic Carbon	Replicate	2	0.3984	0.1992	6.10	0.0060**	0.0042	0.0021	0.14	0.8722
	NPK	3	0.3204	0.1068	3.27	0.0348*	0.1218	0.0406	2.66	0.0662
	NSC	3	0.0356	0.0119	0.36	0.7797	0.0094	0.0031	0.21	0.8918
	NPK*NSC	9	0.4615	0.0513	1.57	0.1697	0.1753	0.0195	1.27	0.2907
	Error	30	0.9802	0.0327			0.4584	0.0153		
	TOTAL	47	2.1962				0.7691			
pH_{water}	Replicate	2	1.9579	0.9790	16.99	<0.0001***	0.9754	0.4877	27.20	<0.0001***
	NPK	3	0.1056	0.0352	0.61	0.6131	0.0123	0.0041	0.23	0.8758
	NSC	3	0.0056	0.0019	0.03	0.9920	0.0423	0.0141	0.79	0.5111
	NPK*NSC	9	0.5719	0.0635	1.10	0.3905	0.2219	0.0247	1.37	0.2429
	Error	30	1.7286	0.0576			0.5379	0.0179		
	TOTAL	47	4.3698				1.7898			

APPENDIX 10 (continued)

AT HARVEST

			2009				2010			
variables	source	Degree of freedom	Sum of squares	Mean square	F – value	Pr > F	Sum of squares	Mean square	F - value	Pr > F
pH_{CaCl2}	Replicate	2	0.2029	0.1015	2.18	0.1308	0.0200	0.1000	1.10	0.3467
	NPK	3	0.0517	0.0172	0.37	0.7753	0.0023	0.0008	0.08	0.9683
	NSC	3	0.1717	0.0572	1.23	0.3165	0.0290	0.0097	1.06	0.3809
	NPK*NSC	9	0.2933	0.0326	0.70	0.7038	0.0835	0.0093	1.02	0.4477
	Error	30	1.3971	0.0466			0.2733	0.0091		
	TOTAL	47	2.1167				0.4081			
Exchangeable Acidity	Replicate	2	0.1213	0.0606	4.64	0.0176*	0.0904	0.0452	9.95	0.0005***
	NPK	3	0.0240	0.0080	0.61	0.6131	0.0090	0.0030	0.66	0.5846
	NSC	3	0.0190	0.0063	0.48	0.6962	0.0323	0.0108	2.37	0.0903
	NPK*NSC	9	0.1169	0.0130	0.99	0.4659	0.0319	0.0035	0.78	0.6362
	Error	30	0.3921	0.0131			0.1363	0.0045		
	TOTAL	47	0.6731				0.2998			

APPENDIX 11

TWO-WAY ANOVA FOR NUTRIENT CONCENTRATION IN SORGHUM TISSUE

			2009				2010			
Variables	Source	Degree of freedom	sum of square	mean square	F-value	Pr > F	sum of square	mean square	F-value	Pr > F
Total Kjeldahl Nitrogen	Replicate	2	58.77	29.39	1.65	0.2093	12.12	6.06	0.79	0.4625
	NPK	3	67.65	22.55	1.26	0.3042	58.84	19.61	2.56	0.0736
	NSC	3	118.12	39.37	2.21	0.1077	20.75	6.92	0.90	0.4515
	NPK*NSC	9	200.61	22.29	1.25	0.3035	107.11	11.90	1.55	0.1750
	Error	30	534.90	17.83			229.86	7.66		
	Total	47	980.05				428.68			
Total phosphorus	Replicate	2	8.51	4.26	0.67	0.518	0.03	0.01	0.17	0.8450
	NPK	3	8.99	3.00	0.47	0.7032	0.21	0.07	0.89	0.4564
	NSC	3	23.41	7.80	1.23	0.315	0.11	0.04	0.49	0.6932
	NPK*NSC	9	42.94	4.77	0.75	0.6583	0.52	0.06	0.73	0.6759
	Error	30	189.90	6.33			2.35	0.08		
	Total	47	273.75				3.22			
Total potassium	Replicate	2	944.2	472.10	0.64	0.5341	180.71	90.35	0.96	0.3951
	NPK	3	1870.38	623.46	0.85	0.4797	291.29	97.10	1.03	0.3936
	NSC	3	4930.54	1643.51	2.23	0.1052	164.03	54.68	0.58	0.6329
	NPK*NSC	9	4233.81	470.42	0.64	0.7556	1074.91	119.43	1.27	0.2950
	Error	30	22114.27	737.14			2829.72	94.32		
	Total	47	34093.20				4540.66			

APPENDIX 12

SAS-mineralization syntax for parameter estimates evaluation:

```
Data N mineralized;

Input Y k h;

Proc nlin method;

PARMS n0= (estimate)

T= (estimate);

MODEL y=n0*(1-EXP (-k*time)) + ne;

y=n0-n0*((k*EXP (-h*time))-(h*EXP (-h*time)))/ (k-h);

y=n0-n0*(EXP (-k*time)*((k*time) +1));

y=n0-n0*EXP (-h*(EXP (-k*time)))-(n0*EXP (-h));

y=n0*(1-EXP (-(k*t)-0.5*h*t*t));

RUN;
```

APPENDIX 13

SAS-decomposition syntax for parameter estimates evaluation:

```
Data N decomposed;

Input Y k t XL XR;

Proc nlin method;

PARMS XL= (estimate)

T= (estimate);

MODEL y = XL*(EXP (Kl*time)));

Y = (XR*(EXP (-Kr*time)));

Y = XR;

RUN;
```