EFFECTS OF FERTILIZER AND SOYBEAN RESIDUE MANAGEMENT ON NITRATE AND SORGHUM YIELDS UNDER INTERCROPPING IN *KANHAPLIC HAPLUSTULTS* OF WESTERN KENYA

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EXTENDED ABSTRACT

Grain sorghum (*Sorghum bicolor* L. Moench) is among the cereals produced under smallholder agriculture and serves as a source of food for most of the world's population. In Kenya, sorghum is ranked the third most important staple food after maize and wheat. Despite the importance attached to the role sorghum plays in food security, its production among the smallholder farmers is low with a fluctuating and/or unstable trend. In Busia County, Western Kenya, sorghum production is below optimum and this is a threat to food security among the smallholder farmers in the region. Demographic factors and farmers' perceptions on the native soil fertility status and its improvement among others has implications on crop yields and determines the level of yield gaps for the crops at the farm level. Further to this, prevailing limitations on soil resource base of well characterized soils in this county prove to be a challenge in forecasting the agricultural potential of the varied soil population and has remained a setback in development of appropriate soil management practices needed to improve soil nutrient status and its sustenance. Low inherent soil fertility has also been reported as the major setback to improved yields in Western Kenya, Busia County inclusive. Cereal-legume intercropping coupled with mineral fertilizer application are among the research interventions that have been developed to improve soil fertility and enhance yields. Despite the research interventions that have been put across through research, sorghum yields are below optimum. Therefore, the main aim of this study was to establish the underlying socio-economic factors and soil fertility management aspects governing sorghum production, conduct pedological characterization of the soils in the study sites, and assess the effects of nitrogen fertilizer application rates and soybean residue

management options on nitrate nitrogen and sorghum yields under intercropping system in some typical soils of the County. Thus, to capture socioeconomic factors and farmers' perceptions on soil fertility management practices with regard to sorghum production, a cross-sectional study was carried out using structured interviews and observations. Gender disparity, social norms, literacy, fertilizer use, accessibility to advisory services and farmers' perception on soil fertility management options were concluded to impact on sorghum production. Women were predominant (57.3%) sorghum producing farmers in the County. Literacy level revealed majority of the farmers (49.3%) had primary education as optimum suggesting sorghum production to be through hands-on experience. Individual land ownership was the norm with most farms being 1.5 to 2.0 hectares. To establish representative research sites on the basis of landforms and other physiographic attributes, standard soil survey was carried out in Western Kenya. Soil profiles were characterized at Emalomba (N 00^0 25'28.8" E $034^0$15' 51.9") (Nambale District) designated (EMA-P1) and at Bukhalalire N 00^0 19'10.1" E $034^0$16' 26.4" (Butula District) named BUMA-P1. Both pedons formed from in-situ weathering of granitic rocks under ustic moisture and iso-hyperthermic temperature regimes. Both soils are highly weathered with BUMA-P1 depicting more advanced stage of weathering. The two pedons differed noticeably in terms of physico-chemical characteristics emphasizing the need to characterize soils before fertilizer recommendations are made. In the USDA Soil Taxonomy, EMA-P1 was classified as *Kanhaplic Haplustults* and BUMA-P1 as *Typic Kandiustults*, both corresponding to *Haplic Cutanic Acrisols* in WRB. To gain a better understanding on soil nitrate supply and enhancement of sorghum yields, field experimentation was carried out at Emalomba in the year 2012 and 2013 to assess the effects of nitrogen fertilizer rates and soybean residue management options on nitrate nitrogen (NO_3-N) under intercropping system. Six soybean residue management options were considered: sole sorghum, sorghum + soybean left to maturity, sorghum + soybean mulched, sorghum + soybean incorporated, sorghum + soybean *exsitu* and sorghum + soybean *exsitu* and plot tilled. Three levels of nitrogen (0 kg N ha^{-1}, 40 kg N ha^{-1}, and 80 kg N ha^{-1}) as urea were applied as top-dress and treatments arranged in randomized complete block design. Nitrogen fertilizer application at 40 kg N ha^{-1} with respect to on-farm soybean residue management in relation to NO_3-N supply was in the order: sorghum + soybean left to maturity > sorghum + soybean mulched = sorghum + soybean incorporated. Experimental plots with legume residues removed had significantly ($P < 0.001$) low NO_3-N. Leaf NO_3-N concentration increased with progressive sampling periods with a decrease noted as the crop leaf senesced. Sorghum intercropped with soybean left to maturity with nitrogen fertilizer applied at 40 kg N ha^{-1} reflected high ($P < 0.001$) soil NO_3-N in comparison to the other management options. In the year 2013, a study was carried out in the previous experimental plots with respective treatments to establish the contribution of soybean residues under varied soybean residue management options and nitrogen fertilizer rates on nitrogen supply to the subsequent sorghum crop and on yield. Soybean left to maturity at 40 kg N ha^{-1} indicated significant ($P < 0.001$) increase of 56% soil NO_3-N. At 40 kg N ha^{-1}, treatments with soybean residues mulched and incorporated indicated an increase in soil NO_3-N but were not significantly different and the concentration levels were lower than that of soybean residues left to maturity. Treatments in which soybean residues were removed had significantly ($P < 0.001$) lower soil NO_3-N contribution. The control treatments and sole sorghum indicated the lowest soil NO_3-N accumulation irrespective of nitrogen fertilizer rates. Application of nitrogen fertilizer at 40 kg N ha^{-1} to sorghum intercropped with soybean left to maturity indicated 43% significant ($P < 0.001$) increase in leaf NO_3-N accumulation while treatments with soybean residues mulched showed 39% increase and residues incorporated, 25% at the same application N fertilizer rate. Treatments with soybean residues *ex-situ* and *ex-situ* and till indicated decrease (- 6% and -7%) in leaf NO_3-N accumulation respectively. Sole sorghum had a uniform NO_3-N increase of 4%

irrespective of nitrogen fertilizer rates. Preceding *insitu* soybean residues and nitrogen fertilizer application had no significant ($P < 0.05$) influence on sorghum yield. Sorghum intercropped with soybean left to maturity with nitrogen fertilizer applied at 40 kg N ha^{-1} is therefore recommended as a possible optimum rate and legume residue management option to improve soil NO_3-N among small scale households with stretched socio-economic status. Further research on nitrogen related nutrient: sulphur, be carried out to optimize yields and soybean residue N contribution to the soil.

DECLARATION

I, Syphyline Jebitok Kebeney, do hereby declare to the Senate of Sokoine University of Agriculture that this is my original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

.... 27.11.2014

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DEDICATION

This dissertation is dedicated to my Father, Simon Kiplagat Birgen and my Mother, Esther Chebet Birgen, who introduced me to school life and paid my school fees, to my uncle Joseph Sanga who financed my high school education and my dear husband Jonah Kebeney who paid my undergraduate fees, gave me moral support and always told me the sky was the limit.

TABLE OF CONTENTS

EXTENDED ABSTRACT ii

DECLARATION vi

COPYRIGHT vii

ACKNOWLEDGEMENTS viii

DEDICATION x

TABLE OF CONTENTS xi

LIST OF TABLES xix

LIST OF FIGURES xxi

LIST OF ABBREVIATIONS, SYMBOLS AND ACRONYMS xxiii

CHAPTER ONE 1

1.0 GENERAL INTRODUCTION 1

1.1 Socioeconomic Factors and Soil Fertility Management Aspects 1

1.1.1 Demographic factors 1

1.1.1.1 Gender and age 2

1.1.1.2 Land ownership and size 3

1.1.1.3 Low education level 4

1.1.1.4 Access to agricultural information and advisory services 4

1.1.2 Smallholder farmers' constraints to soil fertility management 6

1.2 Soil 6

1.2.1 Parent material 7

1.2.2 Pedological characterization 7

1.2.3 Significance of pedological characterization 8

1.2.4 Climatic conditions 8

1.2.5 Landscape descriptions and soil morphology 9

1.2.6 Physico-chemical properties 10

1.2.7 Soil classification 11

1.2.8 Management approaches to improve soil fertility 11

1.3 Soil Nitrogen and Intercropping System 12

1.3.1 Soil nitrogen 12

1.3.2 Research interventions to replenish soil nitrogen 13

1.3.2.1 Inorganic fertilizer use 13

1.3.2.2 Cereal – legume intercropping 14

1.3.2.3 Crop residue management and soil nitrogen 18

1.4 Crop Residue Mineralization and Soil Nitrogen Build up 18

1.5 Problem Statement and Justification 19

1.6 Research Objectives 23

1.6.1 Overall objectives 23

1.6.2 Specific objectives 23

1.7 Research Questions 24

1.8 Outline of the Thesis 24

1.9 REFERENCES **27**

CHAPTER TWO 43

2.0 SOCIO-ECONOMIC FACTORS AND SOIL FERTILITY MANAGEMENT PRACTICES AFFECTING SORGHUM PRODUCTION IN WESTERN KENYA: A CASE STUDY OF BUSIA COUNTY 43

ABSTRACT 43

2.1 INTRODUCTION 44

2. 2 MATERIALS AND METHODS 46

2.2.1 Study Design and Sampling Procedure 46

2.2.2 Statistical Data Analysis 47

2.3 RESULTS AND DISCUSSIONS 48

2.3.1 Demographic Factors of the Smallholder Sorghum Farmers 48

2.3.1.1 Gender and age 48

2.3.1.2 Marital status, education level and household size 49

2.3.1.3 Land ownership, size, income and ranking of sorghum crop among the respondents 50

2.3.2 Soil Fertility Management Practices 52

2.3.2.1 Use of agricultural inputs and soil fertility replenishment 52

2.3.2.2 Intercropping as a farm practice among the respondents 54

2.3.2.3 Benefit of intercropping 54

2.3.2.4 Recycling of crop residues for soil fertility improvement 56

2.3.2.5 Accessibility to agricultural information 57

2.3.2.6 Yields of sorghum 58

2.4 CONCLUSION 59

2.5 RECOMMENDATIONS 59

2.6 REFERENCES 61

CHAPTER THREE 67

3.0 PEDOLOGICAL CHARACTERIZATION OF SOME TYPICAL SOILS OF BUSIA COUNTY, WESTERN KENYA: SOIL MORPHOLOGY, PHYSICO-CHEMICAL PROPERTIES, CLASSIFICATION AND FERTILITY TRENDS 67

ABSTRACT 67

3.1 INTRODUCTION 69

3.2 MATERIALS AND METHODS 71

3.2.1 Description of the Study Sites 71

3.2.2 Field Methods 74

3.2.3 Laboratory Methods 74

3.2.3.1 Pedological Characterization 74

3.2.3.2 Determination of Soil Fertility Levels in Busia County ... 76

3.2.3.3 Statistical data analysis 76

3.2.3.4 Classification of soils 76

3.3 RESULTS AND DISCUSSION 76

3.3.1 Morphological Characteristics 76

3.3.2 Soil Physical Characteristics 79

3.3.2.1 Soil particle size distribution (texture) 79

3.3.2.2 Bulk density, total porosity and available moisture content 81

3.3.2.3 Penetrometer resistance 81

3.3.2.4 Soil moisture characteristic curves 83

3.3.3 Soil Chemical Properties 83

3.3.3.1 Soil pH 85

3.3.3.2 Available phosphorus (P) 85

3.3.3.3 Organic carbon, total nitrogen and carbon: nitrogen ratio 86

3.3.3.4 Exchangeable calcium (Ca), magnesium (Mg) and potassium (K).. 86

3.3.3.5 Cation exchange capacity (CEC) of the soils 88

3.3.3.6 Exchangeable sodium (Na) and exchangeable sodium percentage (ESP) 88

3.3.3.7 CEC_{clay} 88

3.3.3.8 Nutrient balance 89

3.3.4 Soil Classification 89

3.3.5 Soil Fertility Trends of the Major Soils of Busia 91

3.4 CONCLUSIONS **93**

3.5 RECOMMENDATIONS **94**

3.6 REFERENCES **95**

CHAPTER FOUR 101

4.0 EFFECTS OF NITROGEN FERTILIZER RATES AND SOYBEAN RESIDUE MANAGEMENT ON NITRATE NITROGEN IN SORGHUM-SOYBEAN INTERCROPPING SYSTEM 101

ABSTRACT 101

4.1 INTRODUCTION 102

4.2 MATERIALS AND METHODS 106

4.2.1 Experimental Site 106

4.2.2 Experimental Description 108

4.2.3 Field Determination of Soil and Leaf Nitrate Nitrogen 109

4.2.4 Statistical Data Analysis 111

4.3 RESULTS AND DISCUSSION 111

4.3.1 Effects of Nitrogen Fertilizer Rates and Soybean Legume Residue Management Options on Soil NO_3-N. 111

4.3.1.1 Soil NO_3 -N concentrations as affected by soil depth during the growing season of 2012 and 2013 111

4.3.1.1.1 Top soil (0 – 15 cm) 111

4.3.1.1.2 Subsoil (15 – 30 cm and 30 – 45 cm) 113

4.3.1.2 Nitrate-nitrogen (NO_3-N) as affected by soil depth, nitrogen fertilizer rates and soybean residue management options during the growing season 114

4.3.1.2.1 Topsoil (0 – 15 cm) 114

4.3.1.2.2 Subsoil (15 – 30 cm and 30 – 45 cm) 117

4.3.1.3 Soil nitrates response to interactive effects of days after emergence, nitrogen rates and legume residue management options 117

4.3.1.4 Effects of nitrogen fertilizer rates on soil NO_3-N with respect to soybean residue management options 120

4.3.2 Effects of days after emergence, nitrogen fertilizer rates and soybean residue management options on leaf NO_3-N concentrations 122

4.3.3 Yield response of sorghum to nitrogen fertilizer rates and soybean residue management options 125

4.4 CONCLUSIONS 128

4.5 RECOMMENDATIONS 129

4.6 REFERENCES 130

CHAPTER FIVE 139

5.0 INFLUENCE OF SOYBEAN RESIDUE MANAGEMENT ON NITRATE NITROGEN ACCUMULATION AND SUBSEQUENT SORGHUM YIELD IN *KANHAPLIC HAPLUSTULTS* OF WESTERN KENYA 139

ABSTRACT 139

5.1 INTRODUCTION 140

5.2 MATERIALS AND METHODS 142

5.2.1 Study Area 142

5.2.2 Field Experimentation 143

5.2.3 Determination of on-site soil and leaf nitrate nitrogen 145

5.2.4 Statistical data analysis 146

5.3 RESULTS AND DISCUSSION 147

5.3.1 Accumulation of Soil NO_3-N as Influenced by Soybean Residue Management Options and N Fertilizer Rates in Year 2012 and 2013 147

5.3.2 Accumulation of Leaf NO_3-N as Influenced by Soybean Residue Management Options and N Fertilizer Rates during the Year 2012 and 2013 149

5.3.3 Accumulation of Soil- and Leaf - NO_3-N with Respect to Days after Emergence in the Year 2012 and 2013 151

5.3.4 Relationship between Days after Emergence and Leaf NO_3-N Accumulation in the Year 2012 and 2013 152

5.3.5 Sorghum Yield Response to NO_3-N Accumulation as Influenced by Soybean Residue Management Options and N Fertilizer Rates 153

5.4 CONCLUSIONS 157

5.6 RECOMMENDATIONS 157

5.7 REFERENCES 158

CHAPTER SIX 163

6.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS 163

6.1 General Conclusions 163

6.2 General Recommendations 167

6.3 Recommendations for Further Research 168

LIST OF TABLES

Table 1.1: Trend of sorghum production (in 1 000 MT) in Kenya for the years 2005 – 2013 17

Table 2.1: Demographic factors of small holder sorghum farmers 48

Table 2.2: Land ownership, farm size, income and perception of sorghum among the respondents 51

Table 2.3: Agricultural inputs and fertilizer use by the respondents 53

Table 2.4: Smallholder farmers' perceptions on intercropping in reference to crop yields and soil fertility improvement 55

Table 2.5: Accessibility to agricultural information 57

Table 3.1: Site characteristics of the studied soils 72

Table 3.2: Salient morphological features of the studied soil profiles 78

Table 3.3: Some physical properties of the studied profiles 80

Table 3.4: Penetrometer resistance of the studied profiles 82

Table 3.5: Some selected chemical properties of the soil profiles studied 84

Table 3.6: Exchangeable cations and related properties of the pedons 87

Table 3.7: Nutrient ratios of top and subsoils of the studied soils 89

Table 3.8: Summary of the morphological and diagnostic features of the studied soils 90

Table 3.9: Classification of the studied soils 90

Table 3.10: Soil fertility trend of Busia County soils 92

Table 4.1: Physico-chemical properties of the experimental site 107

Table 4.2a: Soil NO_3-N in relation to soil depth, nitrogen fertilizer rates and soybean residue management options in the year 2012 115

Table 4.2b: Soil NO_3-N in relation to soil depth, nitrogen fertilizer rates and soybean residue management options in the year 2013 115

Table 5.1: Rainfall amounts and maximum and minimum temperatures for the years 2012 and 2013 143

Table 5.2: Accumulation and build up of soil NO_3-N as influenced by soybean residue management options and N fertilizer rates 147

Table 5.3: Percentage change in sorghum yield between 2012 and 2013 growing seasons 155

LIST OF FIGURES

Figure 2.1: Crops intercropped with sorghum 54

Figure 2.2: Crop residue management among the respondents 57

Figure 3.1 Mean monthly rainfall and temperature data for the study sites from 1980-2013 73

Figure 3.2: Individual soil particle distribution of the studied soils 79

Figure 3.3: Soil moisture characteristic curves for the studied soils 83

Figure 4.1: Climatic data for the experimental site 106

Figure 4.2: Soil NO_3-N concentrations over the sampling period with respect to soil depths in the years 2012 and 2013 112

Figure 4.3a: Soil NO_3-N response to days after emergence, soybean residue management options and nitrogen rates in 2012 118

Figure 4.3b: Soil NO_3^--N response to days after emergence, soybean residue management options and nitrogen rates in 2013 118

Figure 4.4 Soil NO_3^--N concentrations in response to nitrogen fertilizer rates and soybean residue management options in the years 2012 and 2013 121

Figure 4.5a: Leaf nitrate levels in respect to fertilizer rates and soybean residue management options in year 2012 123

Figure 4.5b: Leaf nitrate levels in respect to fertilizer rates and soybean residue management options rates in year 2013 123

Figure 4.6: Sorghum yields (kg ha^{-1}) in response to soybean residue management options and nitrogen fertilizer rates in year 2012 and 2013 126

Figure 5.1: Comparison of leaf NO_3-N accumulation in the year 2012 and 2013 150

Figure 5.2: Relationship between soil and leaf NO_3-N accumulation during sorghum growing season 152

Figure 5.3: Regression equation of the relationship between sampling times over the growing seasons (2012 and 2013) and leaf NO_3-N accumulation 153

Figure 5.4: Effects of soybean residue management options and nitrogen fertilizer rates on sorghum yields in the year 2012 and 2013. 154

LIST OF ABBREVIATIONS, SYMBOLS AND ACRONYMS

ACCI	-	Adaptation to Climate Change and Insurance
AGRA	-	Alliance for a Green Revolution in Africa
BNARDA	-	Benue State Agricultural and Rural Development Authority
BS	-	Base saturation
BUMA-P1	-	Bumala pedon 1
CEC	-	Cation exchange capacity
CEC_{clay}	-	Cation exchange capacity of clay
CEC_{soil}	-	Cation exchange capacity of soil
cm	-	Centimetre
C/N	-	Carbon to nitrogen ratio
EMA-P1	-	Emalomba pedon 1
ESP	-	Exchangeable sodium percent
FAO	-	Food and Agriculture Organization of the United Nations
FAOSTAT	-	Food and Agriculture Organization of the United Nations Statistics
GFRAS	-	Global Forum for Rural Advisory Services
GPS	-	Global Positioning System
ha	-	Hectare
IFPRI	-	International Food Policy Research Institute
KARI	-	Kenya Agricultural Research Institute
kg	-	Kilogram
KIRDI	-	Kenya Industrial Research and Development Institute
LM	-	Low midland

m	-	metre
mg/kg	-	milligram per kilogram
MLND	-	Maize Lethal Necrotic Disease
ml	-	millilitre
MOA	-	Ministry of Agriculture, Kenya
MT	-	Metric tonne
N	-	Nitrogen
NH_4-N	-	Ammonium nitrogen
NO_3-N	-	Nitrate nitrogen
OC	-	Organic carbon
r	-	Correlation coefficient
R^2	-	Coefficient of determination
SSA	-	sub-Saharan Africa
SSSA	-	Soil Science Society of America
TEB	-	Total exchangeable bases
USD	-	United States Dollar
USDA	-	United States Department of Agriculture
UNESCO	-	United Nations Education and Scientific Organization
WRB	-	World Reference Base for Soil Resources

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Socioeconomic Factors and Soil Fertility Management Aspects

Socioeconomic factors influence production of crops, among them sorghum (*Sorghum bicolor* L. Moench) and, thus, are factored in when appraising the potential of a given farm. Demographic factors (i.e. gender, age, marital status, level of education and household size), land ownership and size, income and constraints to knowledge impact on crop production (Chavas *et al.*, 2010). Farmers' perceptions on developed technologies have been reported to influence their understanding on agricultural technical information and thus have been a setback in adoption of new technologies. According to Maro *et al.* (2014) farmers' awareness and their attitudes on soil fertility depletion contribute significantly to low crop yields.

1.1.1 Demographic factors

In sub-Saharan Africa, land area under cultivation is 183 million hectares, and approximately 452 million hectares of additional suitable land are not being cultivated. Smallholder farmers account for most of the cultivated land and a sizeable share of agricultural production. For example, more than 75% of the total agricultural outputs in Kenya, Tanzania, Ethiopia, and Uganda are produced by smallholder farmers with average farm sizes of about 2.5 ha (Salami *et al.*, 2010). Smallholder production, however, is influenced by demographic factors that have impacted on crop production, which are now briefly reviewed.

1.1.1.1 Gender and age

A report by the World Bank (2012) indicated that women are the majority involved in smallholder food production. Their participation on food production has been estimated to be 65% and in sub-Saharan Africa and they contribute about 50% of the required agricultural labour (Alliance for a Green Revolution in Africa [AGRA], 2013). In Ghana, for example, estimates indicate that women produce 70% of the food crops, while in Burkina Faso, Nigeria, and Zambia it is more than 50 % and in some parts of Cameroon, more than 70%. Women make up about 51% of the agricultural labor force in East Africa as a whole (FAO, 2011). According to Ogeto *et al.* (2013) who carried out research in Nakuru County, Kenya, women make up over 50% participation in agricultural activities. Though women's contribution in small scale crop production is notable, their decision making level is negligible since marginal percentage of them own land. In this regard, advances in food production are severely constrained.

Apart from gender, age has been reported to have an indirect effect on production of crops. For example, Atibioke *et al.* (2012) and Obasi *et al.* (2013) indicated that age bracket among the smallholder farmers ranged between 50 and 60 years and 30 -50 years respectively. According to these authors, this age bracket might not be appropriate for strenuous farm activities like planting, weeding, and adoption of new agricultural interventions aimed at improving soil fertility may be a challenge and may negatively affect production by leading to technical inefficiency. The authors further indicated that the younger people are more likely to adopt improved technological practices that less labourious.

1.1.1.2 Land ownership and size

Prevailing socio-political structures and ideological value systems, impact significantly on gender and agricultural production. Namubiru-Mwaura *et al.* (2012) reported that in Liberia, women may be aware of land and policies that protect their rights but often do not know the details of such laws or how to address land access and ownership problems. According to Duncan (2010) and FAO (2010) who carried out research in Uganda, Malawi, Zambia, Rwanda, Tanzania, and Mozambique, women do not have access to land ownership, even though the land laws and policies mandate equality of men and women under statutory law.

Although women contribute more than 70 % of agricultural labour, they own only 1% – 2% of land in Africa, with most of them only accessing land through male relatives (AGRA, 2013). Under customary tenure, land tends to be held collectively by lineages or families and, in many cases, with complex systems of multiple and overlapping rights (Namubiru-Mwaura *et al.*, 2012). For example, in Western Kenya, land ownership is primarily by men (Mugure *et al.*, 2013; Oino and Mugure, 2013). In Busia County, men own land indicating significant role they play in decision making yet they constitute less than 50% agricultural labour (Ogeto *et al.*, 2013). For example, they have decision power on what should be planted in the farm and whether to employ new technologies or continue with the norm. This has a negative implication on soil fertility improvement as it stands as a challenge to new research interventions aimed at improved soil fertility (Maro *et al.*, 2014). In Ghana, however, more women than men have access to land due to matrilineal system of inheritance (Codjoe, 2010).

In West Africa, land sizes are relatively bigger, with average size of at least 3 hectares, but with larger households. On the contrary, in Kenya, Malawi, Mozambique, Rwanda, Tanzania, and Uganda the average farm sizes are less than 3 hectares (FAO, 2010). In Busia County, the average land size ranges between 0.4 to 1.2 hectares.

1.1.1.3 Low education level

The level of education of a farmer not only influences his/her farm productivity but also enhances his/her ability to understand and evaluate new production techniques. According to Wakili (2012), who carried out a study on sorghum production in Nigeria, formal education has direct influence on better understanding and adoption of new technologies. In Western Kenya, for example, research findings by Marenya and Barret (2007), Chianu *et al.* (2008) and ACCI (2013) indicated that illiteracy level contributed significantly to low understanding and adoption of new agricultural interventions including soil fertility management and consequently impacted on production.

1.1.1.4 Access to agricultural information and advisory services

Agricultural extension and advisory personnel work with farmers and other stakeholders in rural settings (Global Forum for Rural Advisory Services (GFRAS) (2010). According to Birner *et al.* (2009) and Christoplos (2010) extension service delivery channels knowledge, information, and technologies to farmers, farmer organizations and other entrepreneurs. Further to this, it facilitates their interaction with partners in research, education, agribusiness, and other relevant institutions assisting them to develop their own technical, organizational, and management skills and practices aimed at improving the management of their agricultural activities.

In principle, constraint to agricultural information has an impact on crop production. For example, Rege (2006) indicated that though data base of research interventions are available, they are not easily accessed by farmers and some of the information could be outdated. According to Obasi *et al.* (2013) extension personnel need to train farmers on the use of correct type and rate of fertilizers in order to improve soil fertility status and enhance crop yields. Mineral fertilizer use (Ngome *et al.*, 2011) and intercropping (Mucheru-Muna *et al.*, 2010) are among research interventions that have been demonstrated to improve soil nutrient levels and enhancing yields among smallholder households.

The success of the already developed research interventions have been met with a setback due to face-to-face gender disparity. For example, Swanson and Rajalahti (2010) reported that in most African countries, there is the widely recognized difficulty of male extension agents having any type of contact with individual female smallholders due to entrenched norms and cultural difficulties in engaging in face-to-face communication. In addition to this, Peterman *et al.* (2011) who carried out a survey on extension service delivery in Ghana, Ethiopia and India showed that gender disparity on contact with extension service is evident. In Ghana for example, the authors found out that on average, less than 2% of female heads of household and female spouses in male-headed households had contact with extension agents whereas nearly 12% of men did.

1.1.2 Smallholder farmers' constraints to soil fertility management

Improvement and sustenance of soil nutrient status has remained a challenge among the smallholder farmers. Their understanding on soil fertility management practices (Mahasi *et al.*, 2011), constrained income (ACCI, 2013), illiteracy (Wakili, 2012), access to agricultural information and training (Rege, 2006) faulty their perceptions on soil fertility depletion (Maro *et al.*, 2014) and combinations of demographic factors in section 1.1.1 have contributed indirectly to soil nutrient depletion and below optimum crop yields.

1.2 Soil

Soil was first defined by Jenny (1941) as a naturally occurring body composed of the solid, liquid and gaseous phase that has resulted from interaction of parent rock with environmental factors of climate, topography, living organisms over time. According to Gupta (2001), soil is defined as a three-dimensional, dynamic, natural body that occurs on the surface of the earth and acts as a medium for plant growth. In this perspective, soil characteristics have resulted from the integrated effect of climate and living matter acting upon parent material, modified by relief over time. Brady and Weil (2008) described soil as a dynamic natural body on the earth's surface that is composed of mineral and organic materials and living forms and supports plants' life.

Soil Survey Staff (2010) defined soil as a natural body comprised of solids (minerals and organic matter), liquid and gases that occur on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers that are distinguishable from the initial material as a result of additions, losses, transfers and transformations of energy and matter or the ability to support rooted plants in a natural environment.

According to Soil Survey Staff (2010), the upper limit of soil is the boundary between soil and air, shallow water, live plants, or plant materials that have not begun to decompose and that for purposes of classification, the lower boundary of soil is arbitrarily set at 200 cm if the non-soil material is not at a shallower depth.

1.2.1 Parent material

All soils are derived from some kind of parent material. Parent material (lithology) indicates the origin and the nature of material from which a given soil is formed. The material may be consolidated or may be weathered materials overlying the hard rock from which they originate (Food and Agriculture Organization of the United Nations [FAO], 2006). The eventual properties of a soil depend, to a significant measure, on the parent material for example soils may develop from basement rocks like granite or basic igneous rocks like basalt and gabbro (Brady and Weil, 2008).

1.2.2 Pedological characterization

Pedological characterization is a systematic identification, grouping and delineation of different soils occurring in the same locality. It deals with the soil forming processes, morphology and physico-chemical properties. Understanding of soil genesis, morphology and other key soil properties is a pre-requisite to sustainable use of soil resources (Msanya *et al.,* 2003). Dent and Young (1981) were of the opinion that well characterized soils set a platform for better and efficient use of the soil resource.

1.2.3 Significance of pedological characterization

Through pedological characterization, valuable information and knowledge on soil characteristics is obtained and a clear understanding on soil genesis, morphology, classification as well as spatial distribution of soils in an area is derived. Well characterized soils and defined ecological conditions act as a bench mark to soil fertility specialists and other stakeholders of soil information in the transfer of agronomic technologies and provide a pathway for extrapolation to other areas with similar ecological conditions (Msanya *et al.*, 2003). In addition to this, agricultural extension staff and farmers need information on site soil physical and chemical properties and other ecological conditions to determine the correct type and amounts of fertilizer to be applied for enhanced crop yields and soil productivity. According to Junge and Skowronek (2007), extensive knowledge about soil with respect to genesis, morphology and physico-chemical properties is of importance in regard to sustainable use of land resources.

1.2.4 Climatic conditions

The climatic conditions of a place are important site properties that influence plant growth and soil formation (FAO, 2006). Thus, monthly mean temperature and monthly mean precipitation over a period of 30 years obtained from a meteorological station are taken into account when conducting pedological characterization work. Soil climate has two major components, moisture (precipitation) and temperature that influence evaporation. When precipitation exceeds evaporation, leaching of the soil plant nutrients will occur. Temperature determines the rate of reactions, chemical and biological decay, and so has an influence on weathering and humification. Soil climate in terms of soil moisture and soil temperature regimes are important when classifying a given soil (SSS, 2006).

1.2.5 Landscape descriptions and soil morphology

Landscape descriptions consist of landscape position, drainage, stoniness, transect aspect, present erosion and moisture regime. Soil profiles are usually described, sampled, and characterized by genetic horizons extending from the surface to a lower boundary determined by bedrock (lithic) contact or to a depth of 150 – 200 cm (FAO, 2006). Soil morphology and other salient features are described using recently dug profile pit large enough to allow sufficient examination and description of the different horizons. Soil horizons are usually the first data used to infer dominant pedogenic processes within the profile and they are described in terms of texture, colour, structure, boundary and vegetation rooting characteristics. Horizon boundaries are described in terms of depth, distinctness and topography and give information on the dominant soil-forming processes that have formed the soil (FAO, 2006). Other characteristics that are of importance are degree of alteration relative to the parent material, expression of oxidized or reduced forms of iron, accumulation of organic matter, or evidence of cyclical deposition of new material. All these help to define the soil types and associated fertility, with implications on management.

1.2.6 Physico-chemical properties

According to Landon (1991), Pansu and Gautheyrou (2006) and Brady and Weil (2008), the physical properties of a soil are those characteristics which can be seen with the naked eye or felt between the thumb and fingers. These physical soil properties have been derived from soil parent materials that have been acted upon by climatic factors such as rainfall and temperature, by topography (slope and direction, or aspect) and by biota over a period of time. Some of the important physical properties include soil texture, bulk density, total porosity, available moisture content and penetrometer resistance (Lal and Shukla, 2005).

In addition to salient morphological and physical properties, base saturation and cation exchange capacity are some of the chemical properties that play a significant role when classifying soils (FAO, 2006). Base saturation is used to indicate the soil weathering rate and accumulation due to soil processes while cation exchange capacity is important in the assessment of the soil buffering properties (Brady and Weil, 2008). Other chemical properties determined in soils are: soil pH, electrical conductivity, organic matter and macro- and micro-nutrients. The macronutrients are required in large quantities by plants and are nitrogen, phosphorus, potassium, calcium, magnesium and sulphur. The micronutrients are required in small quantities (traces) and include iron, zinc, copper, manganese, boron, molybdenum and chlorides (Gupta, 2001). In addition to cation exchange, these parameters are important for soil fertility management (Brady and Weil, 2008).

1.2.7 Soil classification

According to Msanya *et al.* (2003), soil classification is the systematic arrangement of soils into groups or categories based on their characteristics. The advantages of soil classification have been put forward by Beinroth (1978) as:

- Identification, organization and naming of soils in an orderly fashion aimed at revealing and formulating the relationships within varied soil types.
- Consistency in soil surveys from place to place and
- Classification which serves as a bench mark for transfer and application of developed soil technologies to other areas with similar agro-ecological conditions.

The classification of the soil is attempted as much as possible in the field taking precision into consideration the soil morphological features observed and described which are later combined with analytical data to make final classification of soil (FAO, 2006). Types of soils classified have implications on sustainable soil fertility management.

1.2.8 Management approaches to improve soil fertility

Low crop yields among smallholder households have been attributed to decline in soil fertility (Mugwe *et al.*, 2008; Kisinyo *et al.*, 2013) and scientists have put across management approaches to address this phenomenon. For example, Okalebo *et al.* (2006) and Ngome *et al.* (2011) indicated that combined use of inorganic fertilizer and animal manure enhances soil fertility. However, mineral fertilizers are expensive for most smallholder households (Salasya *et al.*, 2007; ACCI, 2013). Further to this, use of manure has its challenges in that it is bulky and labourintensive for transportation and application, inadequacy to sustain cropping due to their relatively low nutrient contents and inability to provide sufficient amount of nutrients (Odendo *et al.*, 2006; Okalebo *et al.*, 2006).

A widely promoted alternative strategy to enhance soil fertility among smallholder households is use of legumes as intercrops (Kaizzi *et al.*, 2006; Muyayabantu *et al.*, 2012). According to Christopher *et al.* (2013), nutrients, particularly nitrogen, are added to the soil through leaf/root decomposition and nitrogen fixation in the roots, hence, use of nitrogen fertilizer may be saved. Other authors (Kihara *et al.*, 2011; Ambrosano *et al.*, 2013; Usman *et al.*, 2013; Kamkar *et al.*, 2014) were of the opinion that legumes under intercropping system contribute soil N through litter, mulch or incorporation of residues into the soil.

1.3 Soil Nitrogen and Intercropping System

1.3.1 Soil nitrogen

Nitrogen (N) is one of the essential plant nutrients required in large quantities (SSSA, 2012; Brady and Weil, 2008) and plays a significant role in plant protein synthesis and enzymes (Zhao *et al.*, 2005; Barker and Pilbeam, 2007; Taiz and Zeiger, 2010). It is a plant nutrient that is part of many organic compounds and a constituent of amino acids, amides, proteins, nucleic acids, nucleotides, co-enzymes and hexoamines (Taiz and Zeiger, 2010). Thus, nitrogen deficiency rapidly inhibits plant growth. The plant-available forms of soil nitrogen are ammonium-N (NH_4-N) and nitrate-N (NO_3-N). According to Miller *et al.* (2008) and Uwah *et al.* (2009) NO_3-N is the primary form of mineral N taken up from the soils by many crops.

Though nitrogen is abundant in the atmosphere, it is inert and cannot easily be chemically combined with other elements into usable forms by plants (Brady and Weil, 2008). Hence, it has been reported as the most deficient nutrient in the soil and more nitrogenous fertilizers are applied annually than other fertilizers to correct the deficiency (Habtegebrial *et al.*, 2007; SSSA, 2012). Nitrogen deficiency in most soils, therefore, has remained both a challenge and a setback in attempts to achieve long term food security and improve farmers' living standards (International Food Policy Research Institute [IFPRI], 2010; Jensen *et al.*, 2012). Among the attempts made aimed at sustained food security and alleviating living standards are research interventions to replenish soil nutrients; soil nitrogen being the most depleted plant nutrient.

1.3.2 Research interventions to replenish soil nitrogen

1.3.2.1 Inorganic fertilizer use

The use of inorganic fertilizers has been demonstrated to be one of the main interventions in replenishing nutrients in the soil (Okalebo *et al.*, 2006; Vanlauwe *et al.*, 2006; Ngome *et al.*, 2011). For example, Ngome *et al.* (2011) reported significant increase in maize grain yield of up to 100% due to the application of mineral fertilizer, particularly nitrogen and phosphorus in smallholder farms across East Africa. Earlier report by Ogola *et al.* (2002) showed that nitrogen fertilizer application increased grain yield (43 - 68%) and biomass (25 - 42%) in maize. Studies by Habtegebrial *et al.* (2007) and SSSA (2012) indicated that application of nitrogen fertilizers improved soil fertility and increased crop productivity.

Continuous use of inorganic fertilizers, however, has been associated with an increase of soil acidity, nutrient imbalances and soil degradations (Ayoola and Makinde, 2008). Further to this, Maatman *et al.* (2008) indicated that in sub-Saharan Africa (SSA), fertilizer use is estimated at 8 kg ha^{-1}, which is only 10% of the worlds' average. This is as a result of socio-economic constraints coupled with wide-spread rural poverty in the region that limit access to mineral fertilizers (World Bank, 2012).

In Western Kenya, soil nutrient depletion has been pinpointed, with nitrogen and phosphorus as the most limiting plant nutrients (Kifuko *et al.*, 2007; Opala *et al.*, 2009; Kisinyo *et al.*, 2012). In addition to this, smallholder households in Busia County have constrained income (ACCI, 2013), thus, sole mineral fertilizer use is a challenge. As such, the need for alternative sources of fertilization as earlier pointed out by Kiani *et al.* (2005) is apparent. An example of such an alternative intervention on soil N improvement aimed at enhanced yields is supplemental use of nitrogen fertilizer in addition to crop residue management under cereal-legume intercropping system.

1.3.2.2 Cereal – legume intercropping

Intercropping is one of the indigenous cropping systems and soil management practices (Scherr and McNeely, 2008) that date back to 300 B.C. in Ancient Greece (Papanastasis *et al.*, 2004). This cropping system has been described to mimic nature and is considered to be a key strategy for sustainable agriculture (Jackson *et al.*, 2007). Egbe (2010) was of the opinion that intercropping is gaining interest as a means of better utilization of resources and preservation of environment. Other reports by Sanginga and Woomer (2009) and Mucheru-Muna *et al.* (2010) indicated that intercropping resulted in improved soil fertility status and enhanced crop yields. According to Fustec *et al.* (2010) and Lithourgidis (2011), cereal-legume intercropping is an alternative and sustainable way of improving soil nitrogen among smallholder production households, resulting in consequent improved productivity of the subsequent cereal crop.

Cereal-legume intercropping is practised in some parts of the world including sub-Sahara Africa (Maluleke *et al.*, 2005). In Pakistan, Bhatti *et al.* (2006) reported that intercropping offers the possibility of yield advantage relative to sole cropping through yield stability and improvement in environments under water stress. A review on intercropping in Sri Lanka by Seran and Brintha (2010) showed improvement in terms of land use efficiency. In the southern Guinea savanna in Nigeria, sorghum intercropped with soybean increased nutrient use efficiency and proved to be economically profitable (Egbe, 2010). In Saria, Burkina Faso, soil loss was reduced with intercropping by more than 50% compared with sorghum and cowpea monocultures (Zougmore *et al.*, 2000). In Mbeere District of Eastern Kenya, intercropping has been reported to improve soil nutrients and to raise household incomes (Onduru and Du Preez, 2007).

Grain sorghum (*Sorghum bicolor* L. Moench) is a cereal crop that can be intercropped with legumes, and serves as a source of food for a significant portion of the world's population (Jensen, 2012; SSSA, 2012), and has been ranked the third most important staple food in Kenya (AGRA, 2013; MOA, 2013). It is a drought tolerant cereal with unique ability to grow and produce significant yields under a wider range of environmental conditions than most other cereals (Moghadden, 2007). The crop can thrive in agro-ecological zones with rainfall from 250 mm but performs best with more than 900 mm annually. Sorghum can be grown on a wide range of soil types and it tolerates soil pH from 5.0 - 8.5 (Jaetzold *et al.*, 2007).

Under favourable conditions, optimum sorghum yields can be up to 11 000 kg ha^{-1}, with an average of 9 000 kg ha^{-1}. However, average productivity estimates show that the mean yield is about 5 000 kg ha^{-1} in Europe, 4 000 kg ha^{-1} in America, 1 200 kg ha^{-1} in Asia, and 800 kg ha^{-1} in Africa (FAOSTAT, 2009). In Kenya, the optimum yield of sorghum ranges between 3 000 to 3 800 kg ha^{-1} depending on the variety (Jeatzold *et al.*, 2007). It is noted that in the recent past, statistical records of sorghum production in Kenya (MOA, 2010) have indicated an increase in acreage under production and a reduction or stagnation in yield. For example an increase in acreage in reference to years has been tabulated as;

- 254, 125 ha in 2011,
- 225, 767 ha in 2010,
- 173, 172 ha in 2009 and
- 104, 041 ha in 2008.

The increase in acreage is attributed to increased area dedicated to the crop on account of it being drought resistant and hence a primary poverty eradication vehicle especially in marginal areas. On the hand, available production statistics with respect to years are indicated in Table 1.1.

Table 1.1: Trend of sorghum production (in 1 000 MT) in Kenya for the years 2005 – 2013

Year	Annual production (1 000 MT)	Production growth rate (%)
2005	150	114.29
2006	131	-12.67
2007	147	12.21
2008	54	63.27
2009	99	83.33
2010	167	65.66
2011	160	-2.44
2012	167	4.38
2013	150	-10.18

Source: United States Department of Agriculture.

www.indexmundi.com/agriculture/?country=kenya

The fluctuation in sorghum production in Kenya is a threat to food security and income levels of smallholder farmers.

Soybean (*Glycine max*) is among the nitrogen-fixing legumes intercropped with cereals e.g. sorghum (Kadam, 2010). It has higher protein (40%) and higher calcium (2%) which is higher than other leguminous crops (Tinsley, 2009). The crop is considered to be of enormous potential for improving human diet, as animal feed and as raw material base for agro-industries (BNARDA, 2007). Soybean has been produced in Kenya for several years on a small scale, but demand for proteins and biodiesel has renewed interest in its production. Within smallholder production systems, soybean is produced in rotation or intercropping with cereals. Presently, soybean-producing households consume about 80% of the production, while marketing 20% (mainly in local open markets), implying a commercial index of 0.20 or 20%. The commercial index indicates that soybean can easily be traded to supplement household cash income needs (Chianu *et al.*, 2008).

1.3.2.3 Crop residue management and soil nitrogen

In addition to inorganic fertilizer use, management of crop residues is an important aspect in improving the inherent soil fertility status and can contribute to increase in nutrient recycling and crop yield (Johnson *et al.*, 2010). Ambrosano *et al.* (2009; 2011) are of the opinion that legume residue decomposition provides long-term supply of N for subsequent crop. Soybean residues have been demonstrated to contribute to soil nitrogen build up. For example, Kihara *et al.* (2011) estimated the contribution of soil N from soybean litter during plant cycle to be 8.2 to 11.8 kg N ha^{-1} while total nitrogen derived from residues after harvest was 30 kg N ha^{-1}.

Incorporation of legume residues on the other hand has been reported to result in increase of soil nitrogen, crop growth and yields (Kamkar *et al.*, 2014; Ambrosano *et al.*, 2013; Rachid, 2011; Jan *et al.*, 2011). Burning and removal of residues from the field, on the contrary, causes direct loss of plant nutrient and dispossess the soil of organic matter which is the sink of these nutrients and a habitat of soil microbes (Blanco-Canqui and Lal, 2009a).

1.4 Crop Residue Mineralization and Soil Nitrogen Build up

Before crop plants can acquire the nutrient elements from residues, organic compounds must be broken down through mineralization process (Lui *et al.*, 2007) and contribute significantly to nutrient cycling and improved crop production (Blanco-Canqui and Lal, 2009a). In addition to this, it has been shown that decomposing legumes have potential to supply adequate plant available N to the subsequent crop depending on management and soil conditions (Cook *et al.*, 2010; Thorup-Kristensen and Dresboll *et al.*, 2010) and provide long-term supply of N for the subsequent crop as indicated by Ambrosano *et al.* (2009; 2011). Further to this, Zhao *et al.* (2014) argued that decomposition of legume residues can lead to build up of soil NO_3-N to meet the crop demand of N during the growing season and even exceed the demand. Consequently, the amounts of inorganic fertilizer required will be reduced resulting in positive N economy.

1.5 Problem Statement and Justification

Smallholder agriculture has been reported (World Bank, 2012) to have enormous potential to make significant contributions to economic development and poverty reduction in Sub-Saharan Africa. As a sector, it is the largest single source of economic livelihoods, employing up to 80% of the rural population as estimated in recent World Bank and FAO assessments. Grain sorghum is among the cereals produced under smallholder agriculture and serves as a source of food for most of the world's population (Jensen, 2012; SSSA, 2012). In Kenya, the crop has been ranked the third most important staple food after maize and wheat (AGRA, 2013; MOA, 2013). Despite the importance attached to the role sorghum plays in food security, it production among the smallholder farmers is low with a fluctuating and/or unstable trend (Table 1.1). There exists a yield gap between the potential yields and actual harvested yields by the farmers.

Yield improvements of various cereals have been hampered by low technology adoption, high prices of fertilizers and demographic factors among others. The extent to which farmers have addressed these factors is what determines the level of yield gaps for the crops at the farm level. Sub-Saharan Africa displays the greatest gaps between potential yields and realized yields for a number of crops, particularly cereals (Licker *et al.*, 2010; Neumann *et al.*, 2010). In Kenya, though sorghum is ranked the third after maize and wheat in terms of cereal production (Kenya Industrial Research and Development Institute [KIRDI], 2011) yield gap difference is noticeable in the sorghum growing areas of the country, Busia County being one of them. Despite all the efforts through alternative research interventions to improve soil fertility and enhance productivity, sorghum yields in the County are below the research potential of 4 000 – 5 000 kg ha^{-1} (KARI, 2006). Thus, there is variability in production from the expected potential yields and the actual yields. It is worth therefore, to unearth the underlying socioeconomic factors and soil fertility management aspects that could be linked to low sorghum yields in the region and address these issues in order to realize crop improvement and improved soil nutrients. It is important to establish farmers' perceptions on the existing interventions and promotion of soil fertility management practices that include inorganic fertilizer use, intercropping, recycling of nutrients as well as access to agricultural information.

Fertilizer recommendations in Kenya in the past were based on the coarse soil exploratory and/or reconnaissance surveys that were carried out by Sombroek *et al.* (1982) and recommendations embedded in Jaetzold *et al.* (2007). However, the blanket recommendations on fertilizer application that have been carried out in the past have not only resulted in low crop yields but also soil fertility depletion (Ayoola and Makinde, 2008). Thus, fertilizer recommendations should take into consideration specific agro-climatic and environmental conditions. General recommendations need to be adjusted to the conditions of the particular field in order to put into effect appropriate soil fertility management practices suitable to the site soils and extrapolate the same to areas with similar soil type and ecological conditions.

Soil survey works that were undertaken covering the study area of Busia County are limited and are typically of exploratory and/or reconnaissance scales. For example, the soil survey carried out in Kenya by Sombroek *et al.* (1982) was on a generalized scale of 1: 1 000 000 survey that resulted in limited information required to forecast the agricultural potential and limitations of the soils of the County. Though a study by Obura *et al.* (2008) reported on site characterization of some selected areas of Kenya, Western region included, the information derived cannot be extended to other related diverse soils of Busia County. The prevailing limitations on resource base of well characterized soils prove to be a challenge in forecasting the agricultural potential of the varied soil population. Additionally, it remains a setback in development of appropriate soil management practices needed to improve soil nutrient status and its sustenance. Further to this, extrapolation of soil technologies to other areas of similar ecological conditions is hindered. It is also worth noting that promotion of correct type and amounts of fertilizers without site characterization of soils may lead to under/over application of nitrogen fertilizer, exacerbating nutrient depletion, and/or wrong fertilizer use and such practices lead to yield gaps in crop yield. Thus, to arrive at sound choice of correct fertilizer type and amounts of mineral fertilizers required, information on soil characteristics of experimentation sites and farmers' fields is paramount.

In Western Kenya, low inherent soil fertility has been pinpointed as the major setback to improved yields (Kisinyo *et al.*, 2012; Opala *et al.*, 2009). To restore the depleted soil nutrients, a number of technologies (Okalebo *et al.*, 2006; Vanlauwe *et al.*, 2006; Ngome *et al.*, 2011) have been generated. For example, Ngome *et al.* (2011a) reported a 100% increase in maize yield as a result of inorganic fertilizers use. With time, however, sole use of inorganic fertilizer could not meet N crop demand during the growing season. This was attributed to increase in soil acidity, nutrient imbalances and soil degradations due to continuous use of mineral fertilizer (Ayoola and Makinde, 2008). Sanginga and Woomer (2009) put across the importance of integrated soil fertility management through combined use of inorganic fertilizer coupled with cereal – legume intercropping. This intervention proved successful in the highlands of Central Kenya and resulted in improved soil nutrients and increased household income. In Busia County, however, the outstanding challenge of inorganic fertilizer use is the constrained income levels of the smallholder farmers. Coupled with this, Mahasi *et al.* (2011) indicated that though farmers in this region practise intercropping, the choice of the intercrops with respect to soil fertility improvement is not a priority. Additionally, farmers' awareness on the contribution of legumes to soil N improvement is unknown, thus, burning of crop residues after harvest is the norm or alternatively, the residues is fed to livestock. It is worth noting therefore that research on optimization of nitrogen fertilizer rate and residue management option under cereal-legume intercropping that can improve soil mineral N and sustain crop productivity is needed. Further to this, failure to account for NO_3-N in the soil can lead to over-application of nitrogen fertilizers.

Crop residues are under-estimated in nutrient recycling and often overlooked when making fertilizer recommendations. Thorburn *et al.* (2011) was of the opinion that crop residues' contribution to soil nitrogen need to be considered in nitrogen fertilizer management and factored in to reduce mineral fertilizer rates. This opinion is supported by Ambrosano *et al.* (2009; 2011) who pointed out that legume residue decomposition provided long-term supply of N for subsequent crop. Further to this, Zhao *et al.* (2014) reported that legumes under intercropping system have potential to contribute significantly to the buildup of soil N to meet and/or exceed the plant nitrogen requirement during the cropping season and consequently increase yields. A motivation is therefore ignited to investigate on the potential of nitrogen fertilizer rate coupled with soybean residue management as an option that can contribute to adequate soil N for the subsequent sorghum crop and increase in yields.

1.6 Research Objectives

1.6.1 Overall objectives

The overall objective was to improve sorghum yields through combined use of nitrogen fertilizer and soybean residue management as an option to improve soil nitrate nitrogen under intercropping system in some typical soils of Busia County, Western Kenya.

1.6.2 Specific objectives

The specific objectives of the research were:

i. To establish the underlying socioeconomic factors and soil fertility management aspects governing sorghum production in Busia County.

ii. To identify, describe, characterize and classify the soils of the study area.

iii. To determine the effects of nitrogen fertilizer rates coupled with soybean residue management on nitrate-nitrogen and yields of sorghum under sorghum-soybean intercropping.

iv. To evaluate the potential of integrated nitrogen fertilizer rates and soybean residue management options on nitrogen supply to the subsequent sorghum crop.

1.7 Research Questions

i. What socioeconomic factors and soil fertility management aspects influence sorghum production in Busia County?

ii. What are the major morphological and physico-chemical characteristics of the dominant soils of the study area?

iii. What is the optimum nitrogen fertilizer rate and soybean residue management option that results to improved soil nitrogen and enhanced sorghum yields?

iv. What is the optimum nitrogen fertilizer rate and soybean residue management option that can contribute adequate soil nitrogen for the subsequent sorghum crop?

1.8 Outline of the Thesis

Chapter 1 is the general introduction, presenting background information and literature review on:

- Socioeconomic factors and soil fertility management aspects that influence crop productivity
- Pedological characterization; its significance, lithology, climatic conditions, salient soil morphological features and physico-chemical characteristics important in soil classification.
- Soil nitrogen and intercropping system and
- Crop residue mineralization and soil nitrogen build up

Finally, the general introduction provided details of the problem description and justification, research objectives, research questions and the outline of the thesis.

Chapter 2 discusses the results of field survey conducted to establish socioeconomic factors and soil fertility management aspects that influence sorghum production in Busia County. It explores the demographic factors and farmers' perceptions on soil fertility management practices that impact on crop productivity.

Chapter 3 covers the results of pedological characterization of the study sites with focus on soil morphology, physico-chemical characteristics, soil classification and finally presents correlation analysis indicating soil fertility trends of Busia County, Kenya.

Chapter 4 presents the results of field experimentation that was carried out to assess the effects of different nitrogen fertilizer rates and soybean residue management options on nitrate nitrogen under sorghum-soybean intercropping system.

In chapter 5, the potential of soybean residue management options in combination with nitrogen fertilizer rates to contribute adequate soil nitrogen for subsequent sorghum crop and its influence on yield is evaluated.

Chapter 6 presents a synthesis of the results of the different chapters of the thesis. It is summarized as an over view of results and conclusions.

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CHAPTER TWO

2.0 SOCIO-ECONOMIC FACTORS AND SOIL FERTILITY MANAGEMENT PRACTICES AFFECTING SORGHUM PRODUCTION IN WESTERN KENYA: A CASE STUDY OF BUSIA COUNTY

ABSTRACT

Sorghum (*Sorghum bicolor* L. Moench), though ranked as the third most important staple food crop in Kenya, farmers still experience periodic crop failure and this is a threat to food and income security. The paper attempts to find the underlying factors responsible for low production and establish farmers' perceptions on soil fertility management. A cross-sectional study was carried out in Busia County, to relate socioeconomic factors and soil fertility management aspects affecting sorghum yields. Structured interviews and observations were used for data collection, considering the variables: demographic factors, income, farmers' perception on soil fertility replenishing options, access to agricultural advisory services and yields of sorghum. The results indicate that women were predominant (57.3%) sorghum producing farmers in the County. The majority of the farmers (49.3%) have primary education as optimum, suggesting that sorghum production is based on hands-on experience. Individual land ownership was the norm, with most farms being 1.5 to 2.0 hectares. Income among respondents is below USD 1.25 per day. Sorghum is ranked very important (56.7%) and is a resource against food shortage. Many farmers (41.3.0%) use traditional seed from previous harvests, with only 24.0% of them purchasing seed from agro-dealers or being provided by non-Governmental organizations/projects. Intercropping is associated with food security, improved yields and land scarcity and not with soil fertility restoration. Inadequate knowledge on the role of legumes and crop residue recycling for soil fertility improvement exists, and 38.7% of farmers have access to agricultural information. Gender, social norms, literacy, fertilizer use, accessibility to advisory services and farmers' perception on soil fertility management options are concluded to impact negatively on sorghum production in Busia County. The existing database on the alternative researched options to restore soil fertility and increase crop yields could be channelled through demonstration plots to farmers in a participatory manner in order to facilitate adoption.

Keywords: Busia County; demographic factors; income; soil fertility management.

2.1 INTRODUCTION

Socioeconomic factors influence agricultural production and thus, have to be considered when appraising the potential of a given farm. Social norms, constraints to knowledge, labour availability, financial and credit constraints are among the factors impacting negatively on agricultural production (Stoorvogel *et al.*, 2004; Chavas *et al.*, 2010). According to World Bank (2012) and Lastarria-Cornhiel (2006), women are the majority involved in smallholder food production. This notwithstanding, researchers (UNESCO, 2010) pointed out that women constituted 60% of the illiterate population in sub-Saharan Africa. Wakili (2012), was of the opinion that more years of formal education has direct influence on better understanding and adoption of new technologies. Other researchers (Zilberman *et* *al.*, 2012) reported that input prices and economies of scale with respect to inputs can also contribute to practicing intercropping of crops in a given piece of land.

In Western Kenya, soil fertility has been noted as the major setback to improved yields (Kifuko *et al.*, 2007; Kisinyo *et al.*, 2012). Research findings have indicated use of inorganic fertilizers (Okalebo *et al.*, 2006; Vanlauwe *et al.*, 2006; Ngome *et al.*, 2011a) as a way of restoring the low inherent soil fertility in Western Kenya, Busia County inclusive. Other studies (Sanginga and Woomer, 2009; Mucheru-Muna *et al.*, 2010) reported on intercropping as being a possible option to restore fertility in the depleted soils of the region. These research interventions are aimed at improving soil fertility and enhancing crop yields.

Despite the alternative ways put forward by the researchers mentioned above, it is worth noting that sorghum (S*orghum bicolor* L. Moench), though ranked as the third most important staple food crop (AGRA, 2013; Ministry of Agriculture [MOA], 2013), the farmers in the growing areas still experience periodic crop failure and this is a threat to food and income security. The unanswered questions then are: (i) what are the underlying factors responsible for the low sorghum production in Western Kenya and in particular Busia County? (ii) what are the farmers' references used in appraising interventions and promotion of relevant soil fertility management practices that can lead to sustainable soil fertility improvement and enhanced yields? There is need, therefore, to consider the references used by farmers in appraising interventions and promotion of relevant soil fertility management practices.

Thus, the study reported herein sought to establish the relationship of socio-economic factors and soil fertility management aspects that govern sorghum production in Busia County to better understand the farmers' basic principles of evaluating different soil fertility management practices aimed at promoting relevant options for sustainable soil productivity.

2. 2 MATERIALS AND METHODS

2.2.1 Study Design and Sampling Procedure

A cross-sectional study was carried out among sorghum smallholder farmers in Busia County, Kenya, to identify socio-economic factors and soil fertility management aspects affecting the production of the crop for example, sex, age, level of education, family size, land ownership and size, access to agricultural information and extension as well as economic endowment of the smallholder farmers. Structured interviews and observations were used to collect data from May to June, 2013. The variables under the study in regard to socio-economic factors were demographic factors and economic status of the households. In regard to soil fertility management aspects, the focus was on farmers' perception on use of agricultural inputs, agricultural advisory services, intercropping and recycling of crop residues.

Sorghum growing areas in Busia County are Butula, Matayos, Funyula, Nambale and Busia Township. Using the divisions of each district, locations where farmers grew sorghum were stratified into two: lower and upper catchment, leading to choice of stratified random sampling technique being used. Lists of farmers growing sorghum were obtained from Technical Assistants in the Ministry of Agriculture in the respective divisions and locations within the districts in the County. The names were then randomly selected as per the respective catchment and the villages. A sample population size was arrived at using the table on sample size selection and standardization equation,

$$n = (n0 \times N)/ (1 + (n0 - 1))$$

where N is the known population; n is sample size; and n0 is the unknown population (Cochran, 1963; Krejcie and Morgan, 1970).

Instruments of data collection were pre-tested in Butula district on 20 respondents (Kathuri and Pals, 1993) to ensure reliability and validity, and revised before actual administering of the structured interviews and observations. Information was also sourced from extension service providers from the Ministry of Agriculture, non-Governmental organizations and local leaders to facilitate formation of general opinion about behaviour of the variables under investigation. The structured interview schedules were then administered to 150 farmers in a face-to-face interview and their responses recorded accordingly. Farmers' evaluation of major soil management practices was based on the advantages and disadvantages perceived about the different practices.

2.2.2 Statistical Data Analysis

The information derived from the respondents were sorted, coded and analyzed using Statistical Package for Social Sciences version 18.0 (SPSS, 2008) and descriptive analysis using MS-excel.

2.3 RESULTS AND DISCUSSIONS

2.3.1 Demographic Factors of the Smallholder Sorghum Farmers

2.3.1.1 Gender and age

Demographic factors among the smallholder sorghum farmers are presented in Table 2.1. The results showed that the majority of respondents (57.3%) were female, with 42.7% being male.

Table 2.1: Demographic factors of small holder sorghum farmers

Demographic factors	Variable	Frequency	Percent
Gender	Male	64	42.7
	Female	86	57.3
	Total	150	100.0
Age (years)	18 -27	10	6.7
	28 -37	37	24.7
	38 -47	57	38.0
	48 – 59	30	20.0
	> 60 years	16	10.7
	Total	150	100.0
Marital status	Single	4	2.7
	Married	128	85.3
	Widowed	18	12.0
	Total	150	100.0
Level of Education	No formal education	10	6.7
	Adult education	2	1.3
	Primary education	74	49.3
	Secondary education	61	40.7
	Others	3	2.0
	Total	150	100.0
Family size	1-5 members	38	25.3
	6-10 members	96	64.1
	11-20 members	16	10.7
	Total	150	100.0

The findings are in agreement with other works (Lastarria-Cornhiel, 2006; Doss, 2010; FAO, 2011; Africa Union Commission and GIZ, 2012; Ogeto *et al.*, 2013) who reported women participation in farming to be above 50%. The findings of this study reveal that 38% of the farmers belong to age group of 38 to 47 years, 24.7% aged between 28 and 37 years and 20% of them aged between 48 and 59 years. Other researchers (Ogeto *et al.*, 2013) reported 30 - 39 years to be the majority (36.7%) while 40 - 49 years represented 26.6% of the respondents in farm activities. Elsewhere, Okuthe *et al.* (2013) researching on adoption of integrated natural resource management indicated the majority of farmers to be between 31 - 40 years of age. The age bracket by the reports mentioned suggests that that age group is considered to be prime, most productive in terms of energy, responsibility and food providers to the household. Sorghum is considered a traditional crop and thus the younger farmers prefer to grow maize in preference to the crop.

2.3.1.2 Marital status, education level and household size

The data derived further highlights that most of the smallholder farmers (85.3%) were married, with 12% widowed and 2.7% single (Table 2.1). From the respondents, 49.3% had primary education level with 40.7% having secondary education while 6.7% had no formal education. Additionally, 1.3% and 2.0% had finished adult education as well as above diploma qualifications, respectively. The findings indicate that the majority of the smallholder sorghum farmers had pre-secondary school qualifications and, thus, understanding and application of agricultural extension technical advices and practices may be a challenge. The study findings support the reports (Marenya and Barrett, 2007; Chianu *et al.*, 2008;

Sanginga and Woomer, 2009; Chavas, 2010; Codjoe, 2010; Wakili, 2012; ACCI, 2013) that expressed the opinion that education plays a role in the understanding and the practice of new interventions. Study results indicate the number of household ranged from 1 to 20. The highest family size (64.1%) had between 6 and 10 members, with 25.3% being 1 - 5 members in the family and 10.7% being 11-20 members. Family size noted herein agrees with data presented by ACCI (2013) that the household size ranged between 7 - 9 members in Busia County. Family household is the major source of labour and thus imperative during farming activities such as planting, weeding and harvesting.

2.3.1.3 Land ownership, size, income and ranking of sorghum crop among the respondents

Type of land ownership, total land size, income earned from growing sorghum and the ranking of the crop by the respondents is summarized in Table 2.2. Data derived indicated 54.7% of the farmers owned land as individuals, with 42.0% being family owned (inherited) while 3.3% leased the land for growing sorghum. In Busia County, the title deeds to the land are held by men, implying that they play a big role in decision making. However, considering gender participation in crop production, women are predominant (over 50%). The results are supported by Ogeto *et al.* (2013) who reported similar findings in Nakuru County, Kenya.

Table 2.2: Land ownership, farm size, income and perception of sorghum among the respondents

Economic Factor	Variable	Frequency	Percent
Type of ownership	Individual	82	54.7
	Family owned	63	42.0
	Leased	5	3.3
	Total	150	100.0
Farm size in hectares (ha)	< 0.2	10	6.7
	0.3 – 0.5	35	23.3
	0.6 – 0.9	41	27.3
	1.0 – 1.5	20	13.3
	1.5 – 2.0	44	29.3
	Total	150	100.0
Income from growing of sorghum (USD)	Less than 25	74	49.3
	Less than 63	67	44.7
	Above 125	8	5.3
	No response	1	0.7
	Total	150	100.0
Ranking of sorghum among other crops	Very important	59	39.3
	Important	85	56.7
	Less important	6	4.0
	Total	150	100.0

Exchange rate used was Kenya shillings 80 for 1 USD

The study findings are also in line with Kameri-Mboote (2005) who indicated that ownership of land in Kenya was on individual basis. Other studies (Chianu *et al.*, 2008; Mugure *et al.*, 2013; Oino and Mugure, 2013) reported the majority of farmers in Western Kenya owned land and that land ownership was primarily by men.

The findings contrast with a report from Ejura-Sekyedumase district in Ghana (Codjoe, 2010) which indicated that more females (88.9%) than males (75.4%) had access to land as a result of the matrilineal system of inheritance practiced here. Farm size was in the range of < 0.2 to > 1.5 ha among the sample population. From the study 29.3% of the farmers had 1.5 - 2.0 ha of land, while 27.3% owned between 0.6 and 0.9 ha of land and 23.3% between 0.3 and 0.5 ha. The present findings on land size are similar to those established by Oino and Mugure (2013) who reported 31.5 % of the respondents to own farm size of 0.4 to 1.2 ha. The results obtained from the sample population further indicated that most of the farmers (49.3%) earned income less than USD 25, with 44.7% earning less than USD 63 and 5.3% earned above USD 125 at the end of sorghum growing season. On a daily basis, income of the respondents was tallying with the report by ACCI (2013) who indicated income among the communities in Busia County as being below USD 10.63 (exchange rate of Kenya shillings 80 per US dollar). The findings also show that the income of the respondents falls below the international critical level of US dollar 1.25 per day (United Nations, 2013).

Majority of the farmers (56.7%) ranked sorghum as an important crop in comparison to other crops, with 39.3% ranking it as very important. The findings highlight the role sorghum plays in food security and as a cushion against unpredictable maize yields. The importance linked to sorghum by the respondents was based on fear of maize lethal necrotic disease (MLND) that had been reported (MOA, 2013) to have caused 100% maize loss in the primary MLND outbreak zones in Kenya and speculation that the disease could spread to other maize growing areas in the country.

2.3.2 Soil Fertility Management Practices

2.3.2.1 Use of agricultural inputs and soil fertility replenishment

Use of agricultural inputs and soil fertility replenishment options among the respondents are presented in Table 2.3. The results showed that 78% of the farmers bought agricultural inputs (seeds and inorganic fertilizer) of which 58.7% indicated they used certified seeds. It is important to note that farmers perceived that because they already have crops that were grown from certified seeds, there is no need to procure the same seasonally, and hence they use their own seeds from previous harvests. Further to this, 24.0% of the farmers sourced seed from agro-dealers or non-Governmental organizations in the County through project participation.

Table 2.3: Agricultural inputs and fertilizer use by the respondents

Farm inputs	Category	Frequenc	Percen
Buy Agricultural inputs bought	Yes	117	78.0
	No	33	22.0
	Total	150	100.0
Use certified sorghum seeds	Yes	88	58.7
	No	62	41.3
	Total	150	100.0
Source of improved seeds	Seed producers	5	3.3
	Relatives/neighbours	11	7.3
	Own seed	62	41.3
	Seed dealers/shops	36	24.0
	Project/organization	36	24.0
	Total	150	100.0
Fertilizer(s) applied	Inorganic fertilizer	47	31.3
	Farm yard manure	42	28.0
	Compost manure	20	13.3
	Recycling of crop residues	29	19.3
	None	12	8.0
	Total	150	100.0

It was noted that 41.3% planted own seed stored from the previous harvest and the farmers were of the opinion that the seeds are safe since the grains are rarely attacked by storage pests. The farmers' perspective on source of sorghum for planting suggests the reason for the low yields of sorghum prevalent in the County. Both inorganic (31.3%) and organic (60.0%) fertilizers were used by the respondents. Majority of the respondents preferred organic fertilizer due to their level of income and the high cost associated with inorganic fertilizers. The inorganic fertilizers used by the respondents were mainly sourced from projects run by NGOs and thus their use on sorghum production was limited.

2.3.2.2 Intercropping as a farm practice among the respondents

Intercropping of sorghum with other crops and their respective percentages are outlined in Figure 2.1. From the results, it can be deduced that majority of the farmers (54%) practiced intercropping of sorghum with various legumes, with 24.7% of the intercrop being common beans and soybean standing at 5.3%. The farmers' perception on intercropping sorghum with green grams or cowpeas was to find a source of vegetables for the household during the short rains and for use during the dry season. The derived data also noted that a high percentage of the respondents (46.5%) plant their sorghum crops as pure stands without intercropping.

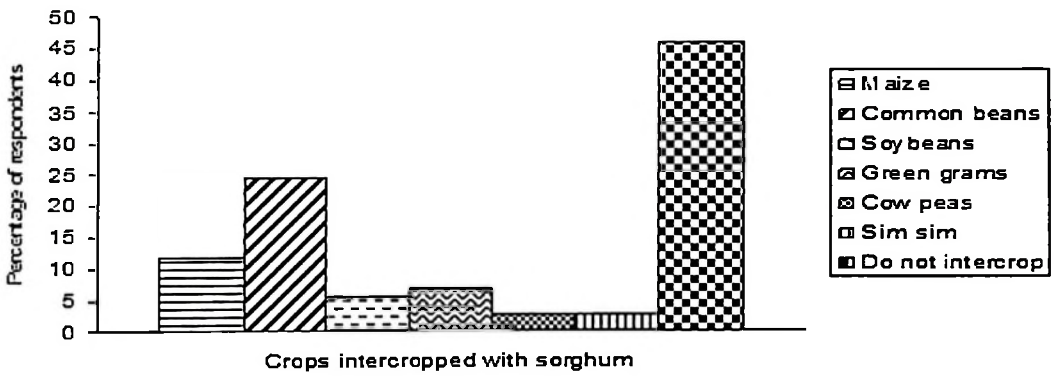

Figure 2.1: Crops intercropped with sorghum

2.3.2.3 Benefit of intercropping

The smallholder farmers' perceptions on advantages and disadvantages of intercropping in reference to crop yields and soil fertility improvement are presented in Table 2.4. From the findings, it was established that the smallholder sorghum farmers had varied opinions and perceptions on the importance of intercropping on crop yields and soil fertility improvement.

Table 2.4: Smallholder farmers' perceptions on intercropping in reference to crop yields and soil fertility improvement

Advantage/disadvantage of intercropping	Frequency	Percentage
Crop yields		
Improved	45	30.0
Reduced	26	17.3
No change	11	7.3
No response	68	45.3
n = 150		
Soil fertility improvement		
Improved	20	13.3
Reduced	46	30.7
No change	14	9.3
No response	70	46.7
n = 150		

Out of the sampled population, 30.0% associated intercropping to improved crop yields, with 17.3% noting that intercropping reduced yields and 7.3% were of the opinion that intercropping of crops had no benefits. It was also noted that 45.3% of the respondents do not practice intercropping hence could not give their opinions on the advantages and disadvantage of the practice. The practice was considered to be traditional and individual farmers intercropped their various crops depending on their objectives regardless of proper agronomic requirements of the crops. The results point out inadequate knowledge regarding intercropping among the respondents.

With regard to soil fertility improvement, 13.3% recognized that intercropping improved soil productivity while 30.7% were of the opinion that intercropping reduced soil productivity. A sample population of 46.7% could not relate intercropping with crop yields or soil improvement. The respondents associated intercropping with food security, improved yields or subsequent sale of the surplus to meet the household needs, and due to inadequate land. The findings indicate that the importance of intercropping and growing of nitrogen fixing legumes for soil fertility is not understood by the respondents, and lack information on the same. Thus, from the data derived, it was imperative to note that low crop yields could be attributed to intercropping without putting consideration other agronomic requirements of crop combinations. The report of the study supports other researchers (Mahasi *et al.*, 2011) who pointed out that the importance of nitrogen fixing legumes in regard to soil fertility improvement is not well understood by the smallholder farmers in western Kenya.

2.3.2.4 Recycling of crop residues for soil fertility improvement

Ultimate use of crop residues among the sampled population is summarized in Figure 2.2. Majority of the farmers (53.3%) recycle the residues from sorghum by incorporating them into the soil to enhance its fertility, with 9.3 % using it for mulching and 6.0% for fodder. However, 5.3% of the respondents burn the crop residues and 4.7% compost them. Out of the sampled population, 21.3% take the legume residues out of the field during harvest to shell the legume grain and neglect the residues thereafter. The results illuminate that though intercropping is practiced by the smallholder households, the importance of soil fertility improvement through recycling of residues is not well understood among the respondents as a soil fertility management practice.

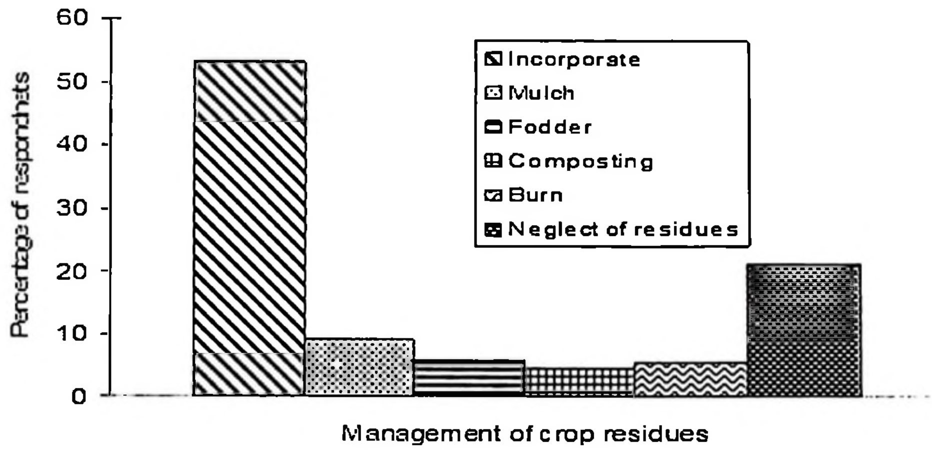

Figure 2.2: Crop residue management among the respondents

2.3.2.5 Accessibility to agricultural information

Data on contact of agricultural extension officers with the sampled population are presented in Table 2.5. From the study, most farmers (61.3%) had no contacts with agriculture extension officers and 38.7% did receive agricultural extension services and information. However, those farmers who had contacts comprised of 28.7% contacted once, 6.7% twice and 3.3% thrice during the crop growing season. The findings showed that there is limited accessibility of agricultural information and probably promotion of new technologies suited to the requirements of smallholder farmers. This coupled with the prevailing demographic factors could negatively affect the overall productivity and crop yield improvement and sustainability.

Table 2.5: Accessibility to agricultural information

Contact with agricultural extension staff		Frequency	Percentage
Yes		58	38.7
No		92	61.3
How many times?	1	43	28.7
	2	10	6.7
	3	5	3.3
	Not at all	92	61.3

The results of the study indicate lack of dissemination of agricultural information, training and other related knowledge which could have had direct influence on the crop production. Some researchers (Odendo *et al.,* 2006) had reported on wide communication gaps between researchers and farmers that had contributed to lack of awareness of new agricultural practices among smallholder households. According to Rege (2006), appreciable quantity of information from research activities in western Kenya has been documented but not easily accessed and, furthermore, in most cases they are outdated. The results of the study emphasizes the need to close the existing dissemination gaps and ensure research findings are communicated to the target farmers for awareness and possible adoption of new agronomic practices and soil fertility management options.

2.3.2.6 Yields of sorghum

In the year 2011, most of the farmers (60.0%) harvested between 0.09 and 0.18 tonnes, with 30.0% harvesting 0.18 – 0.36 tonnes and 10.0% harvested less than 0.09 tonnes per hectare. The number of tonnes harvested by farmers in 2012 varied. Most of the farmers (34.7%) harvested 0.09 tonnes of sorghum, with 19.3% of them harvesting 0.18 tonnes, while 10.7% harvested 0.27 tonnes, 10.0% got 0.36 tonnes and 25.0% harvesting less than 0.09 tonnes of sorghum. In terms of yields, there exists a close similarity in both years i.e. no remarkable change in yields, suggesting stagnation rather than improvement. The findings imply that sorghum production is grown basically for subsistence but when the production is high some of it is sold in the local markets. It agrees with report by ACCI (2013) which indicates that sorghum is grown as a subsistence crop. It may be pointed here that in case of maize crop failure, the yields of sorghum presently obtained cannot probably be taken as a credible cushion against hunger.

2.4 CONCLUSION

From this study, it is concluded that:

- Gender disparity, social norms and low education level are demographic factors associated with the experienced low sorghum yields in Busia County.
- With regard to soil fertility management aspects, minimal fertilizer use, low perception of the farmers on soil fertility management options and inaccessibility to advisory services are concluded to impact negatively on sorghum production in the County.

2.5 RECOMMENDATIONS

In view of the above conclusions, the recommendations are:

- A database of alternative researched options to restore soil fertility and enhance crop yields that have been put forward by research workers in Western Kenya be developed and demonstration plots on the same findings be set up to involve farmers' participation in the hope of changing their perception and facilitating adoption.
- Both male and female (from same household) be involved to receive extension service delivery, with emphasis on intercropping of cereals with nitrogen fixing legumes and residue management to improve soil fertility and enhance crop yields.

- In order to sharpen the precision and convincing power of the extension message, the message be based on carefully characterized soil on a site by site basis, as is subsequently reported for the two locations on this study.

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CHAPTER THREE

3.0 PEDOLOGICAL CHARACTERIZATION OF SOME TYPICAL SOILS OF BUSIA COUNTY, WESTERN KENYA: SOIL MORPHOLOGY, PHYSICO-CHEMICAL PROPERTIES, CLASSIFICATION AND FERTILITY TRENDS

ABSTRACT

Standard soil survey was carried out in Western Kenya to establish representative research sites on the basis of landforms and other physiographic attributes. Soil profiles were characterized at Emalomba (Nambale District) designated (EMA-P1) and at Bukhalalire (Butula District) named BUMA-P1. Both pedons were formed from in-situ weathering of granitic rocks under ustic moisture and iso-hyperthermic temperature regimes. Fourteen soil samples from genetic horizons were analyzed for physico-chemical properties. Both pedons had dark brown sandy clay and sandy clay loam topsoils overlying dominantly clayey subsoils. Both pedons indicate clay eluviation-illuviation as the dominant pedogenic process, with strong acidic soil conditions and available phosphorus of < 7 mg/kg soil. Organic carbon (OC) is high in EMA-P1 and medium to very low in BUMA-P1 while total nitrogen is medium and low to very low. The EMA-P1 and BUMA-P1 soil have C/N ratios of 8.6 - 9.6 and 12.9 - 24.8, respectively. Both pedons have low to very low exchangeable bases with cation exchange capacity (CEC) < 16 cmol(+)/kg soil. CEC_{clay} values in both pedons are < 24 cmol(+)/kg with BUMA-P1 having < 10 cmol(+)/kg. Both soils are highly weathered, with BUMA-P1 depicting a more advanced stage of weathering.

In the USDA Soil Taxonomy, EMA-P1 was classified as *Kanhaplic Haplustults* and BUMA-P1 as *Typic Kandiustults*, both corresponding to *Haplic Cutanic Acrisols* in the WRB. As regards soil fertility trends, OC showed positive correlation with calcium and magnesium, indicating organic matter as the main source of plant nutrients. The two pedons differed noticeably in terms of physico-chemical characteristics, emphasizing the need to characterize soils before fertilizer recommendations are made. Organic fertilizers are recommended to increase organic matter content and intercropping of cereals with nitrogen fixing legumes to enhance nitrogen in the soils. Use of non-acidifying inorganic fertilizers and lime as soil amendments should also be considered to correct acidity.

Key words: Pedological characterization, soil morphology, physico-chemical properties, soil classification, soil fertility trends, Busia County, Kenya.

3.1 INTRODUCTION

Pedological characterization provides valuable information and knowledge on soil characteristics and gives clear understanding on soil genesis, morphology, classification and spatial distribution of soils in an area. According to Jenny (1941), climate, parent material, biota, relief and time are soil forming factors that influence the morphological, physical, chemical and biological characteristics of soil. Understanding of soil genesis, morphology and other key soil properties is a pre-requisite to sustainable use of soil resources (Msanya *et al.*, 2003) and thus detailed knowledge about them is essential. Msanya *et al.* (2003) emphasized the need to have well characterized and defined ecological conditions to aid soil fertility specialists and other stakeholders of soil information to transfer agronomic technologies from one area to another. Well prepared soil resource inventories are a benchmark in determining the potential and management requirements of specific areas for various land uses.

Soil survey works carried out covering the study area of Busia County are limited and are typically of exploratory and/or reconnaissance scales. For example, the work of Sombroek *et al.* (1982) at the scale of 1:1 000 000 described the soils of Busia County (then, Busia District) as well drained, moderately deep to very deep, reddish brown to yellowish brown, friable clay, over petro-plinthite (Orthic Ferralsols, partly petroferric phase; with Orthic Acrisols). The coarse scale nature of this work gives limited information on forecasting the agricultural potential and limitations of the soils of the County. Soil characterization of selected areas in Kenya was carried by Obura *et al.* (2008) and gave general information that cannot be extended to other related diverse soils in the County. According to (Jaetzold *et al.*, 2007), the soils of Western Kenya vary both in their physical and chemical properties and agricultural production is governed by major soil types and precipitation patterns.

Due to limitations pointed above, it is important therefore, to carry out site specific characterization in order to establish the prevailing heterogeneity of the soil pattern so that the required information may be generated for the potential of the soils and appropriate soil management practices. Furthermore, agronomic technologies developed on such well characterized soils can easily be extrapolated to other areas with similar ecological conditions (Msanya *et al.*, 2003). Similar report has also been shown by other workers (Ngome *et al.*, 2011b) who have pointed out the necessity to carry out site specific soil characterization taking into account that crop production is a function of soil properties. Further to this, site soil resource information is required by agricultural extension staff and farmers as a tool for soil fertility management. Thus, knowledge of site-characterized soil physico-chemical properties and other ecological conditions will aid in determining the correct type and amounts of fertilizer to be applied for optimum crop production and sustenance of improved soil fertility.

The current study reports on site identification, description and characterization of some typical soils of Busia County in terms of their morphological characteristics, physico-chemical properties and their classification according to the United States Department of Agriculture (USDA) Soil Taxonomy (SSS, 2006) and the FAO-World Reference Base (IUSS Working Group WRB, 2007). It also reports on the soil fertility trends of the County. The results obtained are anticipated to aid in land use planning for sustainable agricultural production in the County.

3.2 MATERIALS AND METHODS

3.2.1 Description of the Study Sites

The study areas in Busia County, Kenya, are located at Emalomba in Nambale District with a pedon designated as EMA-P1 and at Bukhalalire in Butula District with a pedon named BUMA-P1. Table 3.1 gives the pertinent site characteristics of the study areas. The elevations of the sites are 1 222 m and 1 306 m above sea level, respectively. Both pedons are developed from granitic rocks of pre-Cambrian age. In terms of physiography, the soils are formed on peneplains with gradients ranging between 2 and 2.5%. Surface characteristics depicted slight interill/sheet erosion with no deposition in the identified sites. It was noted that EMA-P1 profile had slow run-off and moderately slow water infiltration in contrast to BUMA-P1 profile that had moderately rapid run-off and rapid infiltration.

Table 3.1: Site characteristics of the studied soils

Pedon	Location	AEZ	Altitude m asl	Landform	Geology / lithology	Slope %	Land use / Vegetation	SMR	STR
EMA-P1	N 00°25′ 28.9″ E 034° 15′ 51.8″	LM1 (Humid Lower Midland Zone)	1222	Peneplain	Pre-Cambrian rocks of the basement complex, comprising mainly granites	2	Agriculture (sugarcane, maize, sweet potatoes, bananas, upland rice (Nerica) and livestock). Dominant vegetation includes *Albizia falcataria*, *Jacaranda mimosifolia*, *Tithonia diversifolia*, *Eucalyptus spp.*, *Grevillea robusta*, *Azadirachta indica* (neem tree).	Ustic	Iso-hyperthermic
BUMA-P1	N 00° 19′ 10.1″ E 034°16′ 26.4″	LM1(Humid Lower Midland Zone)	1306	Peneplain	Pre-Cambrian rocks of the basement complex, comprising mainly granites	2.5	Agriculture (maize, sugarcane, sweet potatoes, bananas, groundnuts, Bambara nuts, upland rice (Nerica) and livestock). Dominant vegetation includes *Albizia falcataria*, *Jacaranda mimosifolia*, *Tithonia diversifolia*, *Eucalyptus spp.*, *Grevillea robusta*, *Azadiracta indica* (neem tree), *Croton megalocarpus* (Musine in Luhya)	Ustic	Iso-hyperthermic

m asl = metres above sea level AEZ = Agro-ecological zone (after Jaetzold, 2006)SMR = soil moisture regime STR = soil temperature regime

The climatic conditions of study area are summarized in Figure 3.1. The study sites experience bimodal rainfall distribution with the long rains having a peak in April-May while the short rains show a peak in October. The maximum temperatures vary between 26.1°C and 29.6°C and minimum temperature range between 13.5°C and 14.9°C (Kenya Meteorological Department, 2014).The maximum temperatures are within the rating of land use requirements for rain-fed sorghum and maize production (Msanya *et al.*, 2001).

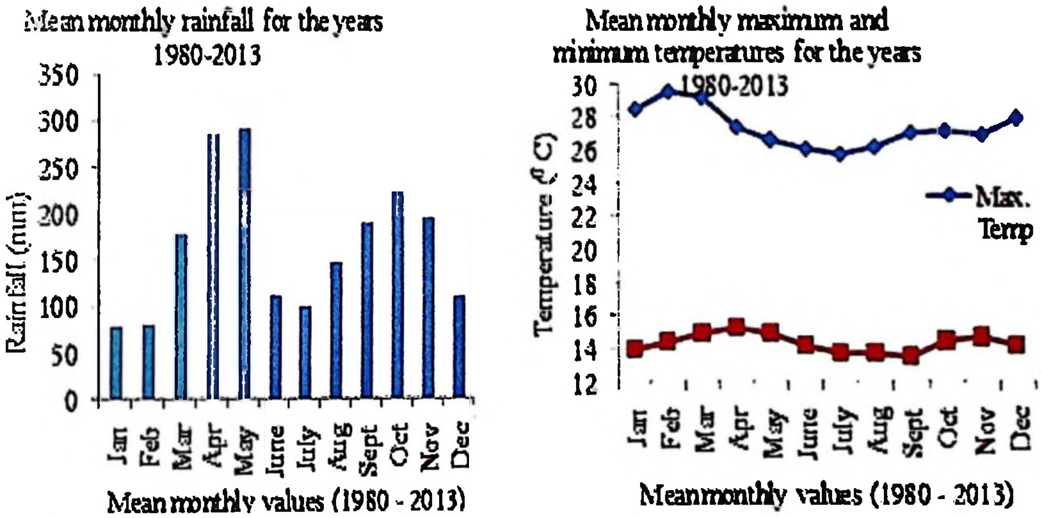

Figure 3.1 Mean monthly rainfall and temperature data for the study sites from 1980-2013
(Source: Kenya Meteorological Department, 2014)

Soil colours were determined by using the Munsell soil colour charts (Munsell Colour Company, 1994). In each profile pit, undisturbed (core) soil samples at depths of 0 - 5 cm, 45 - 50 cm and 95 - 100 cm were sampled, while disturbed samples were taken from all the designated natural horizons for laboratory physical and chemical analysis.

3.2.2 Field Methods

Reconnaissance field survey was carried out using transect walks, auger observations and descriptions to establish representative study sites on the basis of landforms and other physiographic attributes. Data on landform, soil morphological characteristics, elevation, slope gradient, parent material (lithology), vegetation and land use/crops were collected from two observation sites that were selected to represent major landforms and soils as identified from the reconnaissance survey. The data were filled on field description forms designed based on the FAO Guidelines for Soil Description (FAO, 2006). Two representative soil profiles, one from each site, were excavated to represent the major soil types. Soil profile pits measuring of 250 cm by 150 cm were laid out in the east – west direction using GPS compass and dug to a depth of 200+ cm. The soil profile pits were studied, described and sampled according to FAO Guidelines for Soil Profile Description (FAO, 2006). The soil profiles were geo-referenced using a Global Positioning System (GPS) (model OREGON 400t).

3.2.3 Laboratory Methods

3.2.3.1 Pedological Characterization

Undisturbed (core ring) samples were used for determination of bulk density, porosity and moisture retention characteristics. Bulk density was determined by the core method (Blake and Hartge, 1986). Water holding characteristics were determined by a pressure plate/pressure membrane apparatus (NSS, 1990). Disturbed soil samples were air-dried, ground and passed through a 2-mm sieve for physical and chemical soil properties. Particle size distribution was determined by the hydrometer method (Day, 1965) after dispersing soil with sodium hexametaphosphate, and textural classes determined using the USDA textural triangle (USDA, 1975). Soil pH in water was measured potentiometrically using the soil:water ratio of 1:2.5 weight to volume basis (Okalebo *et al.*, 2002). Potentiometric method was used to determine electrical conductivity while available phosphorus was extracted using the Mehlich-3 extraction method (Mehlich, 1984) and determined by spectroscopy at 884 nm following colour development by the molybdenum blue method (Murphy and Riley, 1962). Organic carbon was determined by the Walkey-Black wet oxidation method (Nelson and Sommers, 1982) and total nitrogen was determined by the micro-Kjeldahl digestion method (Bremner and Mulvaney, 1982).

Cation exchange capacity of the soil (CEC*soil*) and exchangeable bases were determined by saturating soil with neutral 1M NH_4OAc (ammonium acetate) and the adsorbed NH_4^+ ions were displaced by using 1M KCl and then determined by Kjeldahl distillation method for estimation of CEC of the soil (Chapman, 1965). The exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+) were determined by atomic absorption spectrophotometer (Anderson and Ingram, 1996). The total exchangeable bases (TEB) were calculated arithmetically as the sum of the four exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) for a given soil sample. Other parameters which were calculated include C/N ratio, exchangeable sodium percentage (ESP) and base saturation percentage (BS %).

3.2.3.2 Determination of Soil Fertility Levels in Busia County

Topsoil composite samples (0-15 cm depth) for soil fertility assessment were collected from ten (10) selected locations from each of five districts of Busia County. The samples were air-dried, ground and passed through a 2-mm sieve for laboratory analysis as in the case of disturbed samples for pedological characterization. The analyses were done to assess the general soil fertility trends in the County.

3.2.3.3 Statistical data analysis

Soil fertility trends analytical data were subjected to Spearman's rank correlation to show the relationship among the soil parameters.

3.2.3.4 Classification of soils

Using field and laboratory analytical data for pedological characterization, the soils were classified to family level of the USDA Soil Taxonomy (SSS, 2006) and to Tier-2 of the FAO World Reference Base (IUSS Working Group WRB, 2007).

3.3 RESULTS AND DISCUSSION

3.3.1 Morphological Characteristics

Salient morphological characteristics of the studied profiles are given in Table 3.2. The EMA-P1 profile is a very deep, well drained pedon, with dark brown sandy clay topsoils overlying dark reddish brown to red clayey subsoils. Abundant distinct clay cutans were observed in the subsoil, indicating that eluviation-illuviation has been a dominant pedogenic process. Profile BUMA-P1 is similar to profile EMA-P1 in many respects. Unlike profile EMA-P1, this profile has fewer and fainter clay cutans, but richer in sesquioxides as indicated by much redder subsoil colours. The subsoil structure of this profile is weaker, breaking into powder, indicating more intense weathering and a more advanced stage of pedogenic development.

Table 3.2: Salient morphological features of the studied soil profiles

Pedon	Horizon	Depth	Texture[1)]	Moist colour[2)]	Consistence[3)]	Structure[4)]	Horizon boundary[5)]
EMA-P1	Ap	0 - 13/17	SC	rdb (7.5YR2.5/3)	fr, s&p	w-m, m, cr	cw
	Bt_1	13/17- 38	C	db (7.5YR3/3)	fr, s&p	m c, sbk	gs
	Bt_2	38-68	C	drb (5YR3/4)	fr, s&p	m c&m, a&sbk	gs
	Bt_3	68-96/101	C	drb (5YR3/4)	vfr, s&p	s m&f, sbk	aw
	CB	96/101-146	C	drb (2.5YR3/4)	fr, ss&sp	w f&p, sbk	as
	$2Bt_1$	146 - 166/171	C	rb (2.5YR4/4)	vfr, s&p	w-m, f&c, sbk	cw
	$2Bt_2$	171 - 200+	C	drb (2.5 YR3/4)	vfr, s&p	w f&m, sbk	-
BUMA-P1	Ap	0 - 9/14	SCL	db (7.5YR3/3)	fr, ss&p	w f&m, cr&sbk	gw
	BA	9/14 - 32/36	SCL	b (7.5YR4/3)	fr, s&p	m m&c, sbk	cw
	Bt_1	32/36 - 63/69	C	rb (5YR4/4)	f, s&p	m m&c, sbk	gw
	Bt_2	63/69 - 87/109	C	rb (5YR4/4)	vfr,ss&p	w-m m&c, sbk-p	gw
	Bts_1	87/109 - 140/144	C	drb (2.5YR3/4)	vfr,ss&p	w m&c, sbk-p	dw
	Bts_2	140/144 – 160	C	rb (2.5YR4/4)	vfr, ss&p	w-m, m, sbk-p	aw
	CB	160 - 200+	C	r (2.5YR4/6)	fr, ss&p	Mass	-

1) SC=sandy clay; SCL=sandy clay loam; C= clay

2) rdb= reddish dark brown; db=dark brown; drb=dark reddish brown; rb=reddish brown; b=brown; r=reddish

3) vfr= very friable; fr=friable; s=sticky; ss=slightly sticky; p=plastic

4) EMA-P1: w-m, m, cr =weak to moderate medium crumby; m c, sbk = moderate coarse subangular blocky; m c&m, a&sbk = moderate coarse & medium angular & subangular blocky; s m&f, sbk = strong medium & fine subangular blocky; w f&p, sbk = weak fine & powdery subangular blocky; w-m, f&c, sbk = weak to moderate fine and coarse subangular blocky; w f&m, sbk = weak fine & medium subangular blocky

BUMA-P1: w f&m, cr&sbk = weak fine & medium crumby; m m&c, sbk = moderate medium & coarse subangular blocky; w-m m&c, sbk-p = weak to moderate medium & coarse subangular blocky; w m&c, sbk-p = weak medium & coarse subangular blocky breaking into powder; w-m, m, sbk-p = weak to moderate medium subangular blocky breaking into powder; mass = massive

5) a= abrupt; c=clear; d=diffuse; g=gradual; s= smooth; w=wavy

3.3.2 Soil Physical Characteristics

3.3.2.1 Soil particle size distribution (texture)

Textural data of the studied pedons are presented in Figure 3.2 and Table 3.3. Figure 3.2 gives the particle size distributions in relation to depth, which clearly indicates that the distribution patterns of the textural separates are similar for both pedons. This supports the fact that the two pedons have developed largely under same soil forming factors and have attained somewhat comparable degree of pedogenesis, though with some differences as observed in section 3.1.

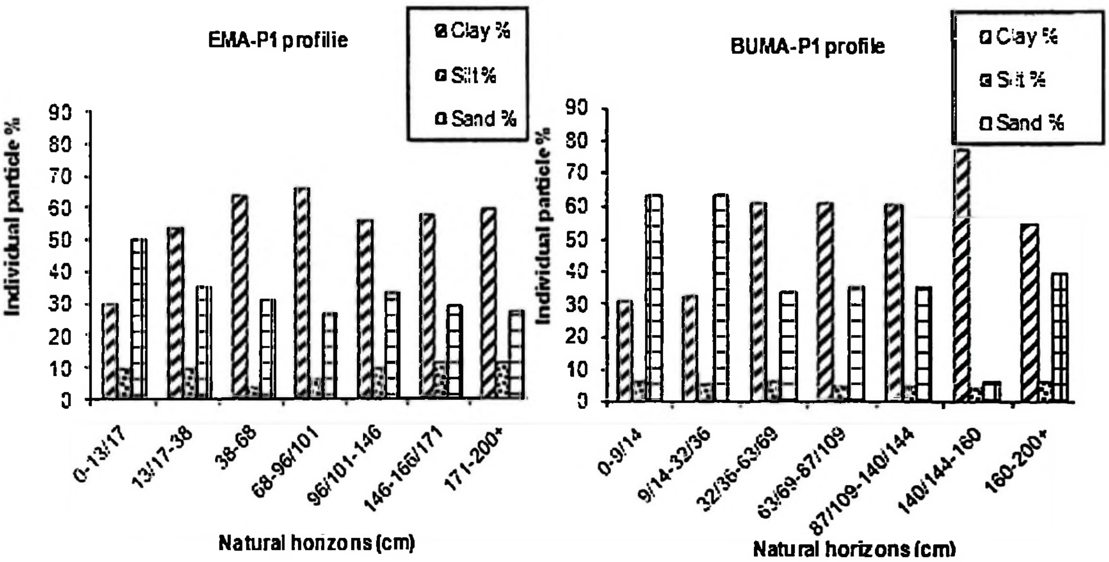

Figure3.2: Individual soil particle distribution of the studied soils

Despite the fact that EMA-P1 has sandy clay topsoil, and BUMA-P1 sandy clay loam topsoil, the two pedons have dominantly clayey subsoils. The silt/clay ratios particularly for subsoils of the two pedons are very low, indicating that the two pedons are highly weathered. The silt/clay ratios in BUMA-P1 are relatively lower than those in EMA-P1 indicating that the former pedon is slightly more weathered than the latter.

Table 3.3: Some physical properties of the studied profiles

Pedon	EMA-P1							BUMA-P1						
Soil depth (cm)	0-13/17	13/17-38	38-68	68-96/101	96/101-146	146-166/171	166/171-200+	0-9/14	9/14-32/36	32/36-63/69	63/69-87/109	87/109-140/144	140/144-160	160-200+
Texture:	SC	C	C	C	C	C	C	SCL	SCL	C	C	C	C	C
Clay %	30.5	54.1	64.5	66.5	56.5	58.5	60.2	30.5	32.1	60.5	60.5	60.1	77.2	54.5
Silt %	9.8	10.1	3.8	6.2	9.8	11.8	11.8	6.2	4.9	6.2	4.2	4.6	3.8	6.2
Sand %	50.3	35.8	31.7	27.3	33.7	29.7	28.0	63.2	62.9	33.3	35.3	35.3	19.0	39.3
Silt/clay	0.32	0.19	0.06	0.09	0.17	0.20	0.20	0.20	0.15	0.10	0.07	0.08	0.05	0.11
Bulk density	1.14	-	1.20	1.23	-	-	-	1.30	-	1.16	1.11	-	-	-
Total porosity	47.9	-	53.2	49.2	-	-	-	46.8	-	48.6	53.6	-	-	-
Av. moisture content (% vol/vol)	54.4	-	64.0	60.7	-	-	-	59.0	-	56.3	59.4	-	-	-

3.3.2.2 Bulk density, total porosity and available moisture content

The analytical results on bulk density, total porosity and available water content of the described profiles are given in Table 3.3. Bulk density determines the magnitude of particle-to-particle contacts and is related to total porosity and has an influence on available soil moisture (Lal and Shukla, 2005). Both profiles have low bulk density (below 1.3 g cm^{-3}) indicating soils that disintegrate into numerous fragments after application of weak pressure (FAO, 2006). These analytical results support the field data on soil structure presented in Table 3.2.

In comparison, the bulk density in EMA-P1 is lower in the topsoil and increases with depth while that in BUMA-P1 is higher in the topsoil and decreases with depth. The high bulk density value in topsoil may likely reduce water infiltration and favour surface water run-off while an increase of the same with depth could result to poor root growth, reduced aeration and decreased water infiltration. Evaluation of bulk density in relation to soil texture in both pedons reveals a 4% more clay content in EMA-P1 pedon in the approximately 80 cm of the sub-horizons (Table 3.3) and has a direct relationship with the available moisture content and consequently water retention capacity (Figure 3.3). EMA-P1 pedon also depicted higher organic carbon in comparison to BUMA-P1 (Table 3.5) suggesting a probable influence on bulk density. According to Aticho (2013) bulk density is influenced by the amounts of organic matter in the soil.

3.3.2.3 Penetrometer resistance

Table 3.4 presents the penetrometer resistance of the two studied pedons. Soil resistance increases with increase in bulk density with decrease in total porosity and soil available moisture content due to increased capillary cohesion (Lal and Shukla, 2005).

Table 3.4: Penetrometer resistance of the studied profiles

Pedon	Horizon	Penetrometer resistance (kg/cm^2)
EMA-P1	Ap	0.65*
	Bt1	10.42
	Bt2	10.42*
	Bt3	4.19*
	CB	8.21
	2Bt1	3.10
	2Bt2	3.10
BUMA-P1	Ap	4.35*
	BA	14.59
	Bt1	10.42*
	Bt2	15.95*
	Bts1	6.29
	Bts2	3.25
	CB	13.97

* profile depths (0 – 5 cm, 45 – 50 cm and 95 – 100 cm) from which undisturbed core soil samples for determination of soil moisture characteristic curves (Fig.2.3) were taken

EMA-P1 soil profile depicts low penetrometer resistance in the upper top-soil and this is attributed to low bulk density (Table 3.3) and reduced matric potential (Figure 3.3) suggesting reduced capillary cohesion due to high available moisture content. BUMA-P1 profile has increasing penetrometer resistance in the representative depths that correlate with the data in Table 3.3, and increased matric potential (Figure 3.3) probably due to increased particle-to-particle cohesion. The results further point to possible soil compaction in the BUMA-P1 profile, which may cause slow growth and development of crops.

3.3.2.4 Soil moisture characteristic curves

Figure 3.3 presents results on soil moisture characteristics. The soil moisture of EMA-P1 indicates a higher retention capacity with a gradual decrease as the suction potential is increased.

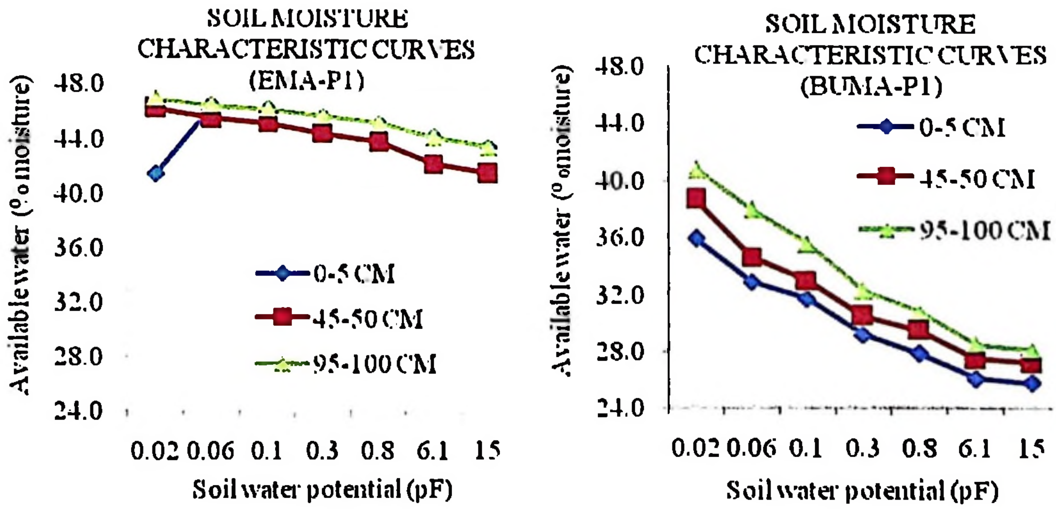

Figure 3.3: Soil moisture characteristic curves for the studied soils

BUMA-P1 profile depicts a drastic decrease in available water content as the suction potential increases, suggesting possibilities of drastic periodic dryness of the soil whenever there is a dry spell within the rainy season, consequently causing plants to experience temporal wilting. The trend of the curves concurs with the seemingly rapid run-off and rapid infiltration under natural drainage observed in BUMA-P1 profile during the field study. Soil moisture characteristic curve (pF curve) depends on soil particle size distribution and organic matter content, which play an important role especially in low suctions (Lal and Shukla, 2005).

3.3.3 Soil Chemical Properties

Some selected soil chemical parameters of the pedons are presented in Table 3.5.

Table 3.5: Some selected chemical properties of the soil profiles studied

Profile	Horizon	pH H_20	pH KCl	EC (mS/cm)	OC %	OM %	N %	C/N Ratio	Avail.P (Mehlich-3)
EMA-P1	Ap	5.45	4.50	28.0	2.58	4.45	0.29	8.90	1.44
	Bt_1	5.43	4.41	17.0	2.49	4.29	0.26	9.58	0.49
	Bt_2	5.40	4.25	17.0	2.49	4.29	0.26	9.58	0.44
	Bt_3	5.49	4.70	22.0	1.71	2.95	0.20	8.55	0.21
	CB	5.74	4.71	8.0	1.54	2.65	0.18	8.56	0.24
	$2Bt_1$	5.74	4.84	17.0	1.35	2.33	0.15	9.00	<0.2
	$2Bt_2$	5.84	4.68	12.0	1.31	2.26	0.15	8.73	<0.2
BUMA-P1	Ap	5.11	4.02	28.0	1.95	3.36	0.16	12.90	4.58
	BA	5.01	4.02	24.0	1.64	2.83	0.12	13.67	2.29
	Bt_1	5.15	4.23	20.0	1.45	2.50	0.10	14.50	1.31
	Bt_2	5.35	4.45	15.0	1.21	2.10	0.08	15.13	1.03
	Bts_1	5.34	4.32	21.0	1.06	1.83	0.06	17.67	0.63
	Bts_2	5.36	4.33	23.0	0.99	1.71	0.04	24.75	0.59
	CB	5.63	4.65	30.0	0.92	1.59	0.04	23.00	0.67

3.3.3.1 Soil pH

According to the ratings by Landon (1991) and EUROCONSULT (1989), both pedons EMA-P1 and BUMA-P1 have strong acidic soil pH conditions. The soil pH finding concurs with research by Kisinyo *et al.* (2013), who reported on low soil pH values in soils of Western Kenya. The results point to the need to consider use of liming materials to raise soil pH to optimal levels to minimize nutrient imbalances, toxicities and unavailability. Low soil pH values below pH < 5.5 have potential to cause toxicity problems and deficiency of some essential plants nutrients as well as affect soil microbial activities (Adamchuk and Mulliken, 2005). Soil pH < 5.5 could also cause dissolution of aluminum and iron minerals which would precipitate with phosphorus, effectively causing its fixation and further lowering the soil pH (Brady and Weil, 2008).

3.3.3.2 Available phosphorus (P)

According to Msanya *et al.* (1995; 1996) and Kileo (2000) both EMA-P1 and BUMA-P1 pedons have very low P (below <7 mg/kg) and by far below the critical level of 2 mg/kg (Okalebo *et al.*, 2002). Low available P in the studied soils may be attributed to low P inherent in the parent materials (which have developed mainly on basement rocks like granite, but also on colluviums from quartzite (Jaetzold *et al.*, 2007). Low P may also be exacerbated by the effects of low soil pH that normally favours P immobilization (Brady and Weil, 2008). Phosphorus availability to plants is strongly influenced by soil pH, and is maximized when pH is between 5.5 and 7.5 (Barker and Pilbeam, 2007).

3.3.3.3 Organic carbon, total nitrogen and carbon: nitrogen ratio

EMA-P1 profile has high to medium organic carbon content, medium total nitrogen and C/N ratios ranging from 8.6 to 9.6 that are within the rating of good quality organic matter. BUMA-P1 has medium organic carbon content, low to very low total nitrogen with C/N ration from 12.9 to 24.8 indicating organic matter of moderate to poor quality according to Msanya *et al.* (1995; 1996) and Kileo (2000). In both profiles, a correlation between organic carbon and total nitrogen is evident and this agrees with other reports e.g. the works of Shelukindo *et al.* (2014) and Msanya *et al.* (2001).

3.3.3.4 Exchangeable calcium (Ca), magnesium (Mg) and potassium (K)

Table 3.6 gives the exchangeable cations of the studied soils. The exchangeable cations can be rated as low to very low (Landon, 1991; Baize, 1993). The low to very low levels of exchangeable cations has direct implications on the cation exchange capacity (CEC), soil pH and ultimately plant nutrient imbalances, unavailability and nutrient induced deficiencies. For example, Mg acts as a phosphorus carrier in plants and, therefore, P uptake is influenced by the nutrient (Barker and Pilbeam, 2007).

Table 3.6: Exchangeable cations and related properties of the pedons

Pedon		Exchangeable bases (cmol(+)/kg						CEC NH_4OAc	CEC $_{clay}$	
		Ca	Mg	K	Na	ESP	TEB	cmol(+)/kg	cmol(+)/kg	BS%
EMA-P1	Ap	3.00	1.31	0.23	0.23	1.55	4.77	14.6	47.87	32.67
	Bt_1	2.28	1.00	0.07	0.24	2.10	3.59	11.20	20.70	32.05
	Bt_2	2.32	1.03	0.08	0.21	1.81	3.64	11.60	17.98	31.38
	Bt_3	2.50	0.88	0.06	0.16	1.46	3.60	11.0	16.54	32.73
	CB	2.09	0.65	0.04	0.21	2.58	2.99	8.05	14.25	37.14
	$2Bt_1$	2.53	0.86	0.05	0.16	1.66	3.60	9.81	16.77	36.70
	$2Bt_2$	2.95	1.06	0.05	0.28	2.44	4.34	11.2	18.60	38.75
BUMA-P1	Ap	1.14	0.54	0.11	0.27	3.67	2.06	7.32	24.00	28.14
	BA	0.70	0.26	0.10	0.15	3.29	1.21	4.50	14.02	26.89
	Bt_1	1.08	0.33	0.06	0.24	4.01	1.71	5.97	9.87	28.64
	Bt_2	1.31	0.32	0.05	0.21	3.44	1.89	5.98	9.88	31.61
	Bts_1	1.31	0.31	0.04	0.18	3.08	1.84	5.92	9.85	31.08
	Bts_2	1.24	0.31	0.03	0.16	2.93	1.74	5.57	7.22	31.24
	CB	1.37	0.36	0.05	0.16	3.04	1.94	5.41	9.93	35.86

3.3.3.5 Cation exchange capacity (CEC) of the soils

The CEC_{soil} of EMA-P1 is medium in the topsoil and low in the subsoil while that of BUMA-P1 is low in the topsoil and very low (< 6 cmol(+)/kg in the subsoils according to Msanya *et al.* (1995; 1996) and Kileo (2000). The CEC values of the pedons indicate possible negative influence on the buffering capacity of the soil and reduced retention of base cations by the soils studied. CEC protects soluble cations from leaching out of the plant root zone and helps soils resist changes in pH (Brady and Weil, 2008; Barker and Pilbeam, 2007).

3.3.3.6 Exchangeable sodium (Na) and exchangeable sodium percentage (ESP)

Based on the work of Msanya *et al.* (1995; 1996) and Kileo (2000), both EMA-P1 and BUMA-P1 pedons have low sodium values ranging between 0.15 - 0.28 and low ESP values (< 6%). The low ESP implies that both soils are non-sodic.

3.3.3.7 CEC_{clay}

The calculated subsoil CEC_{clay} values for both EMA-P1 and BUMA-P1 pedons are below 24 cmol(+)/kg and worthwhile noting is that those of BUMA-P1 are even below 10 cmol(+)/kg. This implies that the soils are highly weathered with BUMA-P1 being more weathered than EMA-P1. CEC_{clay} is an important indicator of the type of clay minerals dominating the soil. Soils with low CEC and CEC_{clay} have reached advanced stages of weathering (Bear, 1965). Soils with low CEC_{clay} values are dominated by 1:1 silicate clay minerals (e.g. kaolinite) that characterize soils that are highly weathered (van Wambeke, 1991).

3.3.3.8 Nutrient balance

Nutrient ratios of the studied pedons are presented in Table 3.7. Both profiles have Ca/TEB ratio of more than 0.5 in both topsoils and subsoils. This may affect the uptake of other bases particularly Mg and/or K due to Ca induced deficiency (Landon, 1991; EUROCONSULT, 1989).

Table 3.7: Nutrient ratios of top and subsoils of the studied soils

Profile	EMA-P1		BUMA-P1	
Nutrient ratio	Top soil (0- 13/17 cm)	Subsoil 13/17- +200 cm	Top soil (0-9/14 cm)	Subsoil 9/14- +200 cm
Ca/TEB	0.63	0.64 – 0.70	0.55	0.69 – 0.71
Ca/Mg	2.29	2.25 -2.94	2.11	3.27 – 4.23
Mg/K	5.7	12.88 – 21.2	4.91	5.5 – 10.3
K/TEB	0.05	0.01 – 0.02	0.05	0.02 – 0.04

The ratios of Ca/Mg are generally within the optimum range of 2 - 4 favourable for plant growth and development. However, due to high Ca/TEB ratio, induced deficiency of Mg could be a major limitation in these soils. The Mg/K ratios in both profiles are above the recommended range for optimum nutrient uptake (Landon, 1991; EUROCONSULT, 1989) implying potential nutrient imbalance and toxicity.

3.3.4 Soil Classification

On the basis of the diagnostic horizons and other diagnostic features (Table 3.8), classification of the soils of the study area is as presented in Table 3.9. EMA-P1 pedon is classified as *Kanhaplic Haplustults* in USDA Soil Taxonomy corresponding to *Haplic Cutanic Acrisols* in the WRB, while BUMA-P1 pedon is classified as *Typic Kandiustults* in USDA Soil Taxonomy corresponding to *Haplic Cutanic Acrisols* in WRB.

Table 3.8: Summary of the morphological and diagnostic features of the studied soils

Profile	Diagnostic horizons, and other features: USDA Soil Taxonomy (SSS, 2006)		Diagnostic horizons, properties and materials: IUSS Working Group WRB (2007)
EMA-P1	Ochric epipedon, Argillic horizon	Very deep, medium to strongly acid, ustic SMR, iso-hyperthermic STR, Slope 2%, subsoil dominantly clayey, presence of many faint and distinct clay cutans, appreciable clay gradient between eluvial and illuvial horizon, low subsoil CEC (<24 cmol(+)/kg clay)	Argic, ferralic properties, cutanic, humic, hyperdystric, clayic, rhodic, chromic
BUMA-P1	Ochric epipedon, Kandic subsurface horizon	Very deep, strongly acid, ustic SMR, iso-hyperthermic STR, Slope 2.5%, subsoil dominantly clayey, presence of faint clay skins in the subsoil, appreciable clay gradient between eluvial and illuvial horizon, very low subsoil CEC (<< 24 cmol(+)/kg clay)	Argic, ferralic properties, cutanic, humic, hyperdystric, clayic, chromic

Table 3.9: Classification of the studied soils

Pedon	USDA Soil Taxonomy (SSS, 2006)					FAO- WRB Soil Classification (IUSS Working Group WRB, 2007)	
	Order	Suborder	Great group	Subgroup	Family	Reference Soil Group – Tier 1	Tier 2 WRB soil name
EMA-P1	Ultisols	Ustults	Haplustults	*Kanhaplic Haplustults*	Very deep, medium to strongly acid, clayey, iso-hyperthermic, *Kanhaplic Haplustults*	Acrisols	Haplic Cutanic Acrisols (Humic, Hyperdystric, Clayic, Rhodic, Chromic)
BUMA-P1	Ultisols	Ustults	Kandiustults	*Typic Kandiustults*	Very deep, strongly acid, clayey, iso-hyperthermic *Typic Kandiustults*	Acrisols	Haplic Cutanic Acrisols (Humic, Hyperdystric, Clayic, Chromic)

Soil profiles: BUMA-P1=Bumala village EMA-P1=Emalomba village

3.3.5 Soil Fertility Trends of the Major Soils of Busia

Spearman's rank correlation of the analytical soil fertility data of the major soils of Busia where sorghum is grown is given in Table 3.10. Percentage sand has negative correlation with sodium and soil pH while silt has positive correlation with calcium, magnesium, phosphorus and potassium. Clay significantly correlates positively with calcium and magnesium as well as sodium showing the role clay plays in either the retention or washing away of these cations and sodium dispersion or flocculation of fine clay particles. Organic matter positively correlates with calcium and magnesium and sodium suggesting organic matter to be the main source of these nutrients. Magnesium and potassium correlate positively indicating the inter-relationship of plant uptake of these bases. Similar findings were reported by Msanya *et al.* (2007) who indicated positive correlation between organic carbon with calcium and magnesium as well as magnesium and potassium.

Table 3. 10: Soil fertility trend of Busia County soils

	% sand	% silt	%clay	% OM	Ca	Mg	P	K	Na	Soil pH
%_sand	1									
% silt	-0.484	1								
%clay	-0.723	-0.166	1							
OM	-0.112	-0.093	0.178	1						
Ca	-0.46	0.309**	0.364**	0.287***	1					
Mg	-0.521	0.33**	0.34**	0.384**	0.847	1				
P	0.199	0.326**	-0.461	-0.116	0.157	-0.008	1			
K	0.075	0.204***	-0.181	-0.108	0.334	0.281***	0.64	1		
Na	-0.195***	0.08	0.198***	0.318**	0.26	0.332**	-0.035	-0.042	1	
Soil Ph	-0.233***	0.486	-0.062	-0.069	0.721	0.56	0.473	0.564	0.151	1

Spearman's rank correlation at 95 % confidence level; (n=50); *** signifies P< 0.001; ** signifies P <0.01

3.4 CONCLUSIONS

The following conclusions can be made from the results of the study:

- Soil physico-chemical characteristics differed from one pedon to the other though the pedons were under similar agro-ecological conditions (LM 1).
- Soil physical properties had an influence on the available water content, soil strength and matric potential which may hinder nutrient uptake and root ramification.
- Soil pH in both sites is strongly acidic with low to very low exchangeable cations that have implications on the CEC, nutrient uptake and consequently nutrient imbalances and induced toxicities.
- The study sites have low to very low organic carbon and total nitrogen with BUMA-P1 site having very low organic matter consequently lowering organic carbon and total nitrogen. Organic matter is the main source of nutrient recycling through microbial decomposition and has an influence on the C/N ratio, rate of decomposition and soil fertility status.
- Both soils are weathered with BUMA-P1 profile showing more advanced stages of weathering, thus, necessitating immediate attention to reverse the trend of already depleted plant required nutrients.

3.5 RECOMMENDATIONS

- Site characterization always needs to be emphasized and be considered as a pre-requisite to meaningful fertilizer trials by soil fertility specialists.
- Use of organic and inorganic fertilizers is recommended in order to increase the level of organic carbon and total nitrogen as well as water retention, root ramification and nutrient recycling in the depleted soils.
- Intercropping of cereals with nitrogen fixing legumes is further recommended in order to introduce nitrogen into the depleted soils via biological nitrogen fixation and to improve soil organic matter through above and below ground biomass.
- Liming is recommended in order to raise the soil pH to favourable levels to minimize loss of base cations, nutrient imbalances, induced toxicities and unavailability.

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CHAPTER FOUR

4.0 EFFECTS OF NITROGEN FERTILIZER RATES AND SOYBEAN RESIDUE MANAGEMENT ON NITRATE NITROGEN IN SORGHUM-SOYBEAN INTERCROPPING SYSTEM

ABSTRACT

An experiment was carried out in Busia County, at Emalomba (N 00^{0}25′28.8″ E 034^{0}15′ 51.9″), Nambale District, Kenya, to assess the effects of nitrogen fertilizer rates and legume management options soil on nitrate nitrogen (NO_3-N) under intercropping system. Six soybean residue management options were considered: sole sorghum, sorghum + soybean left to maturity, sorghum + soybean mulched, sorghum + soybean incorporated, sorghum + soybean exsitu and sorghum + soybean exsitu and plot tilled. Three levels of nitrogen (0 kg N ha^{-1}, 40 kg N ha^{-1}, and 80 kg N ha^{-1}) as urea were applied as top-dress and treatments arranged in randomized complete block design. Soil NO_3-N was significantly high ($P < 0.001$) in topsoil with a notable leaching to subsoil due to precipitation. Control treatments had low soil NO_3-N in comparison to other treatments implying that use of inorganic fertilizers to supplement soil N is important. Fertilizer application at 40 kg N ha^{-1} with respect to on-farm soybean residue management in relation to NO_3-N supply was in the order: sorghum + soybean left to maturity > sorghum + soybean mulched = sorghum + soybean incorporated with 31 mg kg^{-1} NO_3-N and 29 mg kg^{-1} NO_3-N respectively in the year 2012. Experimental plots with sorghum with soybean residues removed had significantly ($P < 0.001$) low NO_3-N concentration ranging between 26.42 and 26.45 mg kg^{-1}. Sorghum leaf NO_3-N concentration increased with

progressive sampling periods with a decrease noted as the crop leaf senesced. The results on yield indicated no significant difference between nitrogen fertilizers applied at 40 kg N ha^{-1} and 80 kg N ha^{-1} irrespective of field managed legume residues. Sorghum intercropped with soybean left to maturity with nitrogen fertilizer applied at 40 kg N ha^{-1} reflected high ($P < 0.001$) soil NO_3-N in comparison to the other management options. It is therefore recommended as a possible optimum rate and legume residue management option to improve soil NO_3-N among small scale households with stretched socio-economic ability in Busia County.

Key words: Nitrate nitrogen levels, sorghum-soybean intercropping, residue management, N fertilizer rates

4.1 INTRODUCTION

Nitrogen (N) is the most deficient nutrient in the soil and to counter this more nitrogenous fertilizers are applied annually than other fertilizers (Habtegebrial *et al.*, 2007; Soil Science Society of America [SSSA], 2012). Nitrogen is an essential plant nutrient required in large quantities (Brady and Weil, 2008) and as a major component of plant protein and enzymes (Zhao *et al.*, 2005; Taiz and Zeiger, 2010; SSSA, 2012). The nutrient element is abundant in the atmosphere. However, it is inert and cannot be chemically combined with other elements into usable forms by plants (Brady and Weil, 2008). Of the three forms of nitrogen; nitrate, ammonium, and dinitrogen, nitrate is the primary form of mineral N taken up from the soils by many crops (Miller *et al.*, 2008; Uwah *et al.*, 2009). This explains why soil testing for nitrate-nitrogen is better than testing for ammonium-nitrogen to predict the sufficiency of soil mineral N supply to crops (Uwah *et al.*, 2009).

Soil fertility improvement is a basic prerequisite to achieve long term food security and improve farmers' living standards (International Food Policy Research Institute [IFPRI], 2010; Jensen *et al.*, 2012). Reports by many authors (Okalebo *et al.*, 2006; Vanlauwe *et al.*, 2006 and Ngome *et al.*, 2011) pointed out the significance of inorganic fertilizer use to replenish nutrients into the soil. Studies by Habtegebrial *et al.* (2007) and SSSA (2012) indicated that nitrogen fertilizers improve soil fertility and increase crop productivity. According to Ogola *et al.* (2002), nitrogen fertilizer application increased grain yield (43 – 68%) and biomass (25 – 42%) in maize. This notwithstanding, crop nitrogen requirements may not be optimally met solely through use of mineral fertilizer. Further to this, economic constraints among small scale farmers in Western Kenya limit sole use of inorganic fertilizer (Adaptation to Climate Change and Insurance [ACCI], 2013). According to Kiani *et al.* (2005), it is necessary to find an additional source of N that would embrace the smallholder socio-economic status.

In addition to inorganic fertilizer use, management of crop residues is an important aspect in improving inherent soil fertility status and can contribute to increase in nutrient recycling and crop yield (Johnson *et al.*, 2010). Studies by Rachid (2011) and Jan *et al.* (2011) pointed out that incorporation of crop residues results in increase in crop growth and yields. Findings by Kihara *et al.* (2011) showed that soybean residues returned to the field after harvest contained total N up to as much as 30 kg N ha^{-1}. The authors further found that litter fall that occurs from planting to physiological maturity of the soybean legume contributed a fixed N of 8.2 to 11.8 kg N ha^{-1}. Other workers (Kamkar *et al.*, 2014) indicated the significance of legumes (alfalfa) as internal input to add N to the soil. On the contrary, burning and removal of residues from the field causes direct loss of the plant nutrient (N) and dispossess the soil organic matter which is the sink of these nutrients and a habitat of soil microbes (Blanco-Canqui, 2009). Though this is so, the norm among the smallholder farmers is to remove the crop, in particular the legumes to tresh in the homes and later burn the residues or feed to livestock.

Sanginga and Woomer (2009) and Mucheru-Muna *et al.* (2010) were of the opinion that intercropping is a possible option to improve low inherent soil fertility status in order to enhance crop yields. According to Fustec *et al.* (2010), cereal - legume crop intercropping is an alternative and sustainable way of improving soil nitrogen among smallholder production farms. Other researchers (Gosh *et al.*, 2007; Sharma and Behera, 2009; Lithourgidis, 2011) have shown that cereal-legume crop farming system results in increased soil fertility, N economy and consequent increase in productivity of the cereal crop. Soybean (*Glycine max*) is among the nitrogen-fixing legumes intercropped with cereals (Kadam, 2010). Grain sorghum (*Sorghum bicolor* L. Moench) is a cereal crop that serves as a source of food for most of the world's population (Jensen, 2012; SSSA, 2012) and has been ranked the third most important staple food in Kenya (Alliance for a Green Revolution in Africa [AGRA], 2013; Ministry of Agriculture [MOA], 2013).

In Western Kenya, the soils are highly weathered, acidic and low in native nutrient status, with nitrogen and phosphorus as the most limiting plant nutrients (Kifuko *et al.*, 2007; Opala *et al.*, 2009; Kisinyo *et al.*, 2012). Taking into consideration the low inherent soil fertility level and the economic status of the smallholder households ((ACCI, 2013), it is imperative to find alternative options that can improve the soil nutrient levels and crop yields. An integrated use of nitrogen fertilizer, cereal-legume intercropping and residue management is probably an option to achieve this. However, the outstanding challenge is the economic status, residue management and importance as well as the contribution of nitrogen fixing leguminous intercrops to soil fertility improvement, which are not well understood by smallholder farmers in the region (Mahasi *et al.*, 2011). A better understanding, therefore, is required to optimize nitrogen fertilizer rate and residue management options under cereal-legume intercropping that can improve soil mineral N and sustain crop productivity.

With regard to the above perspective, the study envisaged to assess effects of nitrogen fertilizer rates and legume residue management options on soil nitrate nitrogen, leaf N contents and yields in sorghum-soybean intercropping system with the specific objectives hereunder:

(i) To determine the effects of nitrogen fertilizer rates and soybean residue management options on soil NO_3-N.

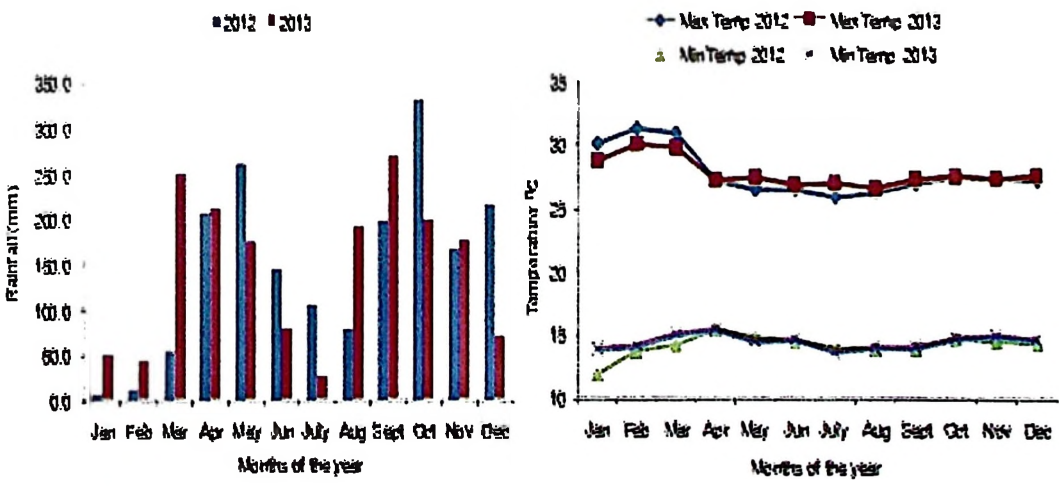
(ii) To determine the effects of nitrogen fertilizer rates and soybean residue management options on sorghum leaf NO_3-N contents.

(iii) To assess the yield response of sorghum to nitrogen fertilizer rates and management of intercropped soybean residues

4.2 MATERIALS AND METHODS

4.2.1 Experimental Site

The study was carried out in Busia County, Kenya, at Emalomba (N 00°25'28.8" E 034°15' 51.9") Nambale District. The site elevation is 1222 m above sea level. Mean monthly rainfall and temperature of the experimental site over a two year period are presented in Figure 4.1. The average annual precipitation in the year 2012 was 1784 mm while in the year 2013 it was 1718 mm. The mean maximum temperatures ranged between 26.3°C to 31.3°C in comparison to mean monthly minimum temperature that varied from 12.0°C to 15.5°C in the year 2012. In the year 2013, mean maximum temperature ranged between 26.5°C to 29.9°C in comparison to mean monthly minimum temperatures that varied from 13.6°C to 15.4°C.



(a) Precipitation (2012 - 2013) **(b) Max. and min. temperature (2012-2013)**

Figure 4.1: Climatic data for the experimental site

(Source: Kenya Meteorological Department, 2014)

The experimental site experiences bimodal rainfall with the long rains beginning in March and the short rains in August/September. The rainfall data indicate variation in both the mean monthly amounts received in the years of study as well as the distribution.

In the year 2013, more rainfall was experienced at the onset of the long rainy season, with a peak in March as compared to the year 2012 when lower precipitation amounts were experienced with a peak in the month of May. The short rains in the year 2013 were higher in amount as compared to 2012 though the short rains in the later was prolonged to the end of the year.

Prior to the start of the study, soil samples taken from 0 - 15 cm, 15 - 30 cm and 30 – 45 cm depths were characterized and their physico-chemical properties are presented in Table 4.1.

Table 4.1: Physico-chemical properties of the experimental site

Parameter	Soil depth (cm)		
	0 – 15	15 – 30	30-45
Clay (%)	30.50	54.10	64.50
Silt (%)	19.20	10.10	3.80
Sand (%)	50.30	35.80	31.70
Textural class	SC	C	C
pH 1:2.5 water	5.45	5.43	5.40
Electrical conductivity ($mScm^{-1}$)	28.00	17.00	17.00
Organic carbon (%)	2.58	2.49	2.49
Total nitrogen (%)	0.29	0.26	0.26
C/N ratio	8.90	9.58	9.58
Organic matter	4.45	4.29	4.29
Nitrate nitrogen (mg/kg)	23.00	19.20	20.7
Avail. P Mehlich-3 ($mgkg^{-1}$)	1.44	0.49	0.44
CEC NH4OAc cmol(+)kg^{-1} soil	14.6	11.20	11.60
Exch. Ca (cmol(+) kg^{-1}	3.00	2.28	2.32
Exch. Magnesium (cmol(+) kg^{-1}	1.31	1.00	1.03
Exch. Potassium (cmol(+) kg^{-1}	0.23	0.07	0.08

SC= Sandy clay, C= Clay

The soils depicted sandy clay texture in the plough layer and clayey in the subsoil. Soil pH is strongly acidic with low available phosphorus below the critical value of 7 mg/kg. Organic carbon is rated medium and organic matter high (Landon, 1991).

Nitrate nitrogen values varied in the profile depths. This was attributed to the variation of clay with soil depth. Exchangeable calcium is low, while exchangeable magnesium is moderate and exchangeable potassium rated low in 0-15 cm depth and very low in the subsoil (Landon, 1991; Pam and Murphy, 2007) and has negative implications on soil pH, CEC and nutrient uptake (Brady and Weil, 2008). Initial soil NO_3-N concentration was 23 ppm which was below the critical concentration of 25 mg/kg recommended for nitrogen fertilizer application with anticipated response (Blackmer *et al.*, 2013; Heckman, 2006).

The soil is classified as *Kanhaplic Haplustults* in USDA Soil Taxonomy (SSS, 2006) correlating with *Haplic Cutanic Acrisols* in WRB (IUSS Working Group WRB, 2007).

4.2.2 Experimental Description

Field experimentation was conducted during the long rains in 2012 and 2013. Each experimental plot measured 3.0 m x 4.5 m with inter-plot distance of 0.5 m and 2 m between blocks. An outer allowance path of 2 m around the experimental plots was included. Sorghum variety KARI Mtama II, suitable to the climatic conditions of the experimental site was sown at the spacing of 75 cm inter-rows and 15 cm between plants. Soybean variety SB 19 inoculated with Biofix ® inoculants and was planted in between the sorghum rows at a spacing of 10 cm. Six treatments were used:

(i) sole sorghum (SS),

(ii) sorghum + soybean left to maturity (SS + SB (maturity),

(iii) sorghum + soybean residue mulched (SS + SB (maturity),

(iv) sorghum + soybean residue incorporated (SS + SB (incorporated),

(v) sorghum + soybean *ex-situ* (SS + SB (*ex-situ*) and

(vi) sorghum + soybean *ex-situ* and plot tilled (SS + SB (*ex-situ* and plot tilled).

The term *ex-situ* is used in reference to removal of soybean residues from the experimental plots while *in-situ* refers to soybean residues being managed within the experimental plots. Triple superphosphate ($Ca(H_2PO_4)_2.H_2O$) was applied uniformly to all the treatments prior to planting by broadcasting and mixing with soil at the rate of 20 kg P ha^{-1}. Three levels of nitrogen (0 kg N ha^{-1} = N_0, 40 kg N ha^{-1} = N_{40}, and 80 kg N ha^{-1} = N_{80}) as urea ($CO(NH_2)_2$ were applied 42 days after emergence to sorghum plants as a top dress by banding. The treatments were arranged in the randomized complete block design with three replications. Soybean residue management options as described in the treatments were carried out 55 days after emergence before pod formation by soybeans.

4.2.3 Field Determination of Soil and Leaf Nitrate Nitrogen

To estimate nitrate-nitrogen (NO_3-N) concentrations in the soil and leaf blade of sorghum, on-farm measurement using ion selective electrode (ISE) as described by (Hartz *et al.* (1994, 2000) and Westervert *et al.* (2005) was adopted. According to (Shaw *et al.*, 2013), ISE has a clear potential for use in rapid on-farm determination of soil NO_3-N.

Three soil samples from each plot were randomly collected by augering at three depths i.e. 0 - 15 cm, 15 - 30 cm and 30 - 45 cm. The respective samples were then mixed thoroughly to obtain a representative sample and each sample placed in a well labelled plastic bag and sealed for determination of soil NO_3-N concentrations. The composite soil samples in sealed plastic bags were placed in cooler box to protect from heat. Soil solution of each composite was extracted by mixing soil with water at the ratio of 1:5 (10 g of soil + 50 mls of water) and 10 mls of calcium chloride was added. The sample was thoroughly shaken for 2 minutes until all the soil clumps had thoroughly dispersed. The sample was left to settle until a clear zone of solution formed at the top of the tube. The ISE meter was calibrated with two standard solutions for NO_3-N which was included in the kit. Using a dropper, 2 - 3 drops of the clear solution was placed on the meter sensor. Once the meter reading stabilized (after 30 - 40 seconds) the value for NO_3-N concentration was recorded. Determination of soil NO_3-N concentrations was performed in duplicate for each treatment and the average recorded.

Leaf nitrate nitrogen was determined by selecting randomly, recently matured leaves from the sorghum plants. From each experimental plot, three sorghum leaf blades were selected, placed in plastic bags, sealed and put in cooler boxes until leaf samples from all experimental plots had been collected. At the end of the sample collection, the leaves were rinsed with distilled water and blot-dried with a paper towel. Direct sunlight and/or high temperatures were avoided during meter reading. With a sharp knife and on a cutting board, leaf blades were chopped and put in a plastic bag. The samples were then punched using a hand hammer to extract the juice. The corner of the bag bottom was cut to puncture the plastic bag then squeezed to obtain the juice. The juice was then dropped to the nitrate meter sensor (about 0.3 ml) to cover the sensor. The measurement values were then read off and recorded once the meter reading stabilized. Leaf NO_3-N concentrations were determined in duplicate for each treatment and the average recorded. A fortnight sampling interval starting from 20 days after emergence up to physiological maturity of sorghum was undertaken to monitor the trends of both soil and leaf nitrate nitrogen. Prior to harvest, an area of 2 x 2 m was demarcated for measurement of crop yields.

4.2.4 Statistical Data Analysis

All data were analyzed using ANOVA in GenStat software (GenStat, 2010). Significant treatment effects were tested using the least significant difference at an alpha level of 0.05.

4.3 RESULTS AND DISCUSSION

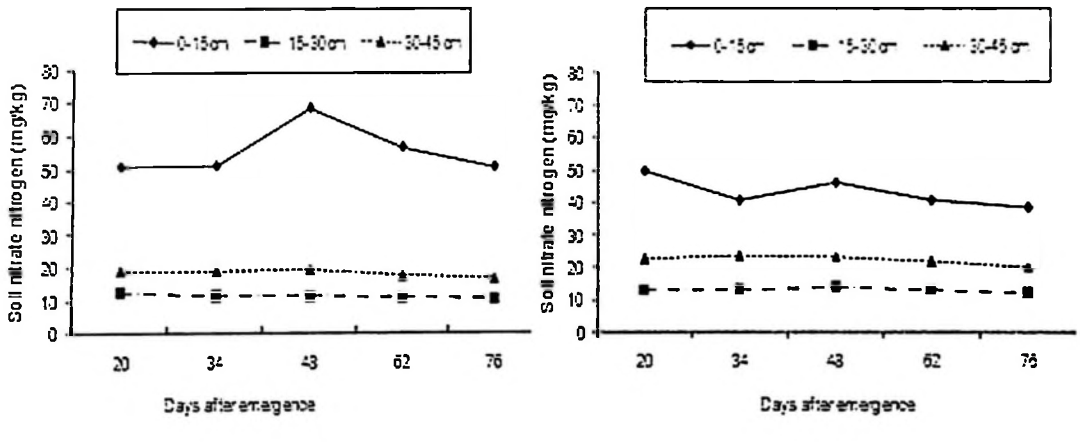
4.3.1 Effects of Nitrogen Fertilizer Rates and Soybean Legume Residue Management Options on Soil NO_3-N.

4.3.1.1 Soil NO_3 -N concentrations as affected by soil depth during the growing season of 2012 and 2013

4.3.1.1.1 Top soil (0 – 15 cm)

The trends of soil NO_3-N concentration over the growing period to physiological maturity for the years 2012 and 2013 are presented in Figure 4.2. The background soil NO_3-N concentration (Table 4.1) in the plough layer was 23 mg kg^{-1} that is below the recommended critical concentration of 25 mg/kg (Blackmer *et al.*, 2013).

In the first sampling (20 days after emergence) NO_3-N concentration increased by more than two times the initial concentration in the year 2012. Before the onset of rains, soil contains mostly organic nitrogen (N) as well as some ammonia and a little inorganic NO_3-N (Brady and Weil, 2008). Thus, the increase in NO_3-N is attributed to nitrogen flush that probably occurred after the onset of the rains. Between the first and second sampling soil NO_3-N in the soil indicated a plateau in the year 2012. This was thought to be as a result of sustained soil NO_3-N derived from decomposition and mineralization of organic materials from previous crop. The site soils had C/N ratio ranging from 8.9 to 9.6 which indicates high levels of organic matter (Landon, 1991). Through decomposition of organic matter, the nutrients; nitrogen, phosphorus, potassium and sulphur are recycled into the soil (Brady and Weil, 2008).



(a) Year 2012 (b) Year 2013

Figure 4.2: Soil NO_3-N concentrations over the sampling period with respect to soil depths in the years 2012 and 2013.

Sampling at 48 days after emergence shows a notable increase in soil NO_3-N in both years with a lower rate of increase, however, in 2013 compared to 2012. The increase was attributed to nitrogen fertilizer application as a top dress to sorghum crop at 42 days after emergence. According to Ngome *et al.* (2011), application of inorganic fertilizers increases plant nutrients in the soil. As the crop growth and development continued in the growing season, demand for NO_3-N increased (Figure 4.3) thus, reducing the concentration of the nutrient in the soil.

In the year 2013, the results of soil NO_3-N concentration showed a sharp drop at second sampling period. This was attributed to the high amount of precipitation that was received in the months of March and April (Figure 4.1) that probably resulted in leaching of the nutrient to lower soil depths as observed in the recorded NO_3-N in the subsoil. The decrease is also presumed to be as a result of under-developed plant root system, thus, NO_3-N losses could have occurred at this period of sampling.

4.3.1.1.2 Subsoil (15 – 30 cm and 30 – 45 cm)

Taking into consideration the soil NO_3-N in the subsoil both years show leaching from the plough layer, further leaching from 15 – 30 cm and consequent accumulation in the 30 – 45 cm depth. The accumulation in the subsoil is attributed to the texture of the soils in the site that had more sand in the plough layer in contrast to the clay content in the subsoil of which higher content is noted in the 30 – 45 cm depth. Similar findings of soil NO_3-N in the subsoil were reported by Phiri *et al.* (2014). Studies by Vagen *et al.* (2012) indicated that sand content in the soil has negative implication on the retention capacity of soil.

4.3.1.2 Nitrate-nitrogen (NO_3-N) as affected by soil depth, nitrogen fertilizer rates and soybean residue management options during the growing season

The comparison of effects of nitrogen fertilizer rates and soybean residue management options with respect to soil depth in the years 2012 and 2013 are given in Table 4.2.

4.3.1.2.1 Topsoil (0 – 15 cm)

Soil NO_3-N concentrations increased with increased nitrogen fertilizer application rates under the intercropping system. The control treatments recorded the lowest soil NO_3-N concentrations, implying the importance of use of inorganic fertilizers with respect to soil N. Nitrogen fertilizer application at 40 kg N ha^{-1} with respect to soybean residue management in relation to NO_3-N supply was in the order: Sorghum + soybean left to maturity > sorghum + soybean residue mulched > sorghum + soybean residue incorporated > sorghum + soybean exsitu > sorghum + soybean exsitu and till > sole sorghum.

It is imperative to note that experimental plots with legume residues removed had significantly ($P < 0.001$) lower NO_3-N concentrations. At 80 kg N ha^{-1} the experimental plots with residues removed had the same trend. However, the trend in relation to soybean residue management was: sorghum + soybean left to maturity < sorghum + soybean mulched < sorghum + soybean incorporated. The reversed trend at higher N fertilizer application is attributed to synergistic effects of immediate legume residue decomposition and nitrogen fertilizer applied which perhaps improved the efficiency of each other (Jan *et al.*, 2007).

Table 4.2a: Soil NO_3-N in relation to soil depth, nitrogen fertilizer rates and soybean residue management options in the year 2012

Soybean residue management option	Soil depth 0 - 15 cm			15 - 30 cm			30 - 45 cm		
	Fertilizer rate (kg N ha^{-1})								
	0	40	80	0	40	80	0	40	80
Sole sorghum	47.15	49.58	50.22	10.74	11.44	11.74	17.36	18.24	19.28
Sorghum+soybean (Maturity)	55.42	61.80	65.26	11.20	11.50	11.70	17.40	18.62	19.48
Sorghum+soybean (residue mulched)	55.62	60.06	65.72	11.33	11.30	11.59	17.29	17.84	18.52
Sorghum+soybean (residue incorporated)	53.29	59.56	66.52	10.76	11.16	10.93	17.06	17.64	17.89
Sorghum+soybean (residue exsitu)	50.08	53.67	57.36	10.59	10.57	11.27	17.44	18.70	20.19
Sorghum+soybean (residue exsitu +Till)	50.62	49.73	51.02	10.85	11.02	11.10	17.38	18.60	19.68

P value $< .001$

L.s.d $_{(0.05)}$ (Soybean residue management option) 0.31

Table 4.2b: Soil NO_3-N in relation to soil depth, nitrogen fertilizer rates and soybean residue management options in the year 2013

Soybean residue management option	Soil depth 0 - 15 cm			15 - 30 cm			30 - 45 cm		
	Fertilizer rate (kg N ha^{-1})								
	0	40	80	0	40	80	0	40	80
Sole sorghum	41.33	42.17	42.64	10.34	11.38	12.15	20.31	21.21	21.58
Sorghum+soybean (Maturity)	43.15	44.14	44.88	12.91	14.47	15.73	22.39	23.74	24.60
Sorghum+soybean (residue mulched)	43.32	44.53	43.83	13.26	14.84	13.82	22.65	23.97	23.19
Sorghum+soybean (residue incorporated)	42.32	43.61	43.92	11.79	13.60	14.00	21.36	22.95	23.38
Sorghum+soybean (residue exsitu)	41.69	43.22	43.46	10.78	13.06	13.43	20.69	22.52	22.78
Sorghum+soybean (residue exsitu +Till)	42.02	42.47	42.75	11.02	12.02	12.30	20.96	21.47	21.72

P value $< .001$

L.s.d.$_{(0.05)}$ (Soybean residue management option) 0.28

Sole sorghum as well as sorghum with soybean residue removed from the experimental plots at flowering and those with plots tilled thereafter recorded the lowest concentrations of NO_3-N. The results from sole sorghum treatments suggest that intercropping has a positive influence on soil N. The findings confirm reports by other workers (Sanginga and Woomer, 2009; Mucheru-Muna *et al.*, 2010; Lithourgidis, 2011; Phiri *et al.*, 2014) on the role intercropping plays in introducing N into the soil. Removal of the soybean residues from the experimental plots decreased the concentration of soil NO_3-N and this agrees with the report of Blanco-Canqui (2009) that residue removal from the field causes direct loss of plant nutrients.

There were significant ($P< 0.001$) differences between soybean left to maturity, residue mulched and residue incorporated in the order: sorghum + soybean residue left to maturity > sorghum + soybean residue mulched > sorghum + soybean residue incorporated. The findings on soybean left to maturity and those mulched agree with the report by Kihara *et al.* (2011) on the significance of litter fall of soybean that occur from planting to physiological maturity.

Soil NO_3-N concentrations was improved with incorporation of legume residue at flowering. The results are in agreement with work reported by Malhi *et al.* (2006) who indicated legume residue incorporation improved soil N due to immediate decomposition. The findings are comparable with results of Kamkar *et al.* (2014) who pointed out that incorporation of alfalfa increased soil N.

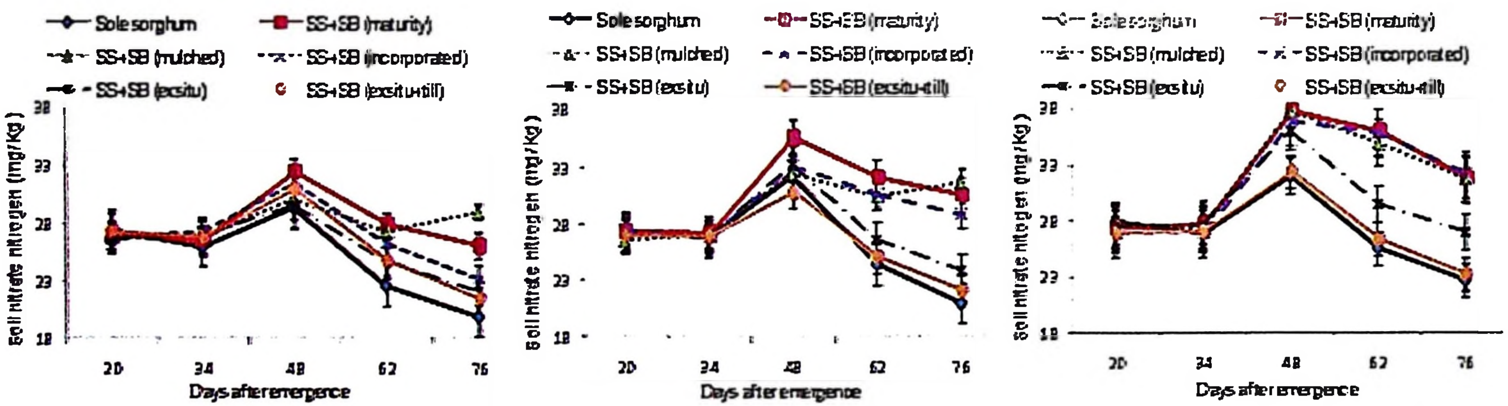
In the year 2013, sorghum + soybean left to maturity indicated significant ($P < 0.001$) NO_3-N but much lower compared to the year 2012. Mulched and incorporated legume residues had no significant difference on NO_3-N concentrations. The low NO_3-N concentrations in the year 2013 is attributed to high rainfall amounts (Figure 1) that probably led to more leaching of NO_3-N as indicated in 30 - 45 cm depth (Figure 4.2). These results are supported by other researchers e.g. Phiri *et al.* (2014), who pointed out the influence of soil moisture (precipitation) on soil NO_3-N concentrations in the soil profile. There was no significant difference between incorporation and mulching of the legume residues in the year 2013 and this is attributed to rapid loss of released N via decomposition through percolation of water to deeper soil depths.

4.3.1.2.2 Subsoil (15 – 30 cm and 30 – 45 cm)

Leaching of NO_3-N to lower soil depths was evident in all the treatments indicating a linear increase with increased N fertilizer rate applied. The loss of NO_3-N to subsoil was attributed to leaching via percolating water due to the sand content of the topsoil in the study site. The findings point out the need to emphasize use of organic fertilizers and intercropping to build above and below ground biomass to improve ion retention capacity of the topsoil.

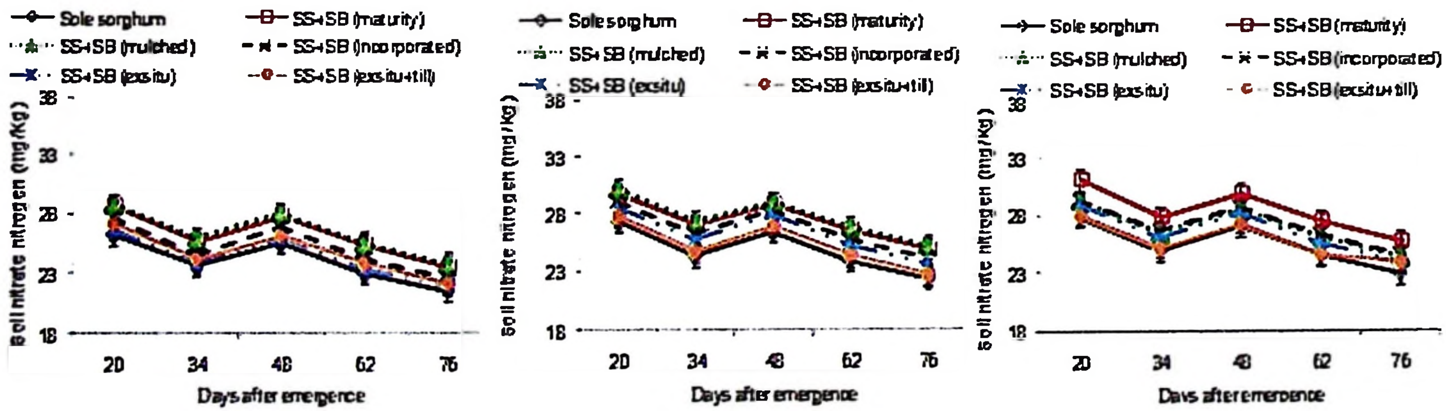
4.3.1.3 Soil nitrates response to interactive effects of days after emergence, nitrogen rates and legume residue management options

The interactive effects of days after emergence, nitrogen fertilizer rates and legume residue management options on soil NO_3-N for both years are presented in Figure 4.3.



(a) 0 kg N ha^{-1} (b) 40 kg N ha^{-1} (c) 80 kg N ha^{-1}

Figure 4.3a: Soil NO_3-N response to days after emergence, soybean residue management options and nitrogen rates in 2012



(a) 0 kg N ha^{-1} (b) 40 kg N ha^{-1} (c) 80 kg N ha^{-1}

Figure 4.3b: Soil NO_3^--N response to days after emergence, soybean residue management options and nitrogen rates in 2013

Soil NO_3-N concentration varied significantly ($P < 0.01$) with sampling time as well as between treatment and reflected a similar trend as presented in Figure 4.1 and as reported in 3.1.2. It is notable, however, that sorghum with mulched soybean showed higher concentrations at late days of plant growth at 40 and 80 kg N ha^{-1}, indicating that mineralization of the residues continues even as the crop approaches physiological maturity.

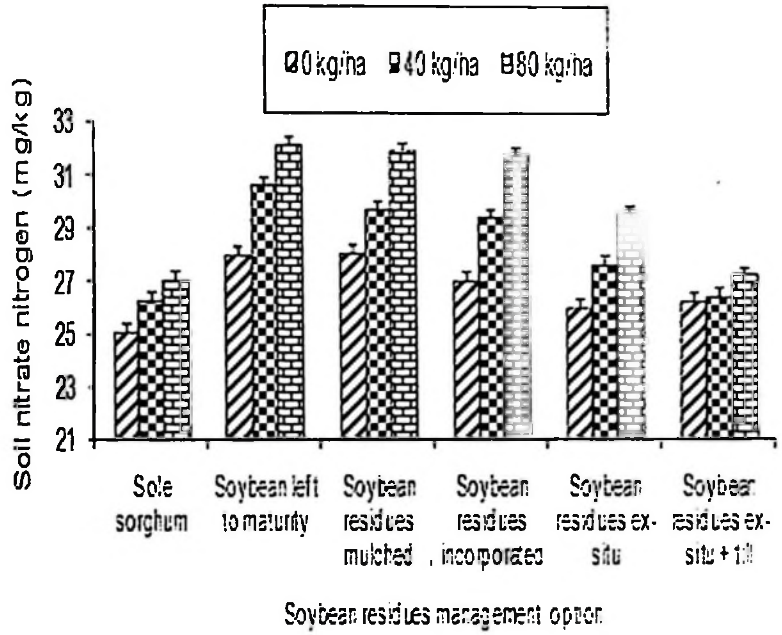
Nitrogen fertilizer application at 40 kg N ha^{-1} and 80 kg N ha^{-1} indicated no significant differences in soil NO_3-N concentrations with respect sorghum + soybean left to maturity. These findings suggest nitrogen fertilizer application at 40 kg N ha^{-1} with soybean left to maturity to be respectively, the potential optimum fertilizer rate and soybean residue management option to improving soil N among small scale households with stretched socio-economic ability as reported by ACCI (2013).

In the year 2013, sorghum + soybean residue mulched recorded slightly higher NO_3-N concentrations though not significantly different from the soybean residues left to maturity and incorporated. The trend of results obtained probably can help in determining the NO_3-N concentrations at different stages of plant growth and assessing the supply of NO_3-N from soil under cereal-legume intercropping and the break-even where NO_3-N concentrations translate to yields.

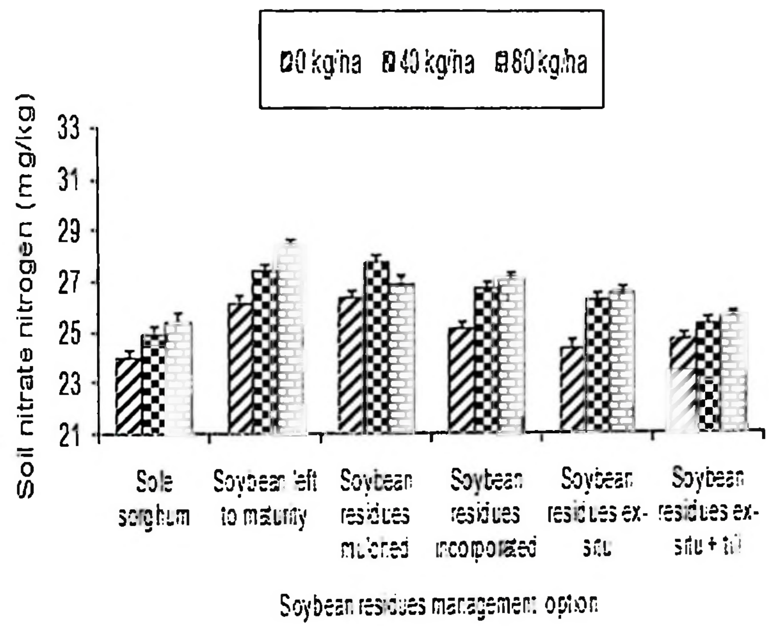
4.3.1.4 Effects of nitrogen fertilizer rates on soil NO_3-N with respect to soybean residue management options

Combined effects of three rates of N fertilizer and soybean residue management options on soil NO_3-N concentrations in the years 2012 and 2013 are presented in Figure 4.4. The data indicate increase in NO_3-N concentrations with increase in nitrogen fertilizer rates in both years. The results further highlight significant ($P \leq 0.001$) difference in nitrogen fertilizer rates applied as top dress. The control treatments had lower nitrate values with sole sorghum giving lower values compared to the other controls. This implies that intercropping plays a role in addition of nitrates to the soil during the growing period of the current crop and this is in agreement with the findings of Jan *et al.* (2007) and Kamkar *et al.* (2014).

Intercropped sorghum with soybean left to maturity showed high ($P \leq 0.001$) soil NO_3-N concentrations in all the treatments in both years. There was no significant difference between incorporated and mulched soybean residue at 40 kg N ha^{-1} in comparison to exsitu soybean residue at 80 kg N ha^{-1} in year 2012. Sorghum intercropped with soybean left to maturity at 40 kg N ha^{-1} resulted in higher ($P \leq 0.001$) soil NO_3-N concentration than the other management options at same N fertilizer levels. The results further indicate that sole sorghum as well as soybean residue removal from the fields has negative implications on soil fertility improvement and management as shown by the levels of soil NO_3-N recorded.



(a) Year 2012



(b) Year 2013

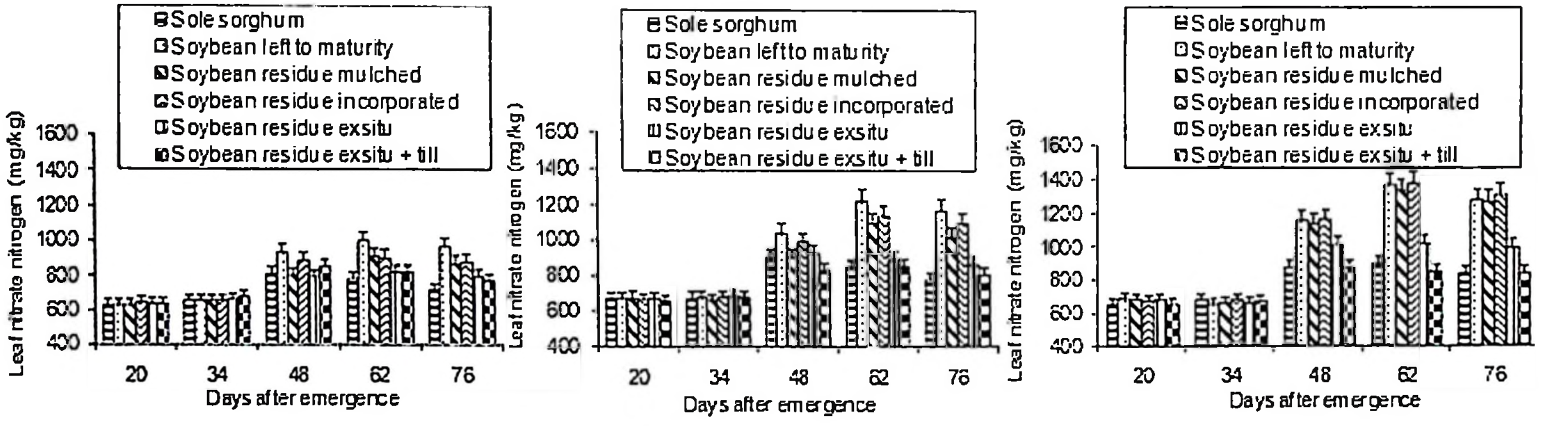
Figure4.4 Soil NO_3^--N concentrations in response to nitrogen fertilizer rates and soybean residue management options in the years 2012 and 2013

The lower soil NO_3-N concentrations recorded in the year 2013 compared to the year 2012 gives a reflection of soil NO_3-N dynamics and the influence of climatic conditions as reported by Phiri *et al.* (2014).

It is worth noting that in the year 2012, soil NO_3-N concentration above 29 mg kg^{-1}, had no significant differences irrespective of N fertilizer rates in respect to insitu soybean residue management options (soybean residues mulched, left to maturity and incorporated). At 80 kg N ha^{-1} there was more less a plateau as soil NO_3-N concentration approached 33 mg kg^{-1} in reference to insitu soybean residue management options. The findings indicate that soil NO_3-N concentration at 29 mg kg^{-1} meets the crop demand for soil N during the cropping season and nutrient concentrations above 33 mg kg^{-1} may result to leaching of the nitrates. The findings of this study agree with report by Blackmer *et al.* (2013) who reported that 31 mg kg^{-1} was probably the optimum soil NO_3-N concentration that meets the crop N demand during the growing season and that concentrations above this optimum level do not translate to yield increase but implies N over application. In the year 2013, rainfall amounts and distribution had an influence on observed soil NO_3-N concentrations and this is in agreement with report by Xue *et al.* (2013) who pointed out the influence of environmental factors on NO_3-N.

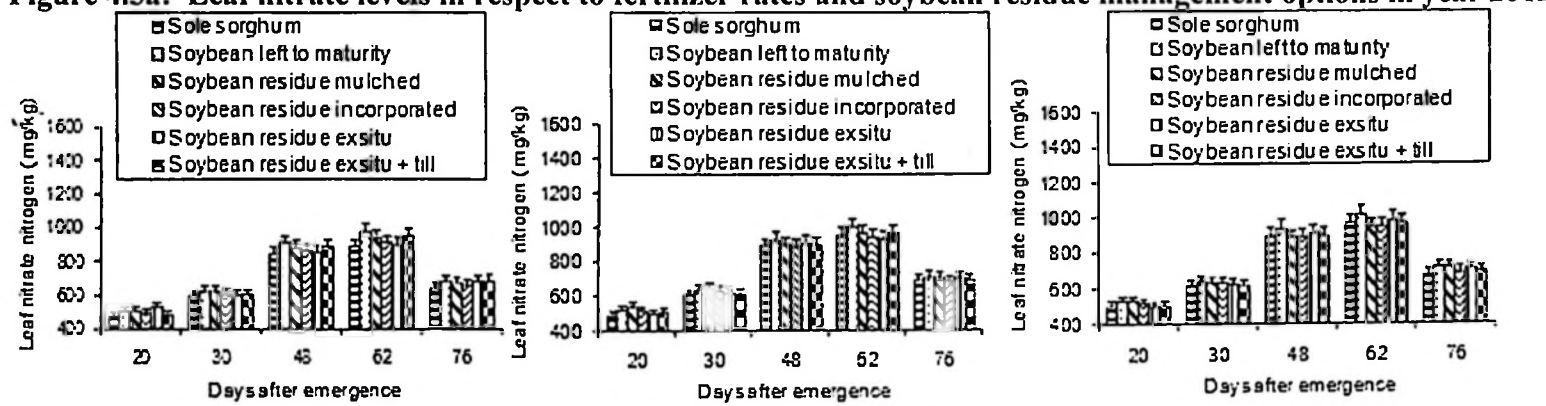
4.3.2 Effects of days after emergence, nitrogen fertilizer rates and soybean residue management options on leaf NO_3-N concentrations

Variations of leaf NO_3-N concentrations in response to days after emergence, nitrogen rates and soybean residue management options is given in Figure 4.5.



(a) 0 kg N ha^{-1} (b) 40 kg N ha^{-1} (c) 80 kg N ha^{-1}

Figure 4.5a: Leaf nitrate levels in respect to fertilizer rates and soybean residue management options in year 2012



(a) 0 kg N ha^{-1} (b) 40 kg N ha^{-1} (c) 80 kg N ha^{-1}

Figure 4.5b: Leaf nitrate levels in respect to fertilizer rates and soybean residue management options in year 2013

The findings depict lower leaf NO_3-N concentrations at the early stage of development and this is attributed to underdeveloped plant rooting system. The leaf nitrate values increased with progressive sampling periods with a decrease noted as the crop leaf senesced. The increase in concentration was presumed to be as a result of fertilizer application as well as supply from soybean residues. The findings agree with report by Arif *et al.* (2011) that was of the opinion that legumes have a potential to transfer N to cereal crop during the growing season and probably result to increased fixing ability of the soybean as suggested by Ning *et al.* (2012).

Other researchers (Kihara *et al.*, 2011; Rachid, 2011; Jan *et al.*, 2011) pointed out the significance of return of crop residues to the field after harvest to take advantage of the total N through nutrient recycling which can be up to 30 kg N ha^{-1}. The authors further found out that litter fall that occur from planting to physiological maturity of the soybean legume constituted a fixed N of 8.2 to 11.8 kg N ha^{-1}. In addition, Kamkar *et al.* (2014) reported on the contribution of nitrogen fixing legumes to soil N improvement.

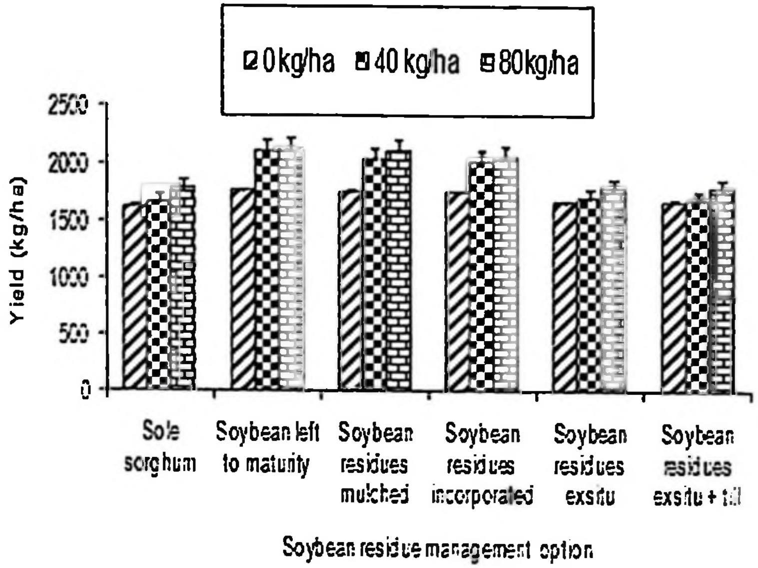
Variation of leaf NO_3-N concentrations in the year 2012 and 2013 is evident indicating the difference in supply of soil N via inorganic fertilizers and that derived from soybean residues with respect to rainfall amounts and distribution (Figure 4.1) in the years of study. Lower leaf NO_3-N concentrations (highest: approximately 1000 mg/kg) in the year, 2013 were attributed to more precipitation in comparison to the year, 2012 where the highest leaf NO_3-N concentration was approximately 1200 mg/kg. The rainfall is presumed to have probably washed away soil N supplied via mineral fertilizer and soybean residues was presumed to have decomposed slowly to supply the plant required N. The findings are in agreement with Forrestal *et al.* (2012) who showed that rainfall has a negative influence on soil N through leaching.

The decrease in NO_3-N concentrations as the crop senesced is in agreement with report by other workers (Ye *et al.*, 2008; Matusso *et al.*, 2014) who reported a decrease in NO_3-N under intercropping at harvest. The results further indicated variation of nitrate levels in the years of study with the year 2012 showing higher NO_3-N concentrations in comparison to the year 2013 suggesting the possible effects of precipitation amounts and distribution on leaf uptake.

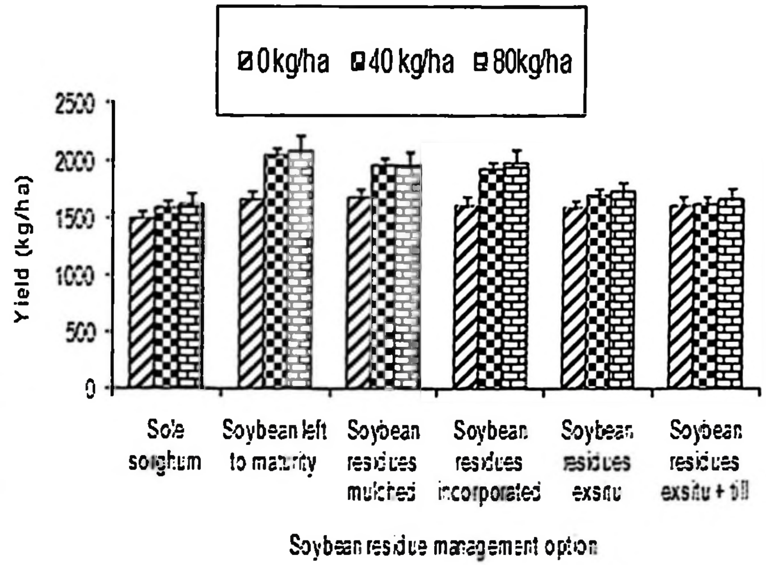
4.3.3 Yield response of sorghum to nitrogen fertilizer rates and soybean residue management options

Sorghum yield data in response to soybean residue management and N fertilizer rates are given in Figure 4.6. The control and treatments where soybean residues were removed gave lower yields than where residues were retained and with no significant differences with rate of nitrogen fertilizer applied.

In both years plots with soybean residues left to maturity, mulched or incorporated had significantly ($P < 0.01$) higher yields compared to control and experimental plots with sole sorghum and those whose residues were removed off field. The results are in agreement with report of other researchers (Rachid, 2011; Jan *et al.*, 2011; Lithuorgidis *et al.*, 2011) who reported increase in yield under intercropping.



(a) Year 2012



(b) Year 2013

Figure 4.6: Sorghum yields (kg ha^{-1}) in response to soybean residue management options and nitrogen fertilizer rates in year 2012 and 2013.

The results on yield shows no significant difference between nitrogen fertilizers applied at 40 kg N ha^{-1} and 80 kg N ha^{-1} irrespective of soybean left to maturity, legume residues mulched or incorporated in both years of study. The yields in the year 2013 however, were lower compared to year 2012. The results, thus, point out that in terms of food security and soil fertility improvement intercropping of sorghum + soybean left to maturity in combination with application of nitrogen fertilizer at 40 kg N ha^{-1} application could be the probable option for adoption by the smallholder farmers in Busia County.

It is worth noting, however, that though N fertilizer application at 40 kg N ha^{-1} with soybean left to maturity has the potential to supply the plant required NO_3-N, the N supply through this management option does not translate to optimum sorghum yield (3 000 – 4 000 kg ha^{-1}) nor the potential research yield of 4 000 – 6 000 kg ha^{-1} in Western Kenya as established according to Jaetzold *et al.* (2007) and KARI (2006) respectively. There is speculation, therefore, that other nutrients inter-related to nitrogen could be deficient. Researchers (Fazil *et al.*, 2008; Jamal *et al.*, 2010) indicated that there is a strong relationship between sulphur and nitrogen nutrition. The researchers pointed out that both nutrients are inter-related and play significant role in protein synthesis and that lack of sulphur limits the efficiency of added N, implying that S addition might be necessary to achieve optimum efficiency of N supply in the study sites.

4.4 CONCLUSIONS

The following conclusions were derived from the results of the study:

- Soil NO_3-N is dynamic and is influenced by soil particle distribution, soil depth, precipitation amounts and distribution, and it varies during crop growth and development.
- Application of nitrogen fertilizer in combination with soybean residue management have synergistic effects in increasing soil NO_3-N and yield while removal of residues off the field dispossess the soil of the nutrient.
- Intercropped sorghum with soybean left to maturity indicated high NO_3-N concentrations in all the treatments in both years. In addition, sorghum intercropped with soybean left to maturity with nitrogen fertilizer applied at 40 kg N ha^{-1} reflected higher soil NO_3-N concentration in comparison to the other management options.
- Leaf NO_3-N is influenced by rainfall amounts and distribution and fertilizer supply via mineral fertilizer should be synchronized with crop demand during growing season to reduce leaching of soil N.
- In terms of food security and soil fertility improvement, intercropping of sorghum + soybean left to maturity in combination with application of nitrogen fertilizer at 40 kg N ha^{-1} application could be the probable option for adoption by the smallholder farmers in Busia County.

4.5 RECOMMENDATIONS

The conclusions given leads to the following recommendations:

- Nitrogen fertilizer application at 40 kg N ha^{-1} with soybean left to maturity under sorghum-soybean intercropping is recommended as an optimum rate and legume residue management option to improve soil NO_3-N among small scale households with stretched socio-economic ability in Busia County.
- A shorter assessment interval of NO_3-N during the growing season of crops is recommended as a further research refinement to establish NO_3-N concentration that translates to expected yields.
- Further research on sulphur in relation to nitrogen be carried out to provide a balanced fertilizer recommendation for optimum sorghum yields in Busia County.

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CHAPTER FIVE

5.0 INFLUENCE OF SOYBEAN RESIDUE MANAGEMENT ON NITRATE NITROGEN ACCUMULATION AND SUBSEQUENT SORGHUM YIELD IN *KANHAPLIC HAPLUSTULTS* OF WESTERN KENYA

ABSTRACT

Crop residues are overlooked when making fertilizer recommendations, yet have potential to contribute to soil nitrogen in addition to mineral fertilizer use. A study was carried out in western Kenya to establish the contribution of soybean residues under varied management options and nitrogen fertilizer rates on nitrogen supply to the subsequent sorghum crop and their influence on sorghum yield. Six soybean residue management options were evaluated; sole sorghum, sorghum + soybean left to maturity, sorghum + soybean mulched, sorghum + soybean incorporated, sorghum + soybean exsitu and sorghum + soybean exsitu and plot tilled. Three levels of nitrogen (0 kg N ha^{-1}, 40 kg N ha^{-1}, and 80 kg N ha^{-1}) as urea were applied as top-dress and treatments arranged in randomized complete block design. Soybean left to maturity at 40 kg N ha^{-1} indicated significant ($P < 0.001$) increase (56%) in soil NO_3-N. Removal of soybean residues resulted in significantly ($P < 0.001$) lower soil NO_3-N increase while control treatment and sole sorghum indicated the lowest soil NO_3-N accumulation irrespective of nitrogen fertilizer rates. Soybean left to maturity indicated significant ($P < 0.001$) increase (43%) in leaf NO_3-N accumulation at 40 kg N ha^{-1} while treatments with soybean residues mulched showed 39% increase and those with residues incorporated, 25% increase. Soybean

residues *ex-situ* and *ex-situ* and till indicated a decrease (- 6% and -7%) in leaf NO_3-N accumulation, respectively. Sole sorghum had a uniform NO_3-N increase of 4% irrespective of nitrogen fertilizer rates. It was observed that *insitu* soybean residues and nitrogen fertilizer application had no significant (P <0.05) influence on sorghum yield. It is concluded, however, that, soil and leaf NO_3-N accumulation by soybean residues in addition to nitrogen fertilizer does not translate to optimum nor potential research sorghum yields. Thus, there is need to carry out research on sulphur and nitrogen interaction to establish their interactive effects on sorghum yields.

Key words: Soybean residue management options, nitrogen fertilizer rates, nitrate accumulation and build up, subsequent sorghum yields.

5.1 INTRODUCTION

Soil organic nitrogen is transformed into mineral nitrogen through mineralization which is the most important process of soil nitrogen cycling (Lui *et al.*, 2007). Nitrogen is an essential element required for successful plant growth (Brady and Weil, 2008). Inorganic nitrogen compounds exist as ammonium, nitrite and nitrate (Brady and Weil, 2008) and of the three, nitrate is the principal N source for plant growth irrespective of inorganic or organic N source (Nasholm *et al.*, 2009). In addition to mineral fertilizer which is the prime source of N for crops (Robertson and Vitousek, 2009), legumes contribute appreciable amounts of N through symbiotic nitrogen fixation (Ning *et al.*, 2012). Dahmardeh *et al.* (2010) are of the opinion that cereal-legume intercropping increases the amount of nitrogen, phosphorus and potassium contents compared to monocropping. According to Parr *et al.* (2011), legume species and several cultivars have potential to adequately contribute N for corn growth. For example, hairy vetch (*Vicia villosa*), and crimson clover (*Trifolium incarnatum*,) were found to contribute 204 kg ha^{-1} and 163 kg ha^{-1} respectively (Brown, 2013). Other researchers (Kihara *et al.*, 2011) showed that soybean litter fall over the growing period of the crop contributed 8.2 to 11.8 kg N ha^{-1} from N fixation while residues returned to the field after harvest had total N content of up to 30 kg N ha^{-1}.

Crop residues have been reported to play a significant role in terms of soil fertility improvement (Wilhelm *et al.*, 2007) and have direct roles on nutrient cycling and crop yields (Blanco-Canqui and Lal, 2009a). Leguminous residues undergoing decomposition have potential to supply adequate plant available nitrogen to the subsequent crop depending on management and soil conditions (Cook, *et al.*, 2010; Thorup-Kristensen, *et al.*, 2010). In addition, Ambrosano *et al.* (2009; 2011) are of the opinion that legume residue decomposition provides long-term supply of N for subsequent crop. The findings reported by van Donk *et al.* (2012) indicated that removal of crop residues negatively impacted on soil nitrate nitrogen (NO_3-N) while residue covered soil showed accumulation of NO_3-N. Other studies (Ambrosano *et al.*, 2013) showed that incorporation of legume residues from velvet bean and sunhemp led to accumulation of N in the soil, high absorption by corn and ultimate increase in corn yields.

According to Liu *et al.* (2010), 55% of overall nitrogen applied in agricultural systems can be recovered; out of this percentage, 35% is in harvested products and 20% is in crop residues. However, crop residues are under-estimated in nutrient recycling and often overlooked when making fertilizer recommendations. Further to this, Zhao *et al.* (2014) reported that legumes have potential to contribute to build up of soil NO_3–N to meet and/or exceed the plant nitrogen requirement during the cropping season and consequently increase yields. Thorburn *et al.* (2011) was of the opinion that crop residues' contribution to soil nitrogen need to be considered in nitrogen fertilizer management and factored in to reduce mineral fertilizer rates. In the light of the findings and opinions of these researchers, this study sought to establish the potential of integrated soybean residue management options and nitrogen fertilizer rates on nitrogen supply to the subsequent sorghum crop and their influence on grain yield in *Kanhaplic Haplustults* of Western Kenya.

5.2 MATERIALS AND METHODS

5.2.1 Study Area

The experiment was carried out in Busia County, Emalomba area (N $00^0$25′28.8″ E $034^0$15′ 51.9″), Agro-ecological zone: LM 1 (Sombroek *et al.*, 1982). The site elevation is 1 222 m above sea level. Table 5.1 presents the mean monthly rainfall and temperature of the experimental site over a two year period (2012 – 2013). The average annual precipitation of the study area ranges between 1 718 – 1 784 mm while the mean maximum temperatures ranged between 26.3^{0}C and 31.3^{0}C in comparison to mean monthly minimum temperature that vary from 12.0^{0}C to 15.5^{0}C.

Table 5.1: Rainfall amounts and maximum and minimum temperatures for the years 2012 and 2013

Month	Rainfall		Max. Temp		Min. Temp	
	2012	2013	2012	2013	2012	2013
Jan	7.2	47.1	30.1	28.6	12	13.9
Feb	12.1	40.7	31.3	29.9	13.8	14.1
Mar	54.2	248.0	31.0	29.6	14.3	15.1
Apr	206.6	209.0	27.2	27.1	15.5	15.4
May	261.2	172.9	26.5	27.4	14.9	14.5
June	146.0	77.2	26.5	26.8	14.5	14.5
July	105.3	24.3	25.9	26.9	14.1	13.6
Aug	79.8	190.5	26.3	26.5	13.9	13.9
Sept	197.4	268.0	26.9	27.2	13.9	14.0
Oct	332.6	196.7	27.4	27.4	14.8	14.7
Nov	166.1	174.6	27.2	27.2	14.6	14.9
Dec	215.8	68.6	27.2	27.5	14.4	14.5

Source: Kenya Meteorological Station, 2014)

The experimental site experiences bimodal rainfall with the long rains beginning in March and the short rains in August/September. The soil is classified as *Kanhaplic Haplustults* in USDA Soil Taxonomy (SSS, 2006) correlating with *Haplic Cutanic Acrisols* in WRB (IUSS Working Group WRB, 2007).

5.2.2 Field Experimentation

The experimental site was prepared preceding the onset of long rains in March, 2012 and 2013. In the year 2013, a study was carried out in the previous experimental plots with respective treatments to establish the contribution of soybean residues under varied management options and nitrogen fertilizer rates on nitrogen supply to the subsequent sorghum crop and on yield. Additionally, in same year, 2013, new experimental site with similar experimental treatments as the previous experimentation in the year 2012 were prepared alongside that of the year, 2012. This was done to allow a comparison on effects of soybean residue management options and N fertilizer rates on NO_3-N accumulation and build up both in the soil and sorghum leaves in the year 2012 and that of year 2013. Each experimental plot measured 3.0 m x 4.5 m with inter-plot distance of 0.5 m and 2 m between blocks. An outer allowance path of 2 m around the experimental plots was considered. Sorghum variety; KARI Mtama II, recommended to the climatic conditions of the experimental site, was sown at the spacing of 75 cm inter-rows and 15 cm between plants. Soybean variety SB 19 inoculated with Biofix ® inoculants was planted in between the sorghum rows at a spacing of 10 cm. Six treatment options were considered;

(i) sole sorghum,

(ii) sorghum + soybean left to maturity,

(iii) sorghum + soybean residue mulched,

(iv) sorghum + soybean residue incorporated,

(v) sorghum + soybean ex-situ and

(vi) sorghum + soybean ex-situ and plot tilled.

Triple super phosphate ($Ca(H_2PO_4)_2.H_2O$) was applied uniformly to all the treatments during planting by broadcasting and mixing with soil at rate of 20 kg P ha^{-1}. Three levels of nitrogen (0 kg N ha^{-1} = N_0, 40 kg N ha^{-1} = N_{40}, and 80 kg N ha^{-1} = N_{80}) as urea ($CO(NH_2)_2$ was applied 42 days after emergence to sorghum plants as a top dress. The treatments were arranged in a randomized complete block design with three replications. Soybean residue management options as described in the treatments were carried out before pod formation by soybeans.

5.2.3 Determination of on-site soil and leaf nitrate nitrogen

Supply of mineralized N was investigated over a sequence of dates as recommended by McSwiney *et al.* (2010) using extractable inorganic soil- and leaf- nitrate-nitrogen and quantified by direct measurement in the field (Hartz *et al.*, 2000; Westervert *et al.*, 2005). Three soil samples from every plot were collected by augering at 0 - 15cm, 15 -30 cm and 30 - 45 cm and each time putting in sealed plastic bags, respectively. The respective samples were then mixed thoroughly to obtain a representative sample for determination of soil NO_3^--N concentrations. The composite soil samples in sealed plastic bags were placed in cooler box to protect them from heat. Soil solution of each composite was extracted by mixing soil with water at the ratio of 1:5 (10 g of soil + 50 ml of water) and 10 ml of calcium chloride was added. The sample was thoroughly shaken for 2 minutes until all the soil clumps had thoroughly dispersed. The sample was left to sit until a clear zone of solution formed at the top of the tube. The ISE meter was calibrated with two standard solutions for NO_3-N which was included in the kit. Using a dropper, 2 - 3 drops of the clear solution was put on the meter sensor. Once the meter reading stabilized (after 30 - 40 seconds) the value for NO_3-N concentration was recorded. Determination of soil NO_3-N concentrations was performed in duplicate for each treatment and the average recorded.

Leaf nitrate nitrogen was determined by selecting randomly, appropriate sizes from recently matured leaves of the sorghum plant on a fort-night interval. From each experimental plot, three sorghum leaf blades were selected, placed in sealed plastic bags and put in cooler boxes until leaf samples from all experimental plots had been collected. At the end of the sample collection, the leaves were rinsed with distilled water and blot-dried with a paper towel. Direct sunlight/high temperatures were avoided during meter reading. With a sharp knife and on a cutting board, leaf blades were chopped and put in a plastic bag. The samples were then punched using a hand hammer to extract the juice. The corner of the bag bottom was cut to puncture the plastic bag then squeezed to collect the juice. The juice was then dropped to the nitrate meter sensor (about 0.3 ml) to cover the sensor. The measurement values were then read off and recorded once the meter reading stabilized. Leaf NO_3-N concentrations were determined in duplicate for each treatment and the average recorded. Concentrations of NO_3-N in the soil and leaf was evaluated over time during the growing period from 20 days after emergence at an interval of 2 weeks up to physiological maturity of sorghum plants to monitor the trends of both soil and leaf nitrate nitrogen. Prior to harvest, an area of 2 x 2 m was demarcated for measurement of crop yields.

5.2.4 Statistical data analysis

Data on concentrations of NO_3-N in the soil and leaf as well as sorghum yields were subjected to analysis of variance using GenStat software version 13.2. To test the differences between different soybean residue management options and N fertilizer rates, the means were analyzed using Tukey's Test at 95 per cent of significance level ($P < 0.05$). Pearson Correlation Coefficient (r) was used to show correlation between leaf nitrates and period of sampling during growing period of sorghum.

5.3 RESULTS AND DISCUSSION

5.3.1 Accumulation of Soil NO_3-N as Influenced by Soybean Residue Management Options and N Fertilizer Rates in Year 2012 and 2013

Accumulation of soil NO_3-N with respect to soil depth (0 – 15 cm) as influenced by soybean residue management options and nitrogen fertilizer rates is presented in Table 5.2. A comparison of soil NO_3-N accumulation with respect to years of study showed significant ($P < 0.001$) difference between treatments. A significant ($P < 0.001$) difference was noted in treatments with soybean left to maturity at fertilizer application rates of 0 kg N ha^{-1}, 40 kg N ha^{-1} and 80 kg N ha^{-1} that indicated 28%, 56% and 38% soil NO_3-N, respectively, in the year 2013 as compared to 2012.

Table 5.2: Accumulation and build up of soil NO_3-N as influenced by soybean residue management options and N fertilizer rates

Soybean residue management option	Year 2012 Fertilizer rate (kg N Ha^{-1})			Year 2013 Fertilizer rate (kg N Ha^{-1})		
	0	40	80	0	40	80
Sole sorghum	25.08	26.28	27.08	28.23	29.75	30.70
Soybean left to maturity	28.01	30.64	32.15	34.88	41.08	39.18
Soybean residues mulched	28.08	29.73	31.94	31.14	38.10	40.79
Soybean residues incorporated	27.04	29.45	31.78	32.37	37.68	38.27
Soybean residues ex-situ	26.04	27.64	29.61	28.36	34.41	34.68
Soybean residues ex-situ + till	26.28	26.45	27.27	28.23	32.49	34.55
P value	0.001			0.001		
$LSD_{(0.05)}$	0.18			0.67		

At 40 kg N ha^{-1}, treatments with soybean residues mulched or incorporated indicated an increase in soil NO_3-N but were not significantly different and the concentration levels were lower than that of soybean residues left to maturity.

In the year 2013, fertilizer N at 40 kg N ha^{-1} with soybean left to maturity and soybean residues mulched at 80 kg N ha^{-1} had significant difference ($P < 0.001$).

However, nitrogen fertilizer application at 80 kg N ha^{-1} indicated significant (P <0.001) difference in soil NO_3-N accumulation between the treatments with soybean left to maturity, soybean residues mulched or incorporated. The findings indicate the role soybean litter and residue incorporation play in nutrient cycling and in particular NO_3-N accumulation for use by the subsequent crop.

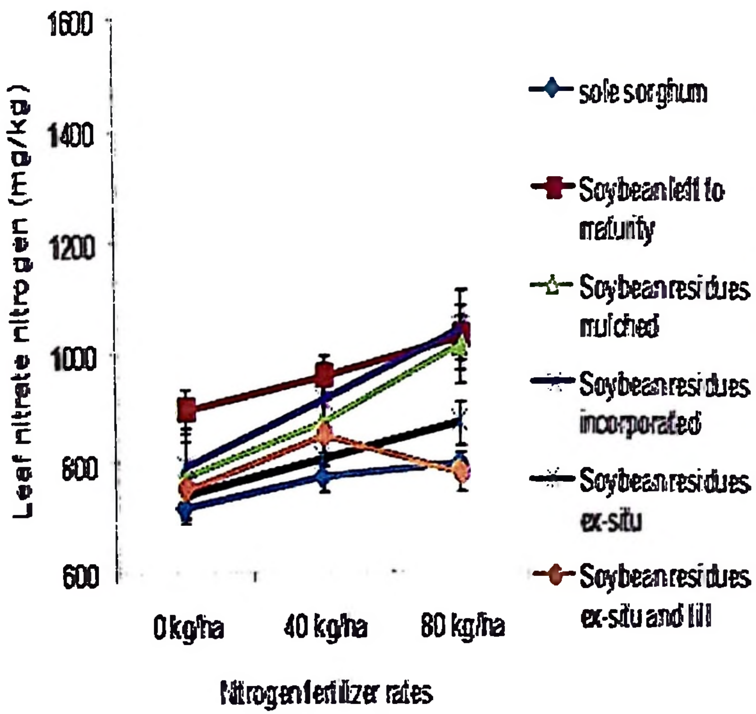
The study findings are supported by Kihara *et al.* (2011) who demonstrated the contribution of soybean litter to soil N build up. The findings are further in agreement with the findings of Usman *et al.* (2013) who reported an increase in NO_3-N with residues incorporated and N application at 40 kg ha^{-1}. The results also agree with Ambrosano *et al.* (2013) who showed that crop residues contribute to NO_3-N accumulation and soil N improvement.

In comparison with *in-situ* soybean residue management, the experiments with soybean residues removed showed significantly (P < 0.001) lower soil NO_3-N accumulation. in response to nitrogen fertilizer application. The control experiment with sole sorghum indicated still lower soil NO_3-N accumulation. The findings are in agreement with those pointed out by van Donk *et al.* (2012) and Dahmardeh *et al.* (2010) indicating negative implications of residue removal on soil N improvement and signifying that intercropping cereals and legumes improves soil fertility.

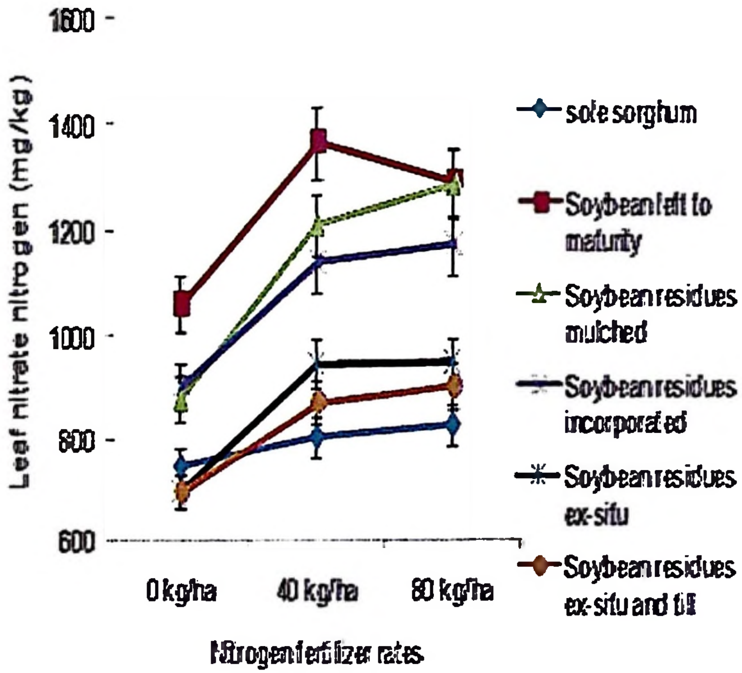
5.3.2 Accumulation of Leaf NO_3-N as Influenced by Soybean Residue Management Options and N Fertilizer Rates during the Year 2012 and 2013

Leaf NO_3-N accumulation evaluated followed similar patterns of increase with increase in nitrogen fertilizer application in the year 2012 (Figure 5.1a). In the year 2013 (Figure 5.1b), there were significant ($P < 0.001$) differences in NO_3-N accumulation with soybean left to maturity, indicating 43% increase from the previous NO_3-N concentrations when N was supplied at 40 kg ha^{-1}. Treatments with soybean residues mulched resulted in 39% increase while those with residues incorporated had 25% increase in NO_3-N accumulation at 40 kg ha^{-1}. Treatments with soybean residues removed, removed and tilled and sole sorghum recorded increase of 17%, 2% and 4%, respectively.

The control treatments (0 kg N ha⁻1) with soybean left to maturity showed 18% increase in leaf NO_3-N accumulation in comparison with that of the previous year while soybean residues mulched and incorporated each indicated an increase of 13%. In contrast, the control treatments with soybean residues ex-situ and ex-situ and till indicated a negative influence of residue removal on NO_3-N accumulation (- 6% and -7%, respectively). Percentage change in leaf NO_3-N concentration in sole sorghum in the year 2013 in comparison with the observed levels in the year 2012 indicated a uniform increase of 4% irrespective of nitrogen fertilizer rates.



(a) Year 2012



(b) Year 2013

Figure 5.1: Comparison of leaf NO_3-N accumulation in the year 2012 and 2013

The results on leaf NO_3-N accumulation with respect to some soybean residues management options (soybean left to maturity, mulched or incorporated) are in agreement with report by Dechorgnat *et al.* (2011) who pointed out that mineralization of soil organic matter always provides a surplus of nitrate to the plant. Other findings (Rahman *et al.*, 2014) also showed an increase in plant N when rice was grown in rotation with winged bean, attributing the increase to addition of above ground plant parts and below ground plant residues of legumes.

Dahmardeh *et al.* (2010) were of the opinion that cereal-legume intercropping increases the amount of nitrogen, phosphorus and potassium contents compared with monocropping and this has been demonstrated by the findings of this study in relation to nitrogen. Removal of soybean residues indicated a negative effect on leaf NO_3-N accumulation and these findings are in agreement with Donk *et al.* (2012) who observed that crop residue removal negatively impacted on soil NO_3-N, which has direct relation with leaf NO_3-N as shown in Figure 5.2.

5.3.3 Accumulation of Soil- and Leaf - NO_3-N with Respect to Days after Emergence in the Year 2012 and 2013

The relationship between soil and leaf NO_3-N accumulation during the sorghum growing season indicates a similar pattern of increase in both years as shown in Figure 5.2. In the year 2013, there was a significant ($P < 0.001$) increase in NO_3-N accumulation than in the year 2012. This was attributed to soybean residue mineralization and subsequent plant absorption resulting in NO_3-N accumulation in the sorghum leaves (Dechorgnat *et al.*, 2011; Rahman *et al.*, 2014). The results are supported by Ambrosano *et al.* (2011; 2013) and Parr *et al.* (2011) who showed that legume species have potential to adequately contribute N for corn growth.

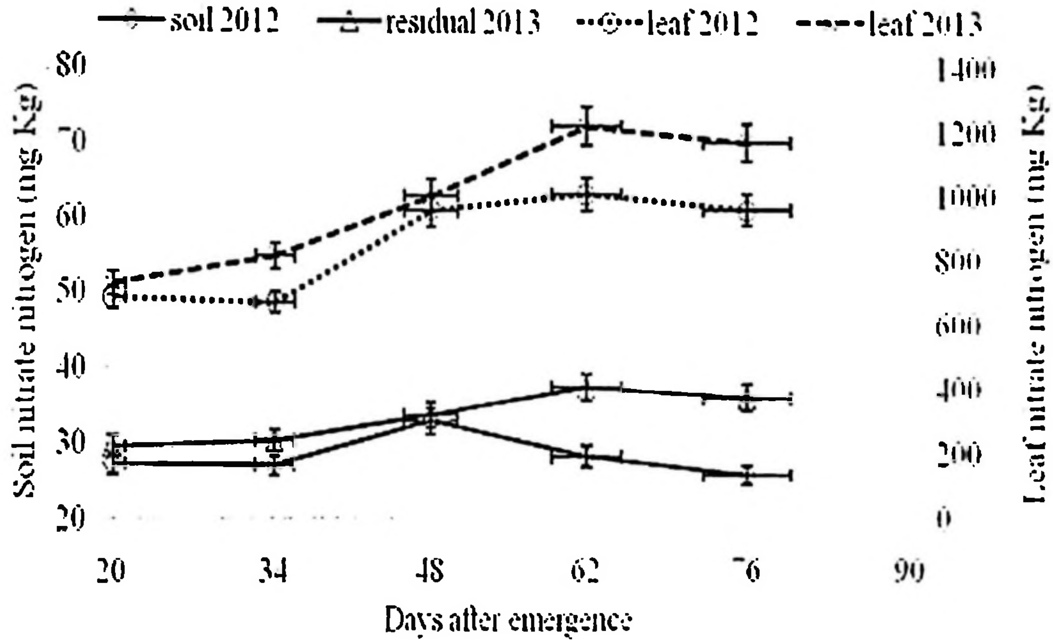


Figure 5.2: Relationship between soil and leaf NO_3-N accumulation during sorghum growing season

5.3.4 Relationship between Days after Emergence and Leaf NO_3-N Accumulation in the Year 2012 and 2013

When leaf NO_3-N accumulation is plotted versus the data sampling period in the year 2012 and 2013 (Figure 5.3) a polynomial increase was noted, with the previous year indicating lower increase. The regression equation further indicated that the highest leaf NO_3-N accumulation occurred between 60 - 70 days. The results suggest the need to apply mineral fertilizer much earlier (approximately 30 - 35 days) after emergence to meet N demand during vegetative stage and not late in the season.

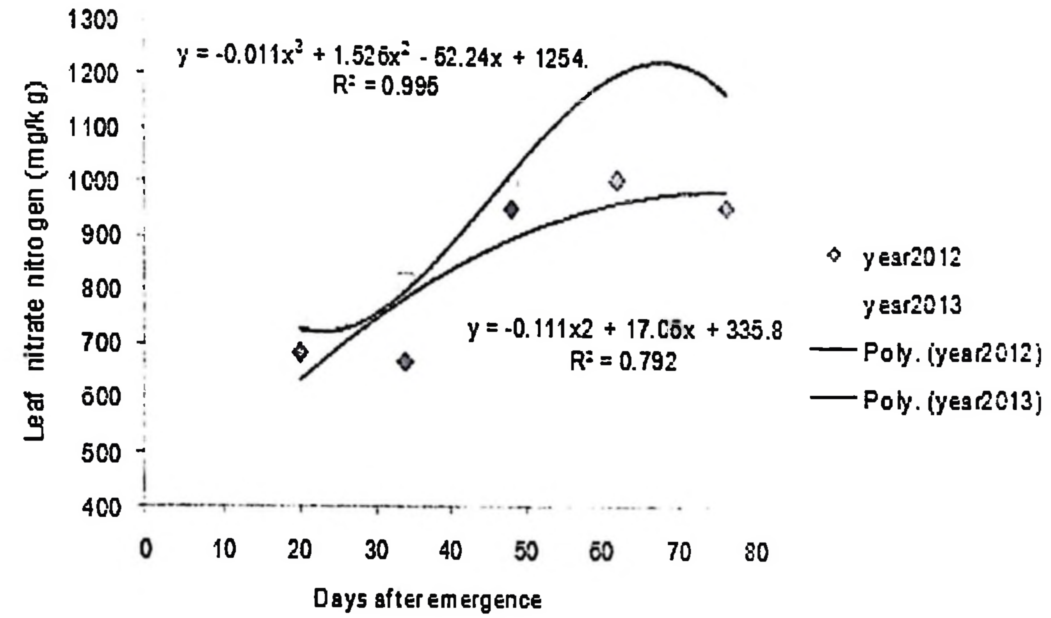
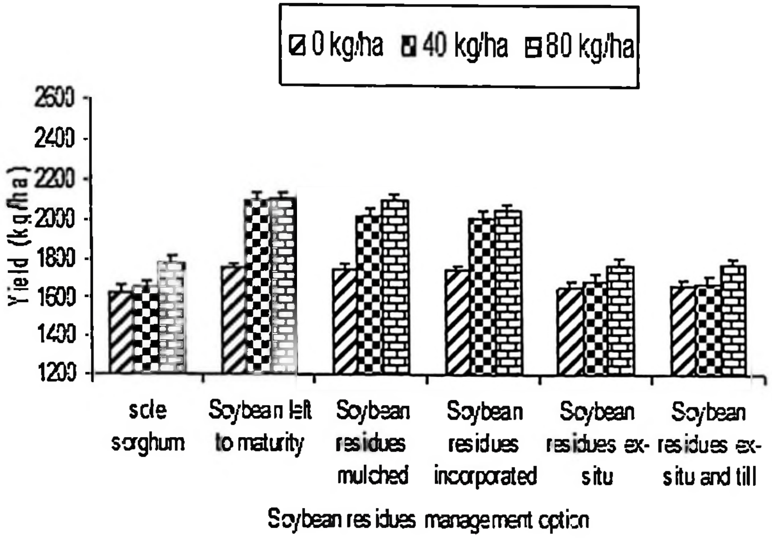


Figure 5.3: Regression equation of the relationship between sampling times over the growing seasons (2012 and 2013) and leaf NO_3-N accumulation.

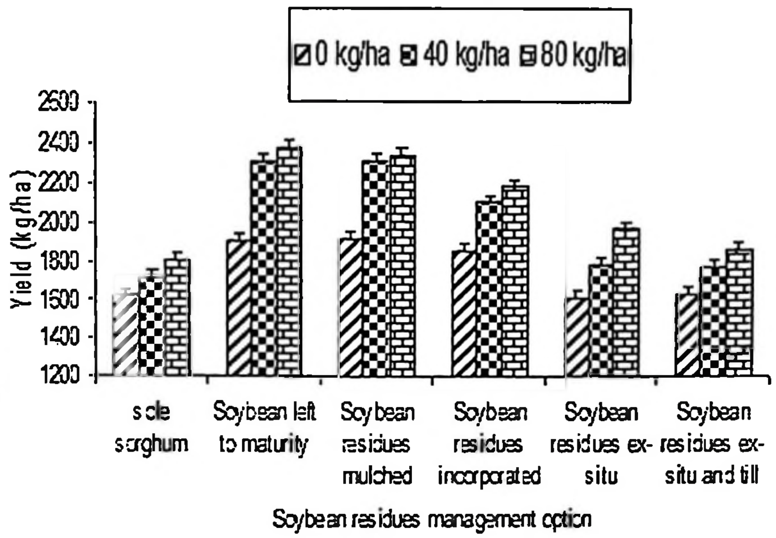
The findings of the study agree with Robertson and Vitousek (2009) who indicated that mineral fertilizer is prime in N supply and report by Parr *et al.* (2011) and Rahman *et al.* (2014) on the important role legume residues play in soil N contribution. Cicek *et al.* (2014) also pointed out positive contribution of legumes on wheat N uptake, maturity and yield.

5.3.5 Sorghum Yield Response to NO_3-N Accumulation as Influenced by Soybean Residue Management Options and N Fertilizer Rates

The response of sorghum yields with respect to NO_3-N accumulation as influenced by soybean residue management options and N fertilizer rates are presented in Figure 5.4.



(a) Year 2012



(b) Year 2013

Figure 5.4: **Effects of soybean residue management options and nitrogen fertilizer rates on sorghum yields in the year 2012 and 2013.**

From the data values, percentage increase of sorghum yields in the year 2013 up from the yields of the year 2012 in reference to soybean management options and nitrogen fertilizer rates is presented in Table 5.3.

Table 5.3: Percentage change in sorghum yield between 2012 and 2013 growing seasons

Soybean residues management option	Nitrogen fertilizer rates		
	0 kg/ha	40 kg/ha	80 kg/ha
Sole sorghum	-0.3	4	2
Soybean residues left to maturity	9	10	13
Soybean residues mulched	10	14	12
Soybean residues incorporated	7	5	7
Soybean residues ex-situ	-2	6	11
Soybean residues ex-situ + till	-2	6	5

The data derived indicated that the preceding soybean residues and nitrogen fertilizer application had significant ($P < 0.05$) influence on yield increase of sorghum in the year 2013 in comparison to year 2012. The increase in yield in the year 2013 suggests carry over soil NO_3-N from decomposing soybean residues and probably below ground biomass in the case of treatments with residues removed. The results on yield are in agreement with report by Rahman *et al.* (2014) who observed an increase in rice grain yield due to influence of legume residues and N fertilizer application.

The results further indicate that in the year 2012, there was no significant difference in sorghum yields between soybean left to maturity, soybean residues mulched and soybean residues incorporated at 40 and 80 kg N ha^{-1}. However, in the year 2013, soybean left to maturity and soybean residues mulched had no significant difference in sorghum yield at 40 kg N ha^{-1} or 80 kg N ha^{-1} but indicated significantly higher yield than when soybean residues were incorporated. The results are supported by Kihara *et al.* (2011); Ambrosano *et al.* (2013) and Usman *et al.* (2013) who emphasized the potential contribution of soybean litter, mulch or incorporation of residues to soil N build up.

From the results obtained, the need for N fertilizer application cannot be over emphasized. The removal of residues from the field and sole sorghum cropping with no nitrogen fertilizer application showed a significant ($P < 0.001$) decrease in sorghum grain yield (lower than the previous yields). The results point out the need to supply inorganic nitrogen during the cropping season to meet the nutrient crop demand in the *Kanhaplic Haplustults* of Western Kenya.

Though there is appreciable accumulation of soil and leaf NO_3-N with respect to soybean residue management and nitrogen fertilizer rates to meet the crop N demand as reported by Zhao *et al.* (2014), it does not translate to research potential sorghum yields of 4 000 – 5 000 kg ha^{-1}(KARI, 2006). It is, thus, speculated that other plant essential nutrients inter-related with nitrogen could have influenced the obtained sorghum grain yield. For example, Fazil *et al.* (2008); Jamal *et al.* (2010) and De Bona and Monteiro (2010) indicated that there is a strong relationship between sulphur (S) and nitrogen (N) nutrition. The authors reported that the assimilatory pathways of S and N are functionally convergent i.e. sulphur is an essential component of enzymes involved in the metabolism of nitrogen (nitrate and nitrite reductase) and that the availability of one of the elements regulates the other.

5.4 CONCLUSIONS

From the results of the study, it can be concluded that:

- Fertilizer N application at 40 kg N ha^{-1} with soybean residues left to maturity has the potential to accumulate soil and leaf NO_3-N accumulation for use during the growing season of grain sorghum.
- N fertilizer application at 40 kg N ha^{-1} with sorghum soybean left to maturity increases soil N by 56% but does not lead to optimal sorghum yields in the *Kanhaplic Haplustults* of Western Kenya, Busia County.
- Previous soybean residue removal and sole cropping in the year 2012 had negative influence on soil and leaf NO_3-N accumulation in the year 2013.

5.6 RECOMMENDATIONS

In the perspective of the above conclusions, the following recommendations are made:

- Growing of grain sorghum intercropped with soybean left to maturity in combination with nitrogen fertilizer application at 40 kg ha^{-1} improves soil NO_3-N and is recommended be adopted to build up soil nitrogen, in the long term.
- Removal of soybean residues from the field should be discouraged as this has a negative influence on soil nitrate nitrogen and yields of grain sorghum.
- Further research on sulphur is recommended to be carried out in order to establish whether the nutrient element is limiting in the studied soils in order to optimize sorghum grain yields.

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CHAPTER SIX

6.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 General Conclusions

The main findings of the study lead to the following general conclusions:

- The socioeconomic factors influencing sorghum yields in Busia County were established to be gender disparity, age, land ownership, education level and access to agricultural information. The female farmers comprised 57.3% of the smallholder farmers and play a significant role in crop production. Sorghum is considered a traditional crop but the younger farmers preferred maize growing to sorghum. In Busia County, men own the land and thus are the main decision makers. Thus, decision making on what should be grown on the farm and the practice is largely by men yet their participation in the production of sorghum is below 50%. Education level had an influence on sorghum production and this was intertwined with understanding of the extension services provided. The farmers' perception on use of seeds stored from previous years coupled with limited fertilizer use was concluded as among the factors contributing to low sorghum production in the County. Farmers practice crop intercropping for food security or as a source of income but not to improve soil fertility. As such, the choice of the crops to be intercropped is not considered in terms of soil improvement but to be able to cushion against possible crop failure. The results in this study showed that access to agricultural information and training was the most noted setback in sorghum production. The data indicated that 61.3% did not access agricultural information and out of the 38.7% that did access, 43% of them received the services only once in a growing season. The study results imply that farmers' participation and training need to be considered in order to change their mind set and facilitate practice of the research interventions available. It is also apparent that both male and female (from same household) should be involved in training on agricultural information to narrow the gender disparity gap.

- In the past, most research carried out in Busia County, the study sites (Emaloba and Bumala in Busia County) inclusive, assumed the soils to be Ferrasols. However, this study has revealed that site characterization has provided clear information on the actual nature of these soils in the field of study, and has aided in development of appropriate soil fertility management practices suited to the particular soils. It was also noted that soil types can be in similar ecological conditions but with varied physico-chemical properties that play significant role in carrying out meaningful research and promotion of correct type and amounts of fertilizer aimed at soil fertility improvement and enhanced crop productivity. For example, the EMA-P1 pedon showed a high water retention capacity while BUMA-P1 showed a drastic decrease in available water content as the suction potential increases with increase in soil depth. The latter pedon suggested an effect of drastic dryness of field crops whenever a dry spell is experienced in the site within the rainy season, consequently causing plants to temporarily wilt. Both pedons indicated the soils are strongly acidic and there is need to consider application of lime as an amendment to raise soil pH to optimal levels to facilitate availability and uptake of essential nutrients for plant growth and development and to reduce nutrient leaching and possible nutrient toxicities. Although EMA-P1 and BUMA-P1 identified, described and classified are in the same agro-ecological zone, they differed noticeably in their physico-chemical properties according to the results of this study. For example, the EMA-P1 profile indicated C/N ratio of 8.6 to 9.6 (within the rating of good quality organic matter) while BUMA-P1 indicate C/N ratio of 12.9 to 24.8 (poor quality organic matter). Though both soils are highly weathered, BUMA-P1 distinctly indicated an advanced stage of weathering with CEC_{soil} of 7.32 in the topsoil and below 6 in the subsoil while EMA-P1 indicated CEC_{soil} of 14.6 in the topsoil and above 10 in the subsoil. The findings emphasize that site pedological characterization is a pre-requisite to fertilizer rate development and recommendations. Thus, future anticipated research trials should consider knowing the physico-chemical properties of the target area soils before carrying out any meaningful trials. The results presented indicate that liming as a soil amendment should be given a priority in the management of the soils of the study area in order to reverse the trend of soil depletion noted.

- The research findings on effects of nitrogen fertilizer rates and soybean residue management options under sorghum-soybean intercropping has revealed the importance of either retaining or returning crop residues to the field after harvest. Soybean residues retained in the plots showed an increase in soil nitrate while removal of the residues indicated reduction in soil nitrate and thus negative implication on soil fertility improvement. Therefore, the farmers need awareness training on the importance of management of soybean residues in order to improve soil N in their farms. The results further indicated that under sorghum-soybean intercropping, soybean litter fall (soybean left to maturity) in combination with nitrogen fertilizer rate at 40 kg ha^{-1} improves soil NO_3-N and signifies the importance of intercropping and its role in improving soil fertility in terms of soil N. It is worth noting that though appreciable contribution of soil nitrate was realized, it did not translate to improvement of sorghum yields in the short term. This led to a speculation that other nutrient related to absorption and assimilation of nitrogen for example sulphur, could have impacted on the sorghum yields.

- The findings of the study have revealed that *in situ* soybean residue management in combination with nitrogen fertilizer application has the potential to contribute soil N for the subsequent sorghum crop. For example, soybean left to maturity in combination with nitrogen fertilizer at 40 kg ha^{-1} increased soil nitrate by 43% while soybean residues mulched indicated 39% increase and incorporated 25%. Removal of the residues increased soil NO_3-N by 17% (probably due to below ground biomass) while removal accompanied by tillage showed 2% increase. Sole sorghum indicated an increase of 4% irrespective of nitrogen fertilizer rates. The results imply that decomposing soybean residues has good potential for increasing soil NO_3-N in combination with nitrogen fertilizer at 40 kg ha^{-1}. In terms of subsequent sorghum yields, however, there was no significant difference on yield though contribution to soil N was observed. These findings support the findings in chapter 5 and points out the need to carry out further research on sulphur to establish if it is limiting in these soils and whether it can had an interactive effect with nitrogen impacting negatively on the expected sorghum yields.

6.2 General Recommendations

In view of the above general conclusions, the following recommendations are deduced:

- A data base of the alternative research options to restore soil fertility and enhance yields is developed and demonstrations on the same findings is set to involve farmers' participation aimed at changing the farmers' perception and facilitating adoption.

- Both male and female be involved to receive agricultural extension services on soil fertility improvement and intercropping of cereals with nitrogen fixing legumes is emphasized.

- Site characterization to be emphasized and considered as a pre-requisite to meaningful fertilizer trials by soil fertility specialists.

- Application of nitrogen fertilizer at 40 kg ha^{-1} in combination with sorghum and soybean left to maturity during the growing season of the intercrops is recommended for NO_3-N improvement and enhanced sorghum yields.

6.3 Recommendations for Further Research

The following are recommendations for further research:

- A further study is recommended to assess soil and leaf NO_3-N concentrations at a shorter interval during the growing season of sorghum-soybean intercrops to establish the concentration level that translates to optimum sorghum yields.

- Further research on sulphur is recommended to establish if it is limiting in the studied soils and its interactive effect on N nutrition.