EFFECT OF CONSERVATION AGRICULTURE ON SELECTED SOIL PROPERTIES, MAIZE AND BEANS PERFORMANCE IN WESTERN KENYA AND EASTERN UGANDA

BY

PATRICK SAMBA OLUKO

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN SOIL SCIENCE OF UNIVERSITY OF ELDORET

2015

DECLARATION

This thesis is my original work and has not been presented for award of degree in any other university. No part of this thesis may be reproduced without prior permission of the author and/or University of Eldoret.

Patrick Samba Oluko

AGR/PGS/08/10

Sign………………………………. Date: ……………………..

This is to confirm that this research thesis has been submitted for final approval by University of Eldoret under our supervision

Prof. J.R. Okalebo

Sign………………………………. Date: ……………………..

Department of Soil Science, School of Agriculture and Biotechnology, University of Eldoret, P.O.Box 1125,

Eldoret, Kenya.

Prof. P.O. Kisinyo

Sign………………………………. Date: ……………………..

School of Agriculture, Natural Resources and Environmental Studies,

Rongo University College

DEDICATION

To my beloved wife Janeclare, my lovely sons Clyde and Danphil. My dad Dan, mom Jane, and grandmother Beliah.

ABSTRACT

Despite Conservation Agriculture (CA) being advantageous towards improving soil quality and thus productivity, farmers in Western Kenya and Eastern Uganda still practice conventional tillage (CT). These result into soil quality decline, impacting negatively on soil chemical, biological and physical aspect. This has led to reduced food production hence increased food insecurity. Objectives of the study were to investigate effects of CA tillage systems (no-till, minimum till) and cropping systems on; i) soil chemical properties, ii) earthworms population, and iii) the economical CA production system; in Bungoma, Trans-Nzoia counties in western Kenya, and Tororo, Kapchorwa districts in Eastern Uganda. This was laid out in 2011 and 2012 cropping seasons. Treatments were tillage [Minimum (MT), No-Till (NT) and conventional (CT)], N-application and cropping systems in a split-split arrangement in a RCBD in 2011-2012. Main plots were tillage systems, nitrogen application [+N and -N] sub plots, and cropping systems [Current practice (CP), Rotation 1(ROT1) and Rotation 2 (ROT2)] as sub-sub-plots. Rotation 1 (ROT1) involved maize-beans intercrop with mucuna relayed after beans harvest. In ROT2, maize, beans and mucuna were planted in strips rotated every season. The strips comprised of 4 rows of maize, 8 rows beans and 6 rows of mucuna. CP was continuous maize-beans intercrop. Test crops were maize and beans, mucuna were a cover crop. Phosphorus and nitrogen was added as DAP and CAN with maize monocrop receiving 26kg P/ha and 30kg starter N/ha, while beans monocrop received 40kg P/ha. Additional 30kg N/ha was added as a split-split plot in a 5m by 10m area (+N). Soil chemical analysis- pH, P, soil organic carbon (SOC), total and mineral nitrogen- was done at each crop harvest. Earthworm population count was done at vegetative stage. Results indicate a significant ($p \leq 0.05$) increase in soil pH, available phosphorus, SOC, mineral and total nitrogen from MT, ROT2 and +N interaction. Earthworms increased under MT having mucuna due to minimum soil disturbance and more organic matter providing more food. In Bungoma, Trans-Nzoia, Tororo and Kapchorwa, the highest recorded means of maize yield were: 2.17 (Table 4.22.2), 3.26 (Table 4.23), 2.67 (Table 4.24.2) and 3.80 (Table 4.25) t/ha respectively in 2012. This were significantly ($p \leq 0.05$) higher from the initial mean of 1.44 (Table 4.22.1), 1.60 (Table 4.23), 1.93 (Table 4.24.1) and 1.36 t/ha (Table 4.25) respectively in 2011. There was a significant increase ($p \leq 0.01$) in beans yields from 0.14t/ha in 2011 to 0.29t/ha (Table 4.26.2): 0.54t/ha (Table 4.27), 1.35t/ha (Table 4.28.2) and 0.30t/ha (Table 4.29) in Bungoma, Trans-Nzoia, Tororo and Kapchorwa respectively. MT, ROT2 and +N interaction was most profitable treatment in all sites.

Keywords: Crop rotation, earthworms, soil organic carbon, soil quality

TABLE OF CONTENTS

DECLARATION i
DEDICATION ii
ABSTRACT iii
TABLE OF CONTENTS iv
LIST OF TABLES viii
LIST OF FIGURES ix
LIST OF PLATES xii
LIST OF APPENDICES xiii
ACRONYMS AND ABBREVIATIONS xiv
ACKNOWLEDGEMENT xv
CHAPTER ONE 1
INTRODUCTION 1
1.1 Background of the Study 1
1.2 Problem Statement 5
1.3 Justification 7
1.4 Objectives 10
1.4.1 Overall Objective 10
1.4.2 Specific Objectives 10
1.5 Hypotheses 11
CHAPTER TWO 12
Literature Review 12
2.1 Conservation Agriculture 12
2.2 Conservation Agriculture and Cropping Systems: Importance in Agriculture 13
2.2.1 Conservation Agriculture Tillage Systems 13
2.2.2 Conservation Agriculture versus Cropping Systems 15
2.2.3 Benefits of Conservation Agriculture 17
2.2.3.1 Healthy soil from crop rotations 17
2.2.3.2 Effect of cultivation on soil quality degradation 19
2.3 Effect of Conservation Agriculture farming systems on soil chemical properties 20
2.4 Effect of Conservation Agriculture farming systems on soil biological properities 22
2.4.1 Effects of Conservation Agriculture on Soil Health 25
2.4.2 The Impacts CA on Soil Structure, Ecosystem and Microbial ctivity 26
2.4.3 The Impacts of Conservation Agriculture on Biodiversity 30

2.4.4 Effects of Conservation Agriculture on Earthworms population................ 30
2.4.5 Effects of tillage and cropping systems on crops performance 32
2.4.6 Economic importance of CA.. 35
CHAPTER THREE 37
MATERIALS AND METHODS 37
3.1 Study Sites 37
3.1.1 Bungoma and Trans-Nzoia 37
3.1.2 Tororo and Kapchorwa.. 39
3.2 Field Procedures 41
3.2.1 Experimental Design and Layout 41
3.2.2 Experimental Treatments 43
3.2.3 Initial land preparation and planting... 45
3.2.4 Treatment application.. 46
3.2.5 Crop harvesting procedures 47
3.2.6 Soil sampling procedures 48
3.3 Laboratory methods 50
3.3.1 Soil analysis 50
3.3.1.1 Soil particle size analysis (Hydrometer method) 51
3.3.1.2 Soil pH 51
3.3.1.3 Total Nitrogen in soil 51
3.3.1.4 Extractable soil Phosphorus (P).. 52
3.3.1.5 Soil Organic Carbon.. 52
3.3.1.7 Soil mineral nitrogen (ammonium and nitrates) 52
3.3.1.7 Soil Earthworm population count 52
3.4 Data collection and analysis.. 53
3.4.1 Data collection 53
3.4.2 Data analysis 53
3.4.2.1 The experiment model.. 53
3.4.3 Economic analysis 55
CHAPTER FOUR 58
Results 58
4.1 Rainfall information for the four sites in the year 2011 and 2012................. 58
4.2 Initial soil characterization for the four sites 59
4.3 Effects of Tillage, Cropping Systems and Nitrogen application on selected soil chemical properties during cropping. 60
4.3.1 Effects of Tillage, Cropping Systems and Nitrogen application on soil pH 60
4.3.2 Effects of Tillage, Cropping Systems and Nitrogen application on available

soil Phosphorus (Sodium Hydrogen Carbonate extractable Phosphorus) 67

4.3.3 Effects of Tillage, Cropping Systems and Nitrogen application on soil organic carbon (SOC)... 74

4.3.4 Effects of Tillage, Cropping Systems and Nitrogen application on soil total nitrogen (N).. 81

4.4 Effects of Tillage, Cropping Systems and Nitrogen application on earthworm population 88

4.5 Effects of Tillage, Cropping Systems and Nitrogen application on crop yield 94

4.5.1 Effects of Tillage, Cropping Systems and N application on Maize grain yield 94

4.5.2 Effects of Tillage, Cropping Systems and Nitrogen application on Beans grain yield 97

4.6 Effects of Tillage, Cropping Systems and Nitrogen application on soil nitrate-N (NO3-N) and ammonium-N.. 101

4.6.1 Effects of Tillage, Cropping Systems and Nitrogen application on soil nitrate-N.. 101

4.6.2 Effects of Tillage, Cropping Systems and Nitrogen application on soil ammonium-N (NH4+-N).. 108

4.7 Economic analysis 117

CHAPTER FIVE 128

Discussion... 128

5.1 Initial soil characterization... 128

5.2 Effects of Tillage, Cropping Systems and Nitrogen application on selected soil chemical properties.. 128

5.2.1 Effects of Tillage, Cropping Systems and Nitrogen application on soil pH 129

5.2.2 Effects of Tillage, Cropping Systems and Nitrogen application on available P in the soil 130

5.2.3 Effects of Tillage, Cropping Systems and Nitrogen application on soil organic carbon 132

5.2.4 Effects of Tillage, Cropping Systems and Nitrogen application on total soil N 135

5.3 Effects of Tillage, Cropping Systems and Nitrogen application on earthworm populations.. 136

5.4 Effects of Tillage, Cropping Systems and Nitrogen application on soil nitrate and ammonium.. 139

5.4.1 Effects of Tillage, Cropping Systems and Nitrogen application on soil nitrate... 139

5.4.2 Effects of Tillage, Cropping Systems and Nitrogen application on soil ammonium 141

5.5 Effects of Tillage, Cropping Systems and Nitrogen application on maize and

bean grain yield 142
5.6 Economic analysis 144
CHAPTER SIX 145
Conlussion and Recommendations 145
6.1 Conclussions 145
6.2 Recommendations 147
REFERENCE 149
APPENDICES 167

LIST OF TABLES

Table 3.1: Location, climatic and soil characteristics of the Western Kenya study sites for the initial soil characteristics determined before the experiment were laid. 37

Table 3.2.: Location, climatic and soil characteristics of the Eastern Uganda study sites for the initial soil characteristics determined before the experiment were laid. 41

Table 3.3: The experimental treatments arrangement in a split-split plot for one block. 42

Table 3.4: Experimental treatments randomized for one block 44

Table 3.6: Skeleton ANOVA Table for all four sites and treatments 55

Table 3.7: Values used for costs and benefits analysis (Ksh) during the years 2011 and 2012. 56

Table 4.1: Initial soil chemical analysis data for the four sites 59

Table 4.2; Added cost of production (Ksh) for Bungoma and Trans-Nzoia in the year 2011 118

Table 4.3; Gross field benefits, TCV, NFB and MRR analysis of treatments for Bungoma and Trans-Nzoia in 2011 120

Table 4.4; Added cost of production (Ksh) for Tororo and Kapchorwa in the year 2011 123

Table 4.5; Gross field benefits, total costs that vary, net financial benefits and marginal rate of returns analysis of treatments for Tororo and Kapchorwa in 2011 125

LIST OF FIGURES

Fig. 2.1: A hierarchical view of the distribution of biotic communities in specific biological spheres in the soil ecosystem (Beare et al., 1997). 25

Fig 3.1: Map of Kenya showing Trans-Nzoia and Bungoma Counties 38

Fig 3.2: Map of Western Kenya showing coordinates Trans-Nzoia and Bungoma sites (Ahmed, 2012).. 39

Fig 3.3: Map of Uganda showing Tororo and Kapchorwa Districts (Ahmed, 2012) 40

Fig 4.1: Rainfall data for Bungoma and Trans-Nzoia in the year 2011 and 2012 58

Fig 4.2: Rainfall data for Tororo and Kapchorwa in the year 2011 and 2012 59

Fig 4.3: Soil pH under different tillage systems 60

Fig 4.4: Soil pH in Bungoma LR2011 ……………………………………..…...61
Fig 4.5: Soil pH in Bungoma SR2011……………………………………….......61
Fig 4.6: Soil pH in Bungoma LR2012………………………………………….....61
Fig 4.7: Soil pH in Bungoma SR2012…………………………………………….....61
Fig 4.8: Soil pH changes in Trans-Nzoia in LR2011……………………..……….63
Fig 4.9: Soil pH changes in Trans-Nzoia LR2012……………………….………63
Fig 5.0: Soil pH changes in Kapchorwa in LR2011………………………………63

Fig 5.1: Soil pH changes in Kapchorwa in LR201………………………………..63

Fig 5.2: Soil ph in Trans-Nzoia (TOS) and Kapchorwa (UKOS) 64

Fig 5.3: Soil pH change in Tororo……………………………………………………65

Fig 5.4: soil pH in Tororo LR2011 ………………………………………………66
Fig 5.5: Soil pH in Tororo SR2011……………………………………………………66
Fig 5.6: Soil pH in Tororo LR2012..…………………………………………………66
Fig 5.7: Soil pH in Tororo SR2012……………………………………………….....66

Fig 5.8: Available P in Bungoma soils 67

Fig 5.9: Available P in Bungoma in LR2011……………………………………..68
Fig 5.10: Available P in Bungoma in SR2011……………………………………..68
Fig 5.11: Available P in Bungoma LR201…………………………………………68
Fig 5.12: Available P in Bungoma SR2012………………………………………..68
Fig 5.13: Available P in Trans-Nzoia LR2011……………………………………70
Fig 5.14: Available P in Trans-Nzoia LR2012 ……………………………………70
Fig 5.15: Available P in Kapchorwa LR2011……………………………………..70
Fig 5.16: Available P in Kapchorwa LR2012……………………………………..70

Fig 5.17: Available P in Trans-Nzoia and Kapchorwa soils................................. 71

Fig 5.18: Available P in Tororo across seasons 72

Fig 5.19: Available P in Tororo LR2011 …………………………………………73
Fig 5.20: Available P in Tororo SR2011. …………………………………………73
Fig 5.21: Available P in Tororo LR2012..…………………………………………73
Fig 5.22: Available P in Tororo SR2012 …………………………………………73

Fig 5.23: Soil organic carbon in Bungoma soils across seasons 75

Fig 5.24: SOC in Bungoma in LR2011 76
Fig 5.25: SOC in Bungoma in SR2011..76
Fig 5.26: SOC in Bungoma in LR2012 76
Fig 5.27: SOC in Bungoma in SR2012 76
Fig 5.28: SOC in Trans-Nzoia in LR2011 78
Fig 5.29: SOC in Trans-Nzoia in LR2012 78
Fig 5.30: SOC in Kapchorwa in LR2011 78
Fig 5.31: SOC in Kapchorwa in LR2012 78

Fig 5.32: Soil Organic Carbon changes in Kapchorwa and Trans-Nzoia............ 79

Fig 5.33: SOC in Tororo in LR2011...80
Fig 5.34: SOC in Tororo in SR2011 80
Fig 5.35: SOC in Tororo in LR2012...80
Fig 5.36: SOC in Tororo in SR2012 80

Fig 5.37: Soil Organic Carbon (SOC) in Tororo across seasons 81

Fig 5.38: % Nitrogen in Bungoma in LR2011 82
Fig 5.39: % Nitrogen in Bungoma in SR2011 82
Fig 5.40: % Nitrogen in Bungoma in LR2012 82
Fig 5.41: % Nitrogen in Bungoma in SR2012 82
Fig 5.42: % Nitrogen in Trans-Nzoia in LR2011 84
Fig 5.43: % Nitrogen in Trans-Nzoia in LR2012 84
Fig 5.44: % Nitrogen in Kapchorwa in LR2011 84
Fig 5.45: % Nitrogen in Kapchorwa in LR2012 84
Fig 5.46: % Nitrogen in Tororo in LR2011 86
Fig 5.47: % Nitrogen in Tororo in SR2011 86
Fig 5.48: % Nitrogen in Tororo in LR2012 86
Fig 5.49: % Nitrogen in Tororo in SR2012 86

Fig 5.50: Earthworms count in LR2011 and SR2011 in Bungoma 88

Fig 5.51: Earthworms count in LR2012 and SR2012 in Bungoma...................... 89

Fig 5.52: Earthworms count in LR2011 and LR2012 in Trans-Nzoia 89

Fig 5.53: Earthworms count in LR2011 and SR2011 in Tororo........................... 90

Fig 5.54: Earthworms count in LR2012 and SR2012 in Tororo........................... 91

Fig 5.55: Earthworms count in LR2011 and LR2012 in Kapchorwa 91

Fig 5.56: Earthworm population count under different tillage systems, cropping systems and nitrogen application across sites 93

Fig 5.57: The status of the soil chemical parameters and earthworm population count under different crops in LR2012 cropping season at Tran-Nzoia.............. 93

Fig 5.58a: Maize grain yield (t/ha) in Bungoma in LR2011 and SR2011 seasons 94

Fig 5.58b: Maize grain yield (t/ha) in Bungoma in LR2012 and SR2012 seasons95

Fig 5.59: Maize grain yield (t/ha) in Trans-Nzoia in LR2011 and LR2012 seasons 95

Fig 5.60: Maize grain yield (t/ha) in Tororo in LR2011 and LR2012 seasons...... 96

Fig 5.61: Maize grain yield (t/ha) in Kapchorwa in LR2011 and LR2012 seasons 97

Fig 5.62: Beans grain yield (t/ha) in Bungoma in LR2011 and SR2011 seasons.. 98
Fig 5.63: Beans grain yield (t/ha) in Bungoma in LR2012 and SR2012 seasons . 98
Fig 5.64: Beans grain yield (t/ha) in Trans-Nzoia in LR2011 and LR2012 seasons 99
Fig 5.65: Beans grain yield (t/ha) in Tororo in LR2011 and SR2011 seasons 100
Fig 5.66: Beans grain yield (t/ha) in Tororo in LR2012 and SR2012 seasons 100
Fig 5.67: Beans grain yield (t/ha) in Kapchorwa in LR2011 and LR2012 seasons 101
Fig 5.68: Nitrates in Trans-Nzoia soils in LR2011 102
Fig 5.69: Nitrates in Trans-Nzoia soils in LR2012.. 102
Fig 5.70: Nitrates in Kapchorwa soils in LR2011 103
Fig 5.71: Nitrates in Kapchorwa soils in LR2012.. 104
Fig 5.72: Nitrates in Bungoma soils in LR2011 ……………………………….104
Fig 5.73: Nitrates in Bungoma soils in SR2011 ………………………………. 104
Fig 5.74: Nitrates in Bungoma soils in LR2012 ……………………………….104
Fig 5.75: Nitrates in Bungoma soils in SR2012 ………………………………. 104
Fig 5.76: Nitrates in Tororo soils in LR2011 ………………………………….106
Fig 5.77: Nitrates in Tororo soils in SR2011 …………………………………..106
Fig 5.78: Nitrates in Tororo soils in LR2012 ………………………………….106
Fig 5.79: Nitrates in Tororo soils in SR2012 …………………………………. 106
Fig 5.80: Ammonium in Bungoma in LR2011 ………………………………..108
Fig 5.81: Ammonium in Bungoma in SR2011 ….……………………………108
Fig 5.82: Ammonium in Bungoma in LR2012 ……………………………… 108
Fig 5.83: Ammonium in Bungoma in SR2012 ………………………………..108
Fig 5.84: Ammonium in Tororo in LR2011 …………………………………..110
Fig 5.85: Ammonium in Tororo in SR2011 …………..……………………….110
Fig 5.86: Ammonium in Tororo in LR2012 …..………………………………110
Fig 5.87: Ammonium in Tororo in SR2012 …………..……………………….110
Fig 5.88: Ammonium-N in Trans-Nzoia soils in LR2011...................................112
Fig 5.89: Ammonium-N in Trans-Nzoia soils in LR2012...................................113
Fig 5.90: Ammonium-N in Kapchorwa in LR2011..114
Fig 5.91: Ammonium-N in Kapchorwa in LR2012..114
Fig 5.92: Miimum Tillage vs ROT2 in LR2012 in Bungoma……………………115
Fig 5.93: No-Till vs ROT2 in LR2012 in Kapchorwa.......................................115
Fig 5.94: Conventional Tillage vs ROT2 in LR2012 in Trans-Nzoia 115

LIST OF PLATES

Plate 1: Representatives groupings of soil macrofauna (Author, 2015)............... 50

Plate 2: ROT2 cropping system with maize-beans-mucuna strips 116

Plate 3: ROT1 cropping system with maize-beans intercrop, with mucuna to be introduced after harvest of beans...116

LIST OF APPENDICES

Appendix I; Modified Anderson and Ingram (1993) protocol for sampling procedure for the soil invertebrates 167

Appndix III: Analysis of Variance: Soil pH LR2012 in Bungoma 168

Appndix IV: Analysis of Variance: Soil Organic Carbon in LR2012 in Bungoma 169

Appndix V: Analysis of Variance: Soil total Nitrogen in LR2012 in Bungoma . 169

Appndix VI Analysis of Variance: Available P in LR2012 in Trans-Nzoia 170

Appndix VII: Analysis of Variance: Soil_pH in LR2012 in Trans-Nzoia 170

Appndix VIII: Analysis of Variance: Nitrogen in LR2012 in Trans-Nzoia 171

Appndix IX: Analysis of Variance: Soil Organic Carbon in LR2012 in Trans-Nzoia 171

Appndix X: Analysis of Variance: Earthworms in LR2012 in Trans-Nzoia 172

Appndix XI: Analysis of Variance: Available_P in LR2012 in Tororo 172

Appndix XII: Analysis of Variance: Soil pH in LR2012 in Tororo 173

Appndix XIII: Analysis of Variance: Soil Organic Carbon in LR2012 in Tororo 173

Appndix XIV: Analysis of Variance: Nitrogen in LR2012 in Tororo 174

Appndix XV: Analysis of Variance: Worms in LR2012 in Tororo 174

Appndix XVI: Analysis of Variance: Available_P in LR2012 in Kapchorwa ... 175

Appndix XVII: Analysis of Variance: Soil_pH in LR2012 in Kapchorwa........ 175

Appndix VIII: Analysis of Variance: Organic Carbon in LR2012 in Kapchorwa 176

Appndix XIX: Analysis of Variance: Nitrogen in LR2012 in Kapchorwa........ 176

Appndix XX: Analysis of Variance: Earthworms in LR2012 in Kapchorwa ... 177

Appendix XXI; Mean separation for tillage and cropping systems on % SOC in Bungoma LR2012 178

Appendix XXII; Mean separation for tillage and cropping systems on NH3-N in Bungoma and Trans-Nzoia 178

Appendix XXIII; Mean separation for tillage and cropping systems on NH3-N in Tororo and Kapchorwa 179

Appendix XXIV; Mean separation for tillage and cropping systems on NO3-N in Bungoma and Trans-Nzoia 179

Appendix XXV; Mean separation for tillage and cropping systems on NO3-N in Tororo and Kapchorwa 180

ACRONYMS AND ABBREVIATIONS

CA Conservation Agriculture

CP Current Practice- In this thesis, current practice was used to mean maize-beans intercropping as practiced by farmers

CT Conventional Tillage

LR Long Rains

MT Minimum Tillage

NT No-Till

P Phosphorus

ROT Rotation

SOC Soil Organic Carbon

SR Short Rains

BOS Bungoma on-station

TOS Trans-Nzoia on-station

UTOS Uganda Tororo on-station

UKOS Uganda Kapchorwaon-station

ACKNOWLEDGEMENT

My sincere gratitude to my supervisors Prof. J.R. Okalebo, Prof. P.O. Kisinyo and Prof. W. N'getich for the support, guidance, advice and encouragement they accorded me throughout this study. I am indebted to SANREM (Sustainable Agriculture and Natural Resource Management) team Prof. J. Norton and Dr. E. Omondi for financially supporting me to undertake both my studies and fieldwork, together with coordinator Mr. D.S. Ngosia and Shibonje Dennis for his selfless efforts with fieldwork.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

In the recent past, soil degradation has resulted to reduction in agricultural productivity and environmental degradation in Sub-Saharan Africa (SSA). Soil erosion and soil fertility loss are considered to be negatively affecting the productive capacity of the otherwise agricultural potential systems (Adjei-Nsiah, *et al*., 2007; Sanchez, 2002; FAO, 2012). These problems have been ascribed to many different causes: social (e.g., marginalization of the poor and women), political (e.g., structural adjustment programs), economic (e.g., poor availability and/or high prices of inputs, limited market opportunities), biological (e.g., increasing population and reducing land sizes), and physical (e.g., climatic change). With the world having an estimated one billion people it is facing imminent hunger (van Straaten, 2007), where almost one in seven people go hungry in a world where there is plenty to eat, a quarter of them being in Sub-Saharan Africa (SSA) (van Straaten, 2007).

Studies have revealed that soil nutrient depletion is threatening the productivity of arable lands in Kenya and Uganda (Bosch *et al*., 1998; de Jager *et al*., 2004; Stoorvogel and Smaling, 1990; Wortzmann and Kaizzi, 1998). These researchers report annual nutrient losses exceeding 30 kg nitrogen and 20kg potassium per hectare of arable land. Soil nutrients are being depleted through crop removals, leaching and soil erosion, especially where farmers have been unable to sufficiently compensate these losses by replenishing soil nutrients via crop residues, manures and mineral fertilizers (Shepherd and Soule, 1998). In Kenya, for instance, production levels of the staple foods (maize and legumes) indicate deficits. The production of maize is at 28 million tonnes per year which is far much below the required annual maize consumption of 34-37 million tonnes (FAO, 2012).

Despite the fact that Uganda has a large proportion of arable land, soil degradation is a substantial problem in the country. Generally it is estimated that 4 to 12 percent of GDP is lost from environmental degradation; 85 percent of this from soil erosion, nutrient loss and changes in crops. Agricultural productivity in Uganda is generally low, with wide gaps between yields on experimental plots and on the average Ugandan farm (Bashaasha, 2011). The low yields are attributed to a lack of yield-enhancing investments from improved science and technology that would come from agricultural research (Bashaasha, 2011). The socio-economic reasons for land degradation and low productivity on small-scale farms nationally have been summarized as: poverty and land fragmentation leading to over-exploitation of the land with inadequate soil and water conservation practices; increasing rural population densities with few non-farm income opportunities; low levels of commodity trade and the production of lower-value commodities, reducing incentives to invest in the soil; little farmer knowledge of improved agricultural technologies; insufficient agricultural research that takes into account the needs and resource constraints of farmers, and a lack of effective agricultural extension; and inappropriate farming practices and systems including deforestation, bush burning and overgrazing (Olson 1998; Zake et al. 1999; NEMA 2001; Kazoora 2002).

Other causes of low crop production in western Kenya and eastern Uganda regions include declining soil fertility, adverse weather conditions and virtual dependence on rainfall together with poor soil and crop management. Soil fertility depletion in small holder farms is the fundamental biophysical root cause of declining per capita food production in Africa as a whole (Sanchez, 2002). Soil quality and fertility replenishment should be considered as an investment in natural resource capital (Sanchez, 2002). Many authors have expressed concern over the increasing land degradation in the highlands of East Africa (Chikowo *et al*., 2004; Vogeler, *et al*., 2008; Vanlauwe and Zingore, 2011). Increases in agricultural production in the last decades have been achieved through intensifying agricultural practices, such as increasing the frequency of cultivation at the expense of natural fallows and through expanding the cultivated areas, especially into fragile environments such as wetlands and steep hill slopes, with negative consequences, including soil degradation from soil erosion and loss of soil fertility. As a result, there has been a continuous soil quality decline accompanied by dwindling maize-beans production. Soil quality comprise of soil physical, biological and chemical parameters. These together with maize-beans production has been on a continuous decline in western Kenya and eEastern Uganda (Zibilske et al., 2002; Palm *et al*., 2001; Nzabi *et al*., 2007; Nkonya *et al*., 2004; Okalebo *et al*., 2003).

All the above factors in singular or combined in turn contribute to food and nutrition insecurity in Western Kenya and Eastern Uganda. Soil nutrient depletion and erosion could also lead to deforestation and loss of biodiversity since farmers are forced to abandon nutrient-starved soils and cultivate more marginal hillsides and rainforests

(Wortmann and Kaizzi, 1998). The overall implication of these impacts is increased poverty, which poses an enormous development challenge in Kenya and Uganda, in the SSA, making finding ways to reverse these trends an urgent need (Nkonya *et al*., 2004; Zake *et al*., 1997; Wortmann and Kaizzi, 1998).

Conservation agriculture (CA) is one of the most concrete and promising ways of implementing sustainable agriculture in practice that can serve as a remedy to this situation in Western Kenya and Eastern Uganda. Conservation agriculture as a concept relies on three main pillars: 1) minimum soil disturbance or no tillage; 2) permanent soil cover and 3) diverse crop rotations (Giller *et al*., 2009; Kaumbutho and Kienzle, 2007). These principles are promoted to cope with soil degradation problems resulting from certain agricultural practices which may disturb the soil quality (nutrient content or soil organic matter), lower the yields and worsen the profitability of the field. Conservation agriculture production systems could be a potential remedy to the lose of soil quality.

Conservation agriculture system is any farming system that leaves about one-third of the soil covered after planting. This includes no-till/strip-till, ridge-till and mulch-till. Managing a conservation tillage system is an important part of the farm management strategy (Giller *et al*., 2009). It includes planning crop rotation; analyzing soil conditions; maintaining adequate soil moisture; adjusting nutrient and weed management approaches; and selecting the equipment attachments to match the favorable farming system. Conservation agriculture farming is an easy and cheap way of increasing the amount of yields, on the same piece of land without need to increase land acreage. If well managed, conservation agriculture (CA) systems play a major role towards improving soil status and quality in general.

Conservation agriculture has over the last 30 years mainly been adopted in rural areas of South and North America. Contrary, Africa accounts for only 0.5% adoption rate. Researchers and institutions expected a higher level of CA adoption in African countries than there is currently. Giller *et al*. (2009) reports that CA adoption in Africa responds to a different agricultural environment characterized by smallholder farming whose constraints have not yet been clearly addressed. Conservation agriculture farming systems involve a number of practices for long-term benefits. Conservation agriculture (CA) is often promoted as a combination of tillage and cropping practices aimed at reducing soil erosion and maintain soil fertility, while decreasing production costs and increasing crop yields consecutively (Giller *et al*., 2009; Apina et al., (2007). Crop residues are incorporated in the soil to increase soil organic matter and also act as a mulch or cover to reduce soil erosion and water loss through evaporation (Giller *et al*., 2009).

1.2 Problem Statement

Population pressure, agricultural intensification, market distortions that limit access to inputs, an unevenly supportive policy climate, and unproductive soils create a degradation spiral that contributes to food insecurity in eastern Uganda and western Kenya. Farmers in western Kenya and eastern Uganda still carry out conventional tillage practice on the vulnerable soils of these regions (Giller *et al*., 2009). Conventional tillage involves use of cultivationas the major means of seedbed preparation and weed control thus leaving the soil unprotected (Wortmann and Eledu, 1999). This has led to the ever declining soil quality (Giller *et al*., 2009) hence poor crop production that reflects into food insecurity in western Kenya and eastern Uganda. Food insecurity which has led to poverty among the locals is attributed to the most practiced intensive tillage which degrades the soil structure and the soil potential to hold moisture, reduces the amount of soil organic matter in the soil and breaks up aggregates. Additionally, it reduces the population of soil fauna such as earthworms that otherwise contribute to nutrient cycling and soil structure improvement (Giller *et al*., 2009).

Through tilling by either hand or machinery, the soil layers invert, air mixes in, and soil microbial activity dramatically decreases over baseline levels. The result is that soil organic matter is broken down much more rapidly, and carbon is lost from the soil into the atmosphere (Nkonya *et al*., 2004; Nkonya *et al*., 2005; Nkonya *et al*., 2008a; Nkonya *et al*., 2008b).

This, in addition to the emissions from the farm equipment itself, increases carbon dioxide levels in the atmosphere contributing to adverse climatic changes (global warming). This has led to adverse effects on soil fertility, soil microbial, physical, and chemical properties. Additionally, there is a continuous soil loss through nutrient mining by harvested crops, soil erosion, and hence a general decline in soil quality. Nutrient depletion is threatening the productivity of soils in western Kenya and eastern Uganda (Bosch *et al*., 1998; de Jager *et al*., 2004; Stoorvogel and Smaling, 1990; Wortzmann and Kaizzi, 1998). This is rampant especially where farmers have been unable to sufficiently compensate these losses by replenishing soil nutrients via crop residues, manures and mineral fertilizers (Shepherd and Soule, 1998). Soil erosion due to lack of proper cultivation systems is on the rise in Kapchorwa district (Wortmann and Eledu, 1999). This has led to a continuous decline in crop yields in western Kenya and eastern Uganda, recording more than 40% maize and bean grain yield lose (Giller, *et al*., 2009; Buresh *et* *al*., 2011; Apina *et al*., 2007: Nkonya *et al*., 2004; Wortmann and Eledu, 1999). This has resulted into high levels of poverty in the region (Nkonya *et al*., 2004; Giller *et al*., 2009; Wortmann and Eledu, 1999).

1.3 Justification

In western Kenyan and eastern Uganda, with population having doubled in the recent years, deforestation and excessive cultivation with little input use have been the predominant land use trends. Additionally, the area has one of the poorest high rural populations. The escalating poverty has hindered sustainable use of land resources increasing degradation which is the most important threat to agricultural productivity. This has led to a reduction of land portion land and the catchment occupied by agriculture (ASARECA, 1997). Western Kenya and eastern Uganda regions face the challenge of producing food for a rapidly growing population that stands at 2.5% increase per annum (CIMMYT, 2002). In order to meet food requirements of the increasing population and achieve food security by 2020, food production would need to increase by 6% per annum (Inocencio *et al*., 2003).

Food security is a major concern. Much of the population depends on rainfed agriculture for its sustainance upon the cultivation of maize (*Zea mays*) and common beans (*Phaseolus vulgaris*) which rank first and second respectively in importance as food staples in these regions (ASARECA, 1997). Continous maize-bean intercropping without crop rotations is practiced on >80% of the arable area in the western Kenya, while 45-80% of arable land in eastern Uganda is under maize-beans intercropping. Soil productivity in these regions has been on decline for decades with farmers recording as low as 0.2t/ha maize grain (Nkonya *et al*., 2004; Wortmann and Eledu, 1999) and 0.1t/ha beans grain (Nkonya *et al*., 2004; Giller *et al*., 2009). This is because of the increased population pressure and the high cost of inputs that have led to excessive cultivation, declining soil fertility and soil physical degradation (World Bank, 1996). The resulting soil is characterized by low soil organic matter (SOM), poor structure, hardpans and poor infiltration of rainwater. Improper agronomic practices including conventional tillage practice have led to enhanced soil erosion. All these plus other factors including climatic change have resulted in a continuous spiral of soil quality degradation.

With a continuous soil quality degradation that has resulted into low and declining maize and beans grain yield in western Kenya and eastern Uganda, immediate measures need to be taken to reverse the declining trends. One such option is conservation agriculture (CA) approaches that enhance productive capacity of soils. This should be able to build upon local agricultural knowledge in order for ease of adoption, as well as increase and stabilize food production. These benefits of CA have been occurring in South American countries for decades, such as Brazil and Argentina or North America, where mucuna has been employed in cropping systems. Nonetheless the practice of CA has been spread out to many other countries around the globe though to a lesser extend in Africa. According to several studies from an agronomic standpoint, CA is beneficial. However more research is needed to investigate the interactive effects of tillage, fertilizer application, and cropping systems as they affect soil quality (soil physical, chemical and biological properties) in tropical soils, where data on this matter is wanting (Giller *et al*., 2009).

By 2009 more than 106 million of hectares under zero tillage were counted across the world (Giller, *et al*., 2009; Ong'ang'a and Munyirwa., 1998). According to Giller et al., (2009), about 47% is practiced in South America and less than 0.5% corresponds to Africa, whereby tillage remains as cornerstone of farming. Continous conventional tillage practice with monocropping is still being practiced. It is attributed in part to lack of site specific recommendations for CA production systems (tillage, cropping systems and inorganic N application) that will aid in replenishing soil quality (Giller, *et al*., 2009; Buresh *et al*., 2011; Apina et al., 2007).

Conservation agriculture production systems in this case involve minimal soil disturbance tillage systems (minimum till and no-till). Cropping systems involve use of cover crops as well as crop rotations. Fertilizer application in this case is the inorganic N fertilizer application. There is no information on synergies to be gained by combining these three components. The integrated use of CA tillage systems, organic residues, crop rotations, use of cover crops and inorganic fertilizers as a useful alternative for improving both soil quality and crop productivity in these regions has not been explored. This information is lacking, forming an entry point for this study. Most previous studies have concentrated on P as a crop nutrient, with little or no emphasis on nitrogen. Maize-bean cropping system components interact strongly but past initiatives have often dealt with individual components and have not addressed inclusion of cover crops e.g. mucuna (*Mucuna pruriens*). Its impact on soil quality improvement has not been explored too.

Previous studies have concentrated mainly on specific soil aspect, with major emphasis on soil chemical properties. Studies did not determine the ability of crop residues from diverse crop species to quantify the amounts of nutrients added in relation to the measured yield responses. In most cases soil changes were not monitored to detect improvements in terms of soil chemical and biological properties. By developing and exploiting these synergies, this study will enhance crop productivity and improve soil quality. This study aims at investigating the effect of integrated use of organic residues and inorganic fertilizers under conservation agriculture production systems, on both soil quality and crop yield improvement. This will aid in reducing the negative downstream impacts of agriculture on soil quality in western Kenyan and eastern Uganda regions.

It is expected that through nutrient cycling and replenishment will enhance soil fertility and quality in general. This is via inorganic N application and crop residue incorporation under CA tillage systems. This is expected in turn to increase and maintain high maize and beans production for longer period besides improving environmental conditions. It will allow farmers to capitalize on soil quality and health improvement.

1.4 Objectives

1.4.1 Overall Objective

To enhance maize and beans yield using intergrated approach of conservation agriculture tillage practices, cropping systems and fertilizer application in Western Kenya and Eastern Uganda.

1.4.2 Specific Objectives

1. To determine the effect of tillage and cropping systems on selected soil chemical properties in Western Kenya and Eastern Uganda,
2. To investigate effect of tillage, cropping and crop rotation systems on earthworms population in Western Kenya and Eastern Uganda, and
3. To investigate effect of tillage, cropping and crop rotation systems on maize and

bean grain yield in Western Kenya and Eastern Uganda.

4. To determine the economical benefit of tillage and cropping systems on maize and bean grain yield production in Western Kenya and Eastern Uganda.

1.5 Hypotheses

1. **H0:** CA tillage systems and cropping systems do not have the potential to enhance Maize-Beans production in Western Kenya and Eastern Uganda relative to conventional production practices

2. **H0:** CA tillage systems and cropping systems do not have the potential to enhance soil chemical status in Western Kenya and Eastern Uganda relative to conventional production practices

3. **H0:** CA tillage systems and cropping systems do not have the potential to enhance soil earthworm population in Western Kenya and Eastern Uganda relative to conventional production practices

4. **H0:** Tillage and cropping systems will not improve on the gross margins and MRR.

CHAPTER TWO

Literature Review

2.1 Conservation Agriculture

Conservation agriculture (CA) aims to achieve sustainable and profitable agriculture, while at the same time it subsequently aims at improved livelihoods of farmers through the application of the three CA principles (FAO, 2012). These are: 1) Minimum soil disturbance or no tillage; 2) Permanent soil cover and 3) diverse crop rotations (Giller *et al*., 2009). It is a way to combine profitable agricultural production with environmental concerns and sustainability. It has being proven to work in a variety of agro-ecological zones and farming systems (FAO, 2012; Narain and Kumar; 1998). This is the reason why it is been perceived by practitioners as a valid tool for Sustainable Land Management (SLM) (FAO, 2012).

Minimum or reduced tillage forms an essential component of CA mainly due to: (i) adverse effects of tillage on soil structure and organic matter, and (ii) tillage operations demand for alot of energy/power which is the main ingredient in agricultural production (Chikowo *et al*., 2004). The emphasis on reduced tillage systems has positive effects on soil quality. It improves soil physical, chemical as well as biological parameters. This resulted from such factors as increasing energy costs, high equipment inventories and costs (e.g., tractors and related implements), high labour costs, increased concern about soil erosion, and the need for more efficient utilization of water for crop production (Chikowo *et al*., 2004). Of the various sources of energy or power, human labour constitutes 11.6% while 50.8% is needed for drafting in various tillage operations in conventional agriculture (Wambua, 2012). Weed control in CA is done either by use of eco-friendly herbicides or shallow cultivation resulting to minimal soil disturbance, water and nutrients retention (Wambua, 2012). By adopting CA production systems we reduce the energy/power requirement and hence reduce the cost of cultivation (Durodoluwa *et al*., 2010). There are two well recognized CA tillage systems that form the basis of CA reduced tillage: (i) minimum tillage, and (ii) no-tillage.

2.2 Conservation Agriculture and Cropping Systems: Importance in Agriculture

2.2.1 Conservation Agriculture Tillage Systems

Minimum tillage refers to the minimum soil manipulation necessary for crop production, without having to turn the soil over (Mashingaidze *et al*., 2012). In conventional agriculture, tilling is used to remove weeds, mix in soil amendments like fertilizers, shape the soil into rows or ridges for crop plants and furrows for irrigation, and prepare the surface for seeding. This can lead to unfavorable effects, like soil compaction, loss of organic matter, degradation of soil aggregates, death or disruption of soil microbes and other organisms including mycorrhiza, arthropods and earthworms, and soil erosion where topsoil is blown or washed away (González, *et al*., 2010).

Research has shown that no-till or zero tillage farming makes soil much more stable than plowed soil (Buresh *et al*., 2011). No-till stores more carbon in the soil and carbon is a key factor in holding soil particles together. The no-till soil is two to seven times less vulnerable to erosion and degradation than that of plowed soil (Apina *et al*., 2007). The practice of no-till farming is especially beneficial to great plain soils e.g. in Kapchorwa because it aids in curbing erosion which is rampant on the cultivated existing steep slopes (Kassan *et al*., 2009). No-till improves soil quality, carbon, organic matter, aggregates, protecting the soil from erosion, evaporation of water, and structural breakdown. Under no-tillage conditions, the internal pore system of the soil is not destroyed through land preparation activities and able to drain rainwater from the surface to deeper layers (Kassan *et al*., 2009; Apina *et al*., 2007; Giller, *et al*., 2009).

In no-tillage systems, the crop is sown into a soil left undisturbed since the harvest of the previous crop. No-till farming, or otherwise referred to as zero tillage, is a way of growing crops from year to year without disturbing the soil through tillage. Crop residue mulch is maintained and anchored firmly to the ground. Several crops e.g. Mucuna (*Mucuna pruriens*) and beans (*Phaseolus vulgaris*) plus previous maize (*Zea mays*) stalks crop residues provide mulching materials and act as cover crops because of their large biomass production. Weed control relies on mechanical slashing or cover crops which suppress the weeds via mulching (FAO, 2012). Eco friendly Contact herbicides are also used in some cases (Giller, *et al*., 2009). In reduced- or zero-tillage systems, soil fauna resume their bio-turbating activities gradually (Castellanos *et al*., 2012). These loosen the soil and mix the soil components (known as bio-tillage) (Chivenge *et al*., 2007). The additional benefit of the increased soil organic matter and burrowing is the creation of a stable and porous soil structure without expensive, time-consuming and potentially degrading cultivations (Justin *et al*., 2012; González *et al*., 2010). In zero-tillage systems, the action of soil macrofauna gradually incorporate cover crop and weed residues from the soil surface down into the soil. The activity of microorganisms is also regulated by the activity of the macrofauna, which provide them with food and air through their burrows (González *et al*., 2010). Justin *et al*., (2012) report that for more than 25 years, data have been collected on the effects of tillage and cropping sequences on crop yields and soil chemical, physical, and biological properties from a dryland farming system in SSA. These data indicate that many soil properties, including soil aggregate formation and organic C and N storage, have improved significantly in response to the no-tillage and crop-rotation practices. Additionally, microbial analyses indicated that microbial related properties, including concentrations of soil carbohydrates and glomalin-related soil proteins (GRSP), increased in the no-tillage plots (Justin *et al*., 2012). González *et al*., (2010), also found that the no-tillage soils contained greater proportions of bacteria relative to fungi, as well as different and more diverse microbial communities than those in continuous tillage plots. Although this study revealed that the treatments had altered the soil microbial communities, it provided limited information on the specific microbial and/or macrobial populations that were affected.

2.2.2 Conservation Agriculture versus Cropping Systems

Conservation Agriculture employs a variety of cropping systems and crop rotations. Crop rotation is a key principle of conservation agriculture as it improves the soil structure and fertility, besides playing a major role in control of weeds, pests and diseases and it has many other advantages according to Justin *et al*., (2012). Some crops have long, strong, deep roots. They can break up hardpans, and tap moisture and nutrients from deep in the soil. Others have many fine, shallow roots. They tap nutrients near the surface and bind the soil. They form many tiny holes so that air and water can get into the soil; cropping systems also aid in improving soil fertility (Watson, 2004; Zibilske *et al*., 2002; Justin *et al*., 2012). For instance, legumes such as groundnuts and beans fix nitrogen in the soil. When their green parts and roots rot, nitrogen can be released which can be used by other crops such as maize. The result is higher, more stable yields, without the need to apply expensive inorganic fertilizer. Conservation agriculture helps control weeds, pests and diseases. Planting the same crop season after season encourages certain weeds, insects and diseases. Planting different crops breaks the life cycle of pests and prevents them from multiplying thus enables prevention of the spread and manifestation of these diseases. Planting different crops results into production of different types of produce. For instance, growing a mix of maize grain, beans, vegetables and fodder means a more varied diet and more types of produce to sell. Producing several different crops reduces the risk of losses as a result of single crop's failure in case of a drought, or due to attack by diseases and pests.

Intercropping, strip cropping and relay cropping bring many of the same advantages as rotation. Strip cropping can involve among other examples, planting alternating strips of maize, soybean and finger millet. This involves planting broad strips of several crops in the field, with each strip covering a recommended 3–9 m wide plots in one season, and in the following year, the farmer can rotate crops by planting each strip with a different crop (Chivenge *et al*., 2007). Strip cropping has many of the advantages of intercropping: it produces a variety of crops, with the legumes improving the soil fertility, and rotation helps reduce pests and weed problems. The residues from one strip can be used as soil cover for neighbouring strips (Justin *et al*., 2012). At the same time, strip cropping avoids some of the disadvantages of intercropping: managing the single crop within the strip is easy, and competition between the crops is reduced. Relay cropping involves growing one crop, then planting another crop (usually a cover crop) in the same field before harvesting the first. This helps avoid competition between the main crop and the intercrop. Monocropping is the most practiced cropping system in Western Kenya and Eastern Uganda by small scale farmers, where the field is used to grow only one crop season after season (Nyende *et al*., 2007). This has several disadvantages: it is difficult to maintain cover on the soil; it encourages pests, diseases and weeds; and it can reduce the soil fertility and damage the soil structure. Crop rotation involves changing the type of crops grown in the field each season or each year or changing from crops to fallow (Justin *et al*., 2012). Sequential cropping is one that involves planting maize in the long rains, then beans during the short rains, while intercropping system refers to planting alternating rows of maize and beans, or growing a cover crop in between the cereal rows. This means growing two or more crops in the same field at the same time.

In some ways, crop rotation takes the place of ploughing the soil: it helps aerate the soil and recycles nutrients. As beneficial as it is, crop rotation can be detrimental in terms of crop production where one crop suppresses the other (Justin *et al*., 2012). Measures should be undertaken therefore to ensure the right crops are chosen for a rotation system.

2.2.3 Benefits of Conservation Agriculture

2.2.3.1 Healthy soil from crop rotations

Several research findings such as those of van Straaten, (2007), Fatondji *et al*., (2006) and Wambua, (2012) reveal that CA contributes to sustainable agricultural production and environmental conservation. Conservation agriculture is one of the most concrete and promising ways of implementing sustainable agriculture in practice as most of the crop production management practices introduced in agriculture in the middle of last century aimed at increasing crop yields lead to substantial degradation of soil quality and water resources (Durodoluwa *et al.*, 2010). CA methods minimize expenses and land preparation, leaving the soil rough, which reduces erosion and increases water intake (Pieri *et al.*, 2002). According to Wambua (2012), to date a larger number of these farmers intercrop maize and beans in the long rains, then plant the shrubs and let them grow in the short rainy season. These are then slashed towards the beginning of the long rains, and left to serve as surface mulch then maize and beans crops planted through the mulch (Wambua, 2012). Two years after start of the conservation agriculture project, one farmer harvested 1.9 tons of maize per hectare. Four years later, the same farmer was harvesting 3.2 t/ha. This is because the shrubs and mulch controled weeds and smoothered the most aggressive grasses like striga weed. Also, the soil became darker and softer, with more organic matter, an indicator of improved fertility (Wambua, 2012). Avoiding mechanical soil disturbance through CA implies growing crops without mechanical seedbed preparation or soil disturbance since the harvest of the previous crop.

Compared with conventional tillage, reduced or zero tillage has an advantage with respect to soil organic matter accumulation and hence improved soil quality (Ngwira *et al.*, 2012). Conventional tillage stimulates the heterotrophic microbiological activity through soil aeration, resulting in increased mineralization rate. Tillage has become the most common method to control weeds. However, mulching as practiced under CA is a more environmentally sound practice than tillage for weed control. Fatondji *et al.*, (2006) reports that the breakdown of soil structure increases and argues that upward and downward movements of soil fauna, such as earthworms, which are largely responsible for humus production through the ingestion of fresh residues are highly affected negatively. Reduced or zero tillage regulates heterotrophic microbiological activity because the pore atmosphere is richer in CO_2/O_2, and facilitates the activity of the humifiers (Fatondji *et al*., 2006). Moreover, tillage when the soil is too moist or too dry leads to compaction or pulverization of soil, but farmers may not have the option to wait for optimal conditions (Adjei-Nsiah *et al*., 2007). Severe, accelerated soil erosion and the high costs in terms of labour and energy associated with plough-based methods of seedbed preparation reflect into lower costs of production and hence greater benefits.

Mechanical soil disturbance also includes soil compaction through wheel impact of machinery, especially important in large-scale mechanized agriculture, e.g. plantations (sugar cane) or biannual crops (cotton) (Bationo *et al*., 2006). (Franzluebbers, 2010) demonstrated the almost total loss of soil porosity in the soil surface as a result of mechanized agriculture and trampling by animals. Recent research has demonstrated the devastating effects of compaction from wheel impact on the occurrence and survival of earthworms (Palm *et al*., 2001). In their study, Palm *et al*, (2001) showed that earthworm population was greater under controlled traffic than under wheeled traffic, demonstrating how tillage affects biological aspect of the soil. Several studies have shown that the benefits of CA are numerous including, reduced labor and farm-power requirements, improved soil fertility, crop yields increase over time compared to conventional farming, livelihood improvement, decreased carbon dioxide in the atmosphere and reduction of climate change (Palm *et al*., 2001; Wambua, 2012).

2.2.3.2 Effect of cultivation on soil quality degradation

Land degradation has become a serious problem in the medium- to high-potential land, especially where cultivation has extended to steep slopes without adequate soil conservation. This is evident in the steep slopes of Kapchorwa in Eastern Uganda. According to Apina *et al*., (2007) in a national conference on revitalizing the agricultural sector for economic growth, 'Kilimo Bora kwa Ustawi', 2005, senior government officials, development partners, NGO's and private businesses agreed on the need to transform the agricultural sector, calling for fundamental policy changes, for institutional, legal and regulatory reforms, and adoption of Conservation Agriculture farming practices.

2.3 Effect of Conservation Agriculture farming systems on soil chemical properties

According to the study by Sanchez (2002), the buildup of organic matter on the surface of No-Till (NT) relative to tilled soils has been attributed to less soil crop residue interaction as a result of limited soil mixing, lower rate of biological oxidation and less erosion. Enhanced soil aeration with tillage promotes rapid bacterial oxidation of soil organic matter (SOM), resulting in a net production of acid, while bases are either leached or removed in the harvest (González, 2012). Under No-Till, soil disturbance is limited to opening the narrow slot for seed and fertilizer placement (Giller, *et al*., 2009) while under conventional tillage (CT), soil is ploughed to a depth of 20 cm followed by disking to ensure an even seedbed. Plant nutrients are held in soil on the exchange sites provided by the clay fraction, organic matter and the clay-humus complex (Franzluebbers, 2010).

Other nutrients are held as components of organic matter. Soil surface accumulation of organic matter under No-Till has been reported to increase cation exchange capacity (CEC) compared to conventional tillage (Franzluebbers, 2010). A study by Haney *et al*., (2008) showed higher soil CEC under No-Till compared to conventional tillage in the 0-

5cm depth under maize/sorghum/wheat rotations in Nebraska, USA. With greater CEC, No-Till has the potential of conserving plant nutrients. In an earlier study, Hussaini *et al*., (2008) reported higher extractable calcium (Ca), manganese (Mn) and zinc (Zn) concentration compared to conventional tillage within the 0 - 2.5 cm depth after 4 years of No-Till on a silt loam soil in USA. No-tillage results in surface accumulation of carbon, nitrogen and phosphorus (P). Apart from contributing to increased P availability through release of inorganic P from decaying residues, organic molecules released during organic residue decomposition could increase nutrient availability through blockage of P sorption sites and complexation of soluble aluminium and iron (Ngwira *et al*., 2012; Nziguheba et al., 1998).

Organic matter increases high affinity binding sites for positively charged cations (K^+ and NH_4) that help retain and protect K^+ from leaching (Haney *et al*., 2008). Acidification of surface soil under No-Till is attributed to nitrification of ammonium ions and leaching of nitrates (Haney *et al*., 2008). Under such circumstances, liming the soil may become necessary for addition and retention of exchangeable bases for sustainable crop production in this system (Bouman *et al*., 1995). Enhanced soil acidification under No-Till relative to conventional tillage was earlier reported by Hobbs *et al*., (2008) whereby No-Till reduced soil pH by 9 % compared to CT in the 0-5 cm depth on a silt loam soil in USA. Acidification of the soil under No-Till may be contributed by release of organic acids upon decomposition of huge amounts of organic matter on the surface of the soil.

Nitrogen (N) mineralization- conversion of organic N into ammonium N (NH_4) - and immobilization- assimilation of NH_4 into amino acids by microorganisms- are important processes in N cycle (Watson, 2004; Castellanos *et al*., 2012). Microbial biomass and mineralizable organic reserves in no tillage may represent either a source or sink for plant available N depending on climate, cropping system, or temporal changes in soil environment. In their study, Kaumbutho and Kienzle (2007) demonstrated that crop residues with a C/N ratio greater than 25:1 will result in immobilization or reduced residue degradation.

2.4 Effect of Conservation Agriculture farming systems on soil biological properities

Hobbs *et al*. (2008) write that under CA the soil biota ‘‘take over the tillage function and soil nutrient balancing’’ and that ‘‘mechanical tillage disturbs this process’’. Whilst the role of soil macrofauna in mixing organic matter into the soil, and in creating macropores in soil is widely accepted (Lavelle, 2000), the role of soil biota in ‘‘nutrient balancing’’ is obscure. Soil organic matter (SOM) is the energy source for the multitude of soil macrofauna, microfauna and flora and as it decreases, so does species diversity and numbers, resulting in soil sterilization and jeopardizing ecosystems resilience. Both soil macro and micro-organisms are the driving force or catalysts behind the decomposition of the organic matter in the soil (Castellanos *et al*., 2012). Production practices of monoculture and conventional tillage deplete SOM and promote soil fauna and flora imbalances. Lavelle (2012) found four to five times' greater earthworm activity in no-tillage areas than in ploughed soils. Improvement in soil structure, enhanced moisture retention and high organic substrates could be linked to high biotic activity under No-Till compared to conventional tillage. Under temperate conditions, Shai and Norton, (2000) found that the population of earthworms doubled after practicing No-Till for 3 years. The population of arthropod was also six fold higher in No-Till compared to conventional tillage with soybean-wheat rotation.

Castellanos *et al*., (2012) report that Soil Microbial Biomass (SMB) is important in transformation of nutrients added into the soil and also constitutes a labile pool of Carbon (C),Nitrogen (N),Phosphorus (P) and other nutrients. Several authors have demonstrated that Soil Microbial Biomass (SMB) constitutes the active fraction of soil organic matter (SOM) whose rapid turnover is important as potential source of nutrient elements (Johan *et al*., 2002). Their study observed amounts of coarse plant debris and organic carbon to decrease in order of No-Till, chisel, Conventional Tillage,while microbial biomass followed a similar pattern in the 0- 5 cm soil depth in Brazil. They also observed that organic matter in the 0-5 cm depth under No-Till and chisel tillage was composed of more easily decomposable materials compared to Conventional Tillagem. In another study, higher microbial biomass C and N under No-Till relative to Conventional Tillage with cereal and legume rotations in Brazil were observed (Johan *et al*., 2002). The stimulatory effect of organic matter amendments on soil biomass was demonstrated on saline soils where compost application more than doubled microbial biomass C and P in Pakistan (González *et al*., 2010). The SMB is important in transformation of nutrients added into the soil and also constitutes a labile pool of C, N, P and other nutrients. The availability of these nutrients depends on their turnover rates through the MB (Justin *et al*., 2012).

Seasonal fluctuations and changes in soil conditions greatly influence microbial activities and the cycling of nutrients through these microbial agencies (Shai and Norton, 2000; Johan *et al*., 2002; Justin *et al*., 2012). Recognition of key roles played by microorganisms in the functioning of ecosystems has led to increased studies on MB and the nutrients held in the soil (González *et al*., 2010; Johan *et al*., 2002; Justin *et al*., 2012). Fundamental soil ecological processes such as decomposition, nutrient cycling, predator-preyrelationships, and organic matter formation and stabilization require knowledge and understanding of plant-microbial-faunal interactions and soil organic matter dynamics within the context of the spatial and temporal dynamics of the soil matrix (Beare *et al*., 1997). Soil biotic communities are placed into defined biological spheres according to their size, composition and function of the soil ecosystem.

A hierarchical model (Fig 1) of spatial distribution of plant roots, microbes and fauna in the soil matrix has been presented by Beare *et al*. (1997).

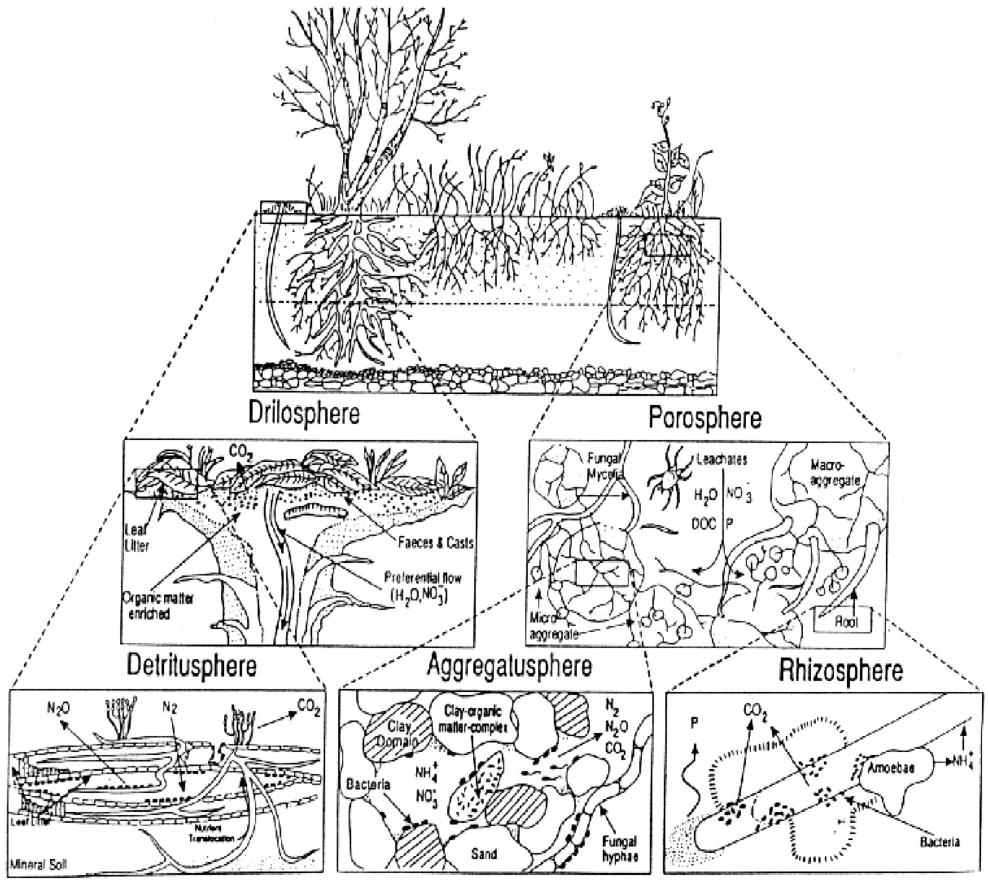


Fig. 2.1: A hierarchical view of the distribution of biotic communities in specific biological spheres in the soil ecosystem (Beare et al., 1997).

2.4.1 Effects of Conservation Agriculture on Soil Health

In CA, soil health is promoted via increasing cropping diversity through crop rotations, cover crops and agro-forestry practices (Beare *et al.*, 1997). Several authors have demonstrated that some crop rotations and zero tillage favor Bradyrhizobia populations, nodulation and thus N fixation and yield (Shai and Norton, 2000; Johan *et al.*, 2002; Justin *et al.*, 2012).

Cover crop improves soil quality by increasing soil organic matter which enhances soil structure, as well as water and nutrient holding and buffering capacity of soil (Beare *et* *al*., 1997). Legume cover crops have the ability to fix atmospheric nitrogen gas into biologically available mineral N (NH_4), as well as having a high "N-fertilizer equivalency" in that they provide a substantial quantity of nitrogen to the succeeding crop and hence reduce the need of chemical fertilizer required to meet the nutritional requirement of the crop (Beare *et al*., 1997). Non legume cover crops take up surplus N remaining from fertilization of the previous crop, preventing it from being lost through leaching, or gaseous denitrification or volatilization (Shai and Norton, 2000; Justin *et al*., 2012).

The nitrogen contained in the non-legume crop biomass is released for the next crop use once the crop residues are either incorporated into the soil as green manure or upon decomposition when left as soil surface cover (Justin *et al*., 2012). Vast cover crop root network helps by anchoring the soil in place and increases soil porosity, creating a suitable habitat for soil microfauna (Shai and Norton, 2000; Justin *et al*., 2012). Dense cover crop stands physically slow down the velocity of rainfall before it contacts the soil surface, preventing soil splashing and erosive surface run off. The different rooting depths of cover crops help in breaking compacted soil layers and mobilizing and recycling of nutrients (Justin *et al*., 2012).

2.4.2 The Impacts CA on Soil Structure, Ecosystem and Microbial ctivity

Microbial activity includes all biochemical reactions catalysed by micro-organisms in the soil (Justin *et al*., 2012). Potential microbial and macrobial activity can be measured in the laboratory with or without additional substrate, whereas actual microbial activity can only be measured in the field or on undisturbed soil samples from the field.

The main constraint for the assessment of the actual microbial activity is due to the difficulty in differentiating between biological and microbial activities (Shai and Norton, 2000; Justin *et al*., 2012; Beare *et al*., 1997). The accuracy of microbial activity assessments based on Carbon dioxide (CO_2) evolution are complicated by contribution from respiration from plant roots, other living vegetative organic materials and the CO_2 contribution from the rhizosphere (Shai and Norton, 2000).

Microbial activity related CO_2 evolution is attributed to the respiration of fungi and bacteria while soil animals especially the mesofauna (< 2 mm) may contribute to CO_2 evolution in soils. The fumigation-extraction method relies on measurements of the chemical constitiuents released from the dead microorganisms (Beare *et al*., 1997; Palm *et al*., 2001). The principle of fumigation-incubation technique is that a portion of the biomass is destroyed and made susceptible to mineralization by fumigation with chloroform vapour. The CO_2 released between the treated and the control sample is used to estimate the amount of degraded C.

Several authors demonstrate that crop residues are precursors of soil organic matter. Biological processes are triggered after the incorporation of soil organic matter in to the soil, with effects on the physical and chemical properties of the soil, which contribute to nutrient cycling efficiency and to maintain and/or increase organic matter contents in the soil (Palm *et al*., 2001).

The decomposition of organic residues, a key process for nutrient cycling, is essentially a biological process, with the participation of the soil's microflora and fauna (Shai and Norton, 2000; Palm *et al*., 2001). Among the animals that make up the soil's fauna, the edaphic macro-fauna comprises the largest invertebrates that dwell in the soil (body diameter >2 mm), including groups such as ants, coleopterans, spiders, worms, centipedes, termites, diplopods, etc (Lavelle and Spain, 2000). The edaphic macrofauna including earthworms play an essential role in the fragmentation and incorporation of organic matter into the soil, thus creating favorable conditions for the decomposing action of microorganisms. The activities of these organisms lead to the creation of biogenic structures (galleries, nests, chambers, and fecal pellets), which influence the aggregation, hydraulic properties, and fate of soil organic matter. In turn, these structures influence the composition, abundance, and diversity of other soil organisms.

In addition, Lavelle and Spain, (2000) show that these organisms contribute toward the vertical mobility of assimilable nutrients, thus being beneficial to the root systems of plants, and can also be the vectors of symbiotic microorganisms of plants, such as nitrogen-fixing organisms and mycorrhizal fungi; and that they can also digest pathogen microorganisms in a selective way. Therefore, the abundance and diversity of the soil's invertebrate macrofauna community are important factors for primary production sustainability in natural ecosystems and in agroecosystems derived from them (Shai and Norton, 2000; Lavelle and Spain, 2000).

According to Lavelle and Spain (2000), the soil's invertebrate macrofauna communities like eartworms respond to the various anthropic interventions made in the environment. These responses are especially related to plant cover modifications mostly enhanced by CA production systems, which directly determine the quantity and quality of the organic resource. Several studies have highlighted the hypothesis that the density and diversity of the edaphic macrofauna community, as well as the presence of a given group of organisms in a system, can be used as soil quality bioindicators (Justin *et al*., 2012; Beare *et al*., 1997; Paoletti 1999; Barros *et al*., 2003; Brown, 1995). Therefore, evaluating the conservation management of the soil's invertebrate macrofauna community is an important step in seeking the sustainability of tropical agroecosystems.

The static description of soil ecosystems involves measurements such as texture, quality and quantity of various inorganic and organic materials, porosity and pore size distribution, and aggregate size distribution. The distribution of biotic communities in specific biological spheres can also be used to measure the status of the soil ecosystem in various horizons of a soil pedon. The distribution of organic carbon in the soil profile is mainly controlled by earthworms in large areas of tropical soils (Justin *et al*., 2012).

Farming systems that increase soil organic matter content including CA cropping and tillage systems, reduce the probability of environmental contamination by herbicides. They improve soil fertility status and the result is better grain yield of e.g. maize per unit area.The relationship between CA and Soil structure heavily impacts on soil biological activities (Lavelle and Spain, 2000). Soil structure describes the arrangement of the solid parts of the soil and of the pore space located between them (Shai and Norton, 2000; Justin *et al*., 2012; Beare *et al*., 1997). Beare *et al*., (1997) consider soil to be of good structure, from an agricultural perspective, when it is of an aggregated and a low density/high porosity condition.

A well-structured soil will enable robust biological activity by readily accepting, storing, and transmitting water, gases, nutrients, and energy; and by providing adequate and suitable surfaces and space for life and biochemical exchanges (Lavelle and Spain, 2000; Beare *et al*., 1997) Soil structure has a major influence on water and air movement, biological activity, root growth and seedling emergence. The benefits of improving soil structure for the growth of plants, particularly in an agricultural setting, include reduced erosion due to greater soil aggregate strength and decreased overland flow, improved root penetration and access to soil moisture and nutrients, improved emergence of seedlings due to reduced crusting of the surface and, greater water infiltration, retention and availability due to improved porosity.

2.4.3 The Impacts of Conservation Agriculture on Biodiversity

Thus, CA brings about significant changes in the vegetation structure, cover and landscape. The change in vegetal cover during the conversion of forest and pastures to cropping affects plants, animals and micro-organisms (González *et al*., 2010). Through increasing specialization of certain plant species (food and fibre crops, pasture and fodder crops, and tree crops) and livestock species, some functions may be affected severely, e.g. nutrient cycling and biological control.

Shai and Norton (2000), argue that through appropriate crop rotations, crop-livestock interactions and the conservation of soil cover, a habitat can be created for a number of species that feed on pests. This will in turn attract more insects, birds and other animals. Thus, rotations and associations of crops and cover crops as well as hedgerows and field borders promote biodiversity and ecological functions (González *et al*., 2010; Justin et al., 2012)..

2.4.4 Effects of Conservation Agriculture on Earthworms population

Earthworms (Anelida, Clitellata, and Oligochaeta) are familiar to almost everyone. They are one of the most popular forms of live bait for fishing ; gardeners hold them in high esteem as nature's ploughmen (Johan *et al*., 2002); folklore and scientific accounts tell of their medicinal uses (Shai and Norton, 2000), and soil inhabiting vertebrates (moles, voles, etc.) store them as a source of food. The role of some species in organic matter decomposition and mineral cycling may be important (Johan *et al*., 2002; Justin et al., 2012)

, and a great deal has been written concerning earthworm farming (Shai and Norton, 2000) (Johan *et al*., 2002) (Justin et al., 2012). The main activities of earthworms that affect the soil involve the ingestion of soil and the mixing of the main soil ingredients of clay, lime, and humus; the production of castings of a fine crumb structure which are ejected on the soil surface by some species; the construction of burrows that enhance aeration, drainage, and root penetration; and the production of a tilth that makes suitable habitats for the smaller scale soil fauna and micro-organisms. The influence of earthworms on the translocation of soil material may be quite considerable. There have been abundance estimates as high as three million worms per acre and their role in soil fertility is very important. Studying forms that eject casts to the surface, (Shai and Norton, 2000) estimated that between 7.5 and 18 tons of soil per acre per year (about 3 cm per 10 years) can be moved, and the burial of many Roman ruins in Europe has been attributed to the activities of earthworms. Earthworms are omnivorous and can utilize many materials in the soil as food, including plant remains, and occasionally animal remains. Lumbricids can withstand considerable starvation and, in *L. terrestris* at least, a water loss of up to 70% of the body weight. Some species can withstand total immersion in water for many weeks, though normally they avoid waterlogged soils.

Earthworms are also an important component of the diet of many birds and mammals that prey on them. In Europe moles may store them as a source of food (Shai and Norton, 2000; Johan *et al*., 2002; Justin et al., 2012), usually after biting off four or five of the anterior segments to prevent the worms from escaping.

Daylight and ultraviolet light are injurious to earthworms unless the intensity is very low. Conservation agriculture enables moderation of soil temperature conditions. This is made possible through the numerous crop residue return and canopy from growing cover crops (Johan *et al*., 2002; Justin et al., 2012). Temperature relations have been reviewed by (Johan *et al*., 2002; González-Chávez, *et al*., 2010) quotes interesting accounts of lumbricids eathworms studied from the Arctic circle; *Eisenia foetida*, for example, has been found in snow, even though generally associated with warm habitats such as manure piles, and it remains vigorous below 5^0C. In Maine *L. terrestris* has been seen copulating while bathed with melt water, and other individuals crawled from under the ice and remained active. The Oligochaeta are defined as annelids with internal and external metmeric segmentation throughout the body, without parapodia, but possessing setae on all segments except the peristomium and periproct, with a true coelom and closed vascular system, generally hermaphroditic with gonads few in number in specific locations, with special ducts for discharge of genital products, with a clitellum that secretes cocoons in which ova and spermatozoa are deposited, and which are fertilized and develop wtihout a free larval stage (González-Chávez, *et al*., 2010)

2.4.5 Effects of tillage and cropping systems on crops performance

Maize is the most important staple food crop for smallholder farmers in western Kenya and eastern Uganda. However, yields on farmers’ fields of 1.5 t/ha (national average) are low compared to research yields of 9 t/ha (Okalebo *et al*., 2003). Low adoption and implementation of CA technologies (e.g cropping systems that involve crop rotation) has been observed, and hence farmers resolving to continuous maize-beans intercropping. This is among the major constraints to maize production in the region. Common bean (*Phaseolus vulgaris*) is a major source of plant proteins in the diets of many families in western Kenya and eastern Uganda. It is grown mainly for the grain. The plant residue is either fed to the livestock or burnt as chaff. *Mucuna pruriens* (commonly known as velvet bean or simply mucuna) is a vigorously growing and trailing harbacoeous legume species capable of fixing atmospheric nitrogen. This improves the soil's fertility and benefits crops grown after it especially in a crop rotation system (Nyambati and Sollenberger, 2003). It grows best on well-drained soils. The use of herbaceous legumes has also shown potential in combination with slash/mulch systems. Velvet bean (*Mucuna pruriens utilis*), for example, has produced around 30 T biomass/ha/yr, 90-100 kg N/ha/yr, and increased humus 0.5 in/yr (Holt-Giménez and Rubén, 1994). In addition to levodopa, it contains minor amounts of serotonin (5-HT), 5-HTP, nicotine, N,N-DMT (DMT), bufotenine, and 5-MeO-DMT (Manyam *et al*., 2004). The benefits of mucuna-maize rotation depend on among other factors, soil type, rainfall distribution, management of both crops, and the amount of mucuna dry matter produced and incorporated (Nyambati and Sollenberger, 2003). Improved maize performance after a legume crop is mainly attributed to N fixing ability of the legume as demonstrated by Sanchez, (2002) and Fatondji *et al*., (2006) who observed a 2 t/ha increase in grain yields in a maize-pea rotation compared with unfertilized continuous maize in South Africa. Nyambati *et al.*, (2002) working in Kitale and Kisii evaluated mucuna and lablab as relay intercrops for both soil fertility improvement and as supplementary feed for livestock when either whole or part of the biomass was incorporated, compared to cattle manure, inorganic N, and natural weed fallow. Defoliation of the top canopy of legumes was included as a treatment to mimic controlled grazing. On farmers' fields, undefoliated mucuna yielded more biomass (2.3 t/ha, mean of two seasons) than undefoliated lablab (0.8 t/ha). Nitrogen contribution ranged from 6 kg/ha in defoliated lablab to 65 kg/ha in undefoliated mucuna treatment. Hobbs *et al*., (2008), also reported yield increases of 13 and 29 % for 2-year soybeans-maize and 3-year maize-dry bean-wheat rotations, respectively. Cropping systems including crop rotations from a central pillar of CA, and many studies highlight the use of cereal–legume rotations. The most widely grown legumes in the farming systems of SSA are the grain legumes; groundnut (*Arachishypogaea L.*), cowpea (*Vignaunguiculata (L.) Walp)* and common bean (*Phaseolus vulgaris L.*). These crops have the advantage over other legumes in that they provide a direct economic yield for food or for sale. The rotational soil fertility benefits of grain legumes to subsequent crops can be substantial, giving double the yield of subsequent cereal crops in some cases (Giller *et al*., 2009). Thus a substantial rotational benefit, although not a perfect soil cover, can be achieved for the subsequent season. Comparisons of a range of soil fertility improving technologies, including grain legumes, green manures, fodder legumes and legume tree fallows have indicated smallholder farmers invariably choose grain legumes due to the immediate provision of food (Chikowo *et al*., 2004; Adjei-Nsiah *et al*., 2007; Kerr *et al*., 2007; Ojiem *et al*., 2007). These potential environmental and economic benefits of Conservation Agriculture remains to be demonstrated and quantified in the larger East Africa region according to

Giller *et al*., (2009), which comprises of counties Bungoma and Trans-Nzoia in Western Kenya, as well as Tororo and Kapchorwa districts in Eastern Uganda, hence the decision to carry out this study.

2.4.6 Economic importance of CA

Conservation agriculture (CA) aims to make better use of agricultural resources through the integrated management of available soil, water and biological resources, combined with limited external inputs. It contributes to environmental conservation and to sustainable agricultural production by maintaining a permanent or semi-permanent organic soil cover. Conservation agriculture (CA) improves resource use through an integrated management approach. It contributes to sustainable production and its advantages include lower inputs, stable yields and improved soil nutrient exchange.

Adoption of CA at the farm level is associated with lower labour and farmpower inputs, more stable yields and improved soil nutrient exchange capacity. Crop production profitability under CA tends to increase over time relative to conventional agriculture. Other benefits attributed to CA at the watershed level relate to more regular surface hydrology and reduced sediment loads in surface water. At the global level, CA sequesters carbon, thereby decreasing carbon dioxide in the atmosphere and helping to dampen climate change. In addition to financial factors, CA-adoption conserves soil and terrestrial biodiversity.

Economic evaluation of a technology e.g. CA, aids in assessing performance under farmers' environmental, economic and managerial conditions with the aim of either implementing or revising the proposed technology and make it more consistent with farmers' conditions with the aim of facilitating adoption (Kipkoech *et al*., 2002; Macharia *et al*., 2005; Zeddies *et al*., 2001). Cost and return analysis are the most commonly used methods for economic analysis of treatment combinations, which are used to determine the impact of a new technology (Macharia *et al*., 2005). Parameters used in economic analysis include gross margin analysis (GM), returns to land, labour, capital and value of cost ratios among others.

CHAPTER THREE

MATERIALS AND METHODS

A field experiment was conducted from February, 2011 to February, 2013 in Bungoma and Trans-Nzoia Counties, in Western Kenya region (Fig 3.1), and in Kapchorwa and Tororo districts in Eastern Uganda (Fig 3.2).

3.1 Study Sites

3.1.1 Bungoma and Trans-Nzoia

Bungoma has two rainy seasons distribution: the long rains- March to June, and short rains from September to November. Bungoma County is the county in the old Western Province of Kenya with a population of 876,491 and an area of 2,069 km².

Table 3.1: Location, climatic and soil characteristics of the Western Kenya study sites for the initial soil characteristics determined before the experiment were laid.

Western Kenya		
Parameter	**Site 1; Bungoma**	**Site 2; Trans-Nzoia**
Latitude	0^{0} 34' 0" N	1^{0} 03' 42" N
Longitude	34^{0} 34' 0" E	35^{0} 02' 25" E
Altitude (m.a.s.l)	1200-1800	2000-2400
Total annual rainfall (mm)	1500mm to 1800	1700mm to 2000
Daily temperatures (^{0}C)	23	25
Soil type	Ferralsol	Ferralsol
% Sand: Silt : Clay ratio	61 : 7 : 32	62 : 10 : 28
Soil Textural Class	Sandy Clay Loam	Sandy Clay Loam
pH (1:2.5H_2O)	4.54	5.01
Av. P (mg P kg^{-1} of soil)	6.46	8.45
Soil Organic Carbon (%)	1.48	1.32
Total Nitrogen (%)	0.168	0.131
Magnesium (cmol kg^{-1} of soil)	0.195	0.263
Potassium (cmol kg^{-1} of soil)	0.160	0.152

The economy of Bungoma County is mainly agricultural, centering on the sugar cane and maize industries.

Trans-Nzoia has unimodal rainfall pattern from March to August. The site is located in the Great Rift Valley on coordinates of 0°49'60" N and 35°0'0" E. It is located at an elevation of 1,828 meters above sea level. Its urban population was estimated at 220,000 in 2007. The main cash crops grown in the area are sunflower, tea, coffee, Pyrethrum, seed beans and seed maize.

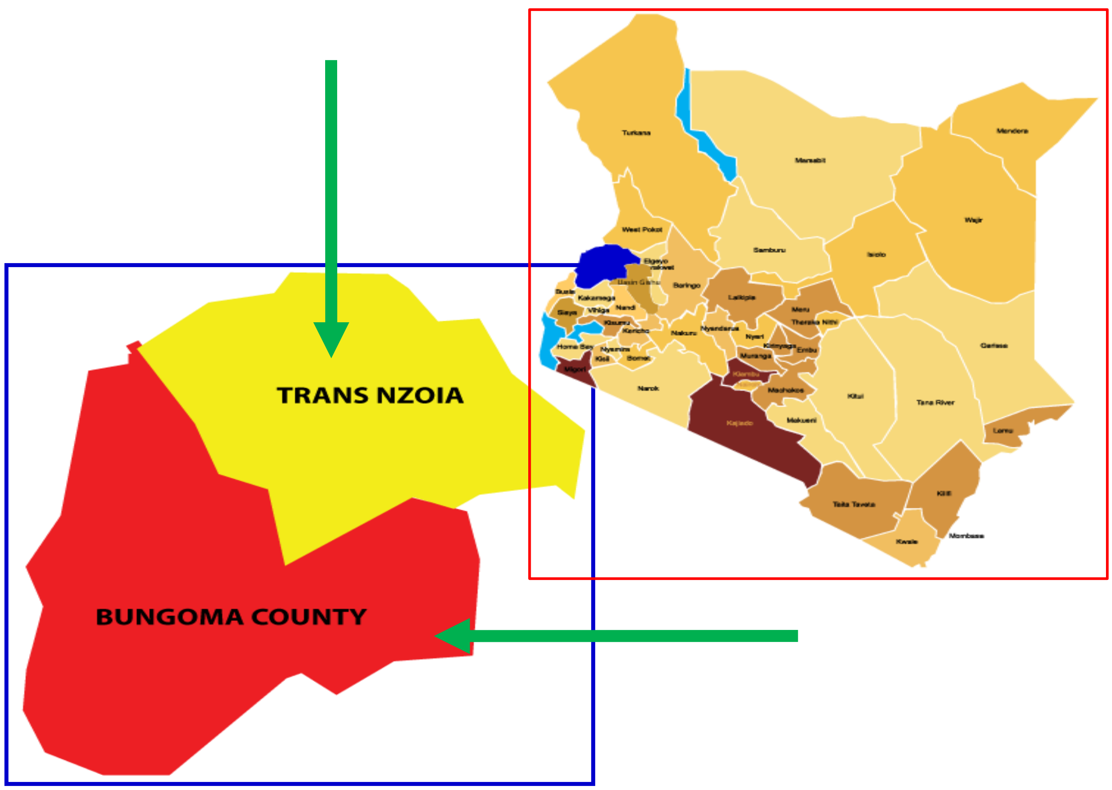


Fig 3.1: Map of Kenya showing Trans-Nzoia and Bungoma Counties

Bungoma and Trans-Nzoia sites are both characterized by weathered and well drained slightly acidic red soils (ferralic Ferralsols) (Table 3.1).

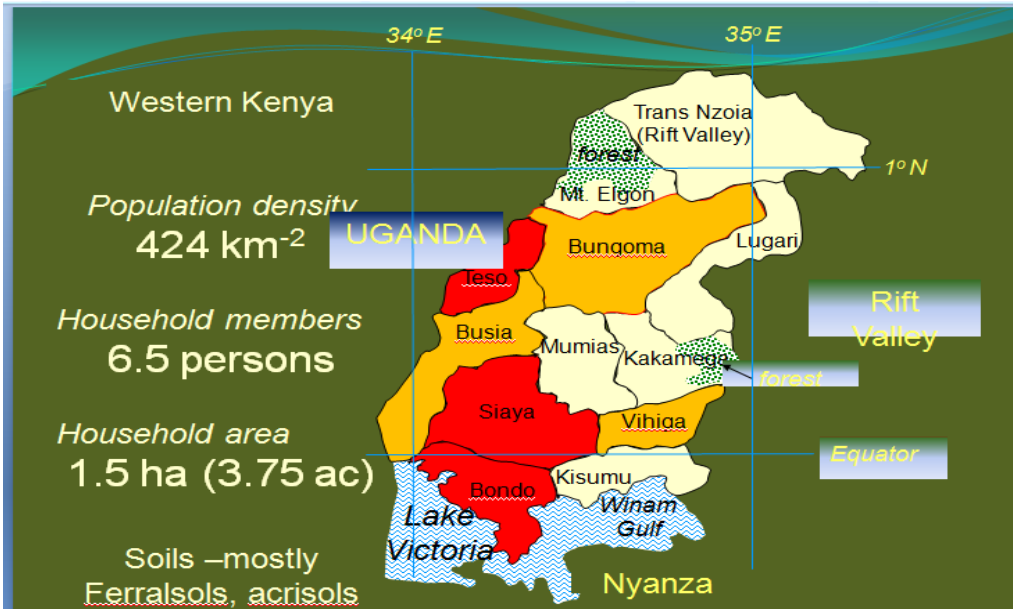


Fig 3.2: Map of Western Kenya showing coordinates Trans-Nzoia and Bungoma sites (Source: Ahmed, 2012)

Daily rainfall data in Bungoma and Trans-Nzoia was recorded using rain gauges installed on the entire four experimental areas (Fig 5). These were located in Mabanga farmers training enter in Bungoma, and Manor house Trans-Nzoia in western Kenya.

3.1.2 Tororo and Kapchorwa

In eastern Uganda, the experiment was laid at Datic Agricultural Training centre in Tororo and Keere Agricultural station in Kapchorwa (Table 3.2). The sites are characterized by acidic sandy clay loam ferralsosls (Table 3.2). Tororo has two cropping seasons while Kapchorwa has only one long rain cropping season. Long rain season runs from March to July, while short rains come between August and December. Cropping season runs from March to August in Kapchorwa.

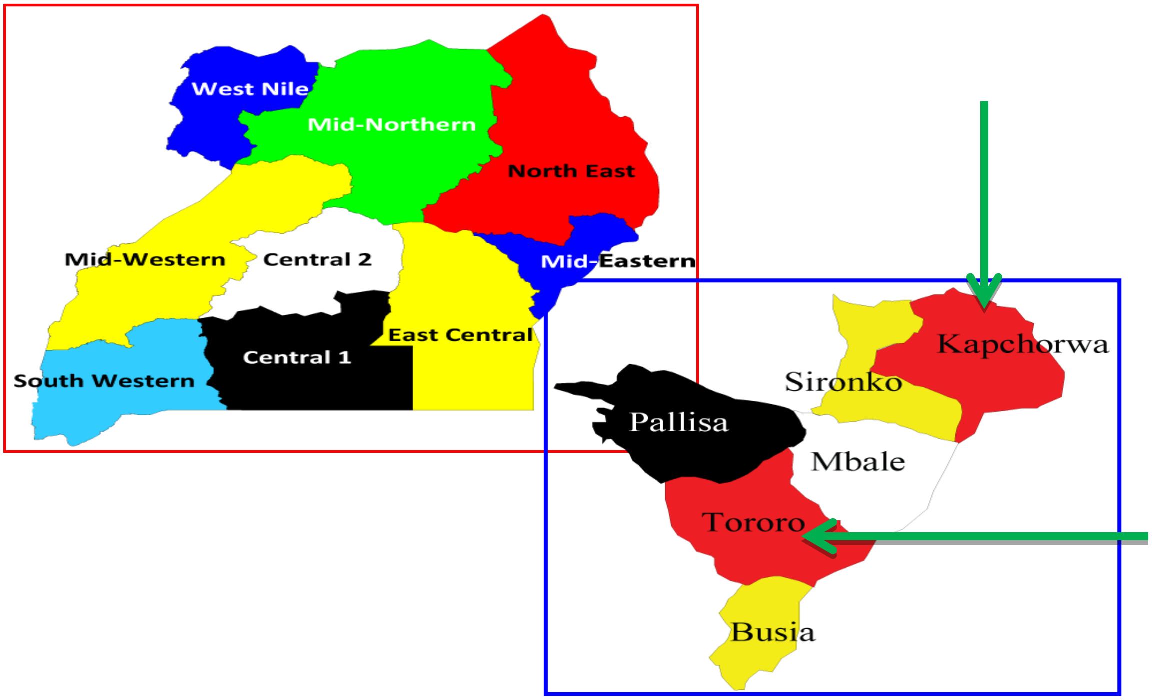


Fig 3.3: Map of Uganda showing Tororo and Kapchorwa Districts (Source: Ahmed, 2012)

Tororo district is found in eastern Uganda bordering Kenya to the East. The 2002 national census estimated the population of Tororo District at 398,601 with an annual population growth rate of 2.7%. Most of the district is flat, lying at an altitude of 1,097 to 1,219 m above sea level (m.a.s.l) and a temperature range of 15.7° to 30.6° C. The annual rainfall is more than 1,200 mm per year. The district is well known for its highly unproductive sandy ferralsols (Miiro, R. et al., 2010), with low Carbon (C), Nitrogen (N) and phosphorus (P).

The soils in Kapchorwa are derived mainly from volcanic parent material and are typically red clay loam, well drained, highly leached, often acid, but of good nutrient supply. The zone extends south to the lower steps, or terraces of Mt Elgon where the clay loam soils are more often acidic.

Table 3.2.: Location, climatic and soil characteristics of the Eastern Uganda study sites for the initial soil characteristics determined before the experiment were laid.

Eastern Uganda		
Parameter	**Site 3; Tororo**	**Site 4; Kapchorwa**
Latitude	0^0 41' 06" N	01^0 24' 00" N
Longitude	34^0 11' 01" E	34^0 27' 00" E
Altitude (m.a.s.l)	1170-1500	2345- 2700
Total annual rainfall (mm)	1300	1200
Daily temperatures range (^{0}C)	30	27
Soil type (USDA classification)	Haplic Ferralsol	Volcanic Ferralsols
Sand : Silt : Clay ratio	66 : 12 : 22	64 : 28 : 8
Soil Textural Class	Sandy clay loam	Sandy clay loam
pH (1:2.5H2O)	4.01	4.41
Av. P (mg P kg^{-1} of soil)	6.05	6.44
Soil Organic Carbon (%)	1.43	1.10
Total Nitrogen (%)	0.139	0.113
Magnesium (cmol kg^{-1} of soil)	0.107	0.347
Potassium (cmol kg^{-1} of soil)	0.121	0.134

Soil erodibility is high while rainfall is moderate. Loss of land productivity is most severe on steep slopes around Mt Elgon in the Mt Elgon High Farmlands Agro Ecological Zone (AEZ). The soils there are not prone to erosion but because of cultivation on steep slopes and lack of soil conservation measures, soil erosion is rampant.

3.2 Field Procedures

3.2.1 Experimental Design and Layout

The experiment was laid down in a split-split plot arrangement. The main plots were the three main tillage systems (no-till, minimum tillage and conventional tillage termed farmer practice-FP).

Table 3.3: The experimental treatments arrangement in a split-split plot for one block.

Main plot; Tillage systems	Sub plot; Nitrogen application	Sub-sub plot; Cropping systems	Description of treatmnts
Minimum Till (NT)	N0(30 kg N/ha)	CP	Continuous maize-beans intercropping
		ROT 1	Maize-beans intercropping, with mucuna relay
		ROT 2	Maize, beans and mucuna grown in monocrop strips
	N1(60kg N/ha)	CP	Continuous maize-beans intercropping
		ROT 1	Maize-beans intercropping, with mucuna relay
		ROT 2	Maize, beans and mucuna grown in monocrop strips
No-Till (NT)	N0(30 kg N/ha)	CP	Continuous maize-beans intercropping
		ROT 1	Maize-beans intercropping, with mucuna relay
		ROT 2	Maize, beans and mucuna grown in monocrop strips
	N1(60kg N/ha)	CP	Continuous maize-beans intercropping
		ROT 1	Maize-beans intercropping, with mucuna relay
		ROT 2	Maize, beans and mucuna grown in monocrop strips
Conventional Tillage (CT)	N0(30 kg N/ha)	CP	Continuous maize-beans intercropping
		ROT 1	Maize-beans intercropping, with mucuna relay
		ROT 2	Maize, beans and mucuna grown in monocrop strips
	N1(60kg N/ha)	CP	Continuous maize-beans intercropping
		ROT 1	Maize-beans intercropping, with mucuna relay
		ROT 2	Maize, beans and mucuna grown in monocrop strips

Tillage Systems: NT-No Till, MT-Minimum Tillage and FP-Farmers Practice. Cropping Systems; ROT 1-Rotation 1, ROT 2-Rotation 2 and CP- Current Practice.

The sub-sub plots were represented by nitrogen application at vegetative stage that is +N and –N. The sub-sub-plots representing three cropping systems (strip cropping-ROT 2, maize-beans intercropping or Current Practice (CP), and maize-beans intercrop with *mucuna* relay-ROT 1).

Each study areas had four experimental blocks measuring 32m by 32m. Each block had 9 experimental plots measuring 10 m by 10 m. The main plot, sub-plot and sub sub-plots were randomly distributed in these plots in a Randomized Complete Block Design (RCBD) (Table 3.3).

3.2.2 Experimental Treatments

The experiment involved three tillage and three cropping systems. Tillage systems studied were traditional/local farmer practices (Current Practice-CP), No-Till (NT) but using herbicides to control weeds, and Minimum Till (MT) by use of shallow tillage to control weeds. Strip cropping and relay cropping systems that utilize cover crops and, traditional/local cropping systems were studied.

Table 3.4: Experimental treatments randomized for one block

		10-m width, 30 m total			
Main plots	**Sub plot**	**Sub-sub plots**			
		Current Practices (CP)	Rotation 1	Rotation 2	10-m width, 30 m total
Farmer Tillage Practice (FP/CT)	**+N fertilizer (60kgN/ha)**	**Maize-bean intercrop**	**Maize-bean mucuna relay**	**Maize 4 rows** **Beans 8 rows** **Mucuna 6 rows**	
	-N fertilizer (30 kg N/ha)	**Maize-bean intercrop**	**Maize-bean mucuna relay**	**Maize 4 rows** **Beans 8 rows** **Mucuna 6 rows**	
No-till (NT)	**+N fertilizer (60kgN/ha)**	**Maize-bean intercrop**	**Maize-bean mucuna relay relay**	**Maize 4 rows** **Beans 8 rows** **Mucuna 6 rows**	
	-N fertilizer (30 kg N/ha)	**Maize-bean intercrop**	**Maize-bean mucuna relay**	**Maize 4 rows** **Beans 8 rows** **Mucuna 6 rows**	
Minimum Till (MT)	**+N fertilizer (60kgN/ha)**	**Maize-bean intercrop**	**Maize-bean mucuna relay**	**Maize 4 rows** **Beans 8 rows** **Mucuna 6 rows**	
	-N fertilizer (30 kg N/ha)	**Maize-bean intercrop**	**Maize-bean mucuna relay**	**Maize 4 rows** **Beans 8 rows** **Mucuna 6 rows**	

The order of the three tillage practice main plots was randomized within each block, with each tillage practice occurring across the whole block. However, cropping system and N fertilizer sub-sub plots were completely randomized within each tillage practice main plot. The treatments were then randomly distributed in the four blocks (Table 3.4).These treatments were then randomized in four blocks in every site.

Table 3.5: Experimental layout showing treatments randomized for four blocks in one site

BLOCK1			**BLOCK2**		
MTN1CP	MTN0R1	MTN1R2	CTN0CP	CTN1R1	CTN1R2
MTN0CP	MTN1R1	MTN0R2	CTN1CP	CTN0R1	CTN0R2
NTN0R1	NTN1R2	NTN0CP	MTN1R2	MTN1CP	MTN0R1
NTN1R1	NTN0R2	NTN1CP	MTN0R2	MTN0CP	MTN1R1
CTN1R2	CTN0CP	CTN1R1	NTN1R2	NTN0CP	NTN0R1
CTN0R2	CTN1CP	CTN0R1	NTN0R2	NTN1CP	NTN1R1
BLOCK3			**BLOCK4**		
NTN0CP	NTN0R1	NTN1R2	MTN1CP	MTN0R1	MTN1R2
NTN1CP	NTN1R1	NTN0R2	MTN0CP	MTN1R1	MTN0R2
CTN1R1	CTN0CP	CTN1R2	NTN0R1	NTN1R2	NTN0CP
CTN0R1	CTN1CP	CTN0R2	NTN1R1	NTN0R2	NTN1CP
MTN1R2	MTN1CP	MTN0R1	CTN1R2	CTN0CP	CTN1R1
MTN0R2	MTN0CP	MTN1R1	CTN0R2	CTN1CP	CTN0R1

3.2.3 Initial land preparation and planting

Land preparation was done by hand digging using a hoe for conventional/current tillage practice according to the local practice of that particular site as recommended by advisory group. For minimum tillage, limited manipulation of soil cover by scratching to reduce or eliminate weeds was done. Zero or No-till was done by use of eco-friendly chemicals before planting. Seeding in the minimum and zero tillage was done using a sharp stick. Maize (*Zea mays*) and beans (*Phaseolus vulgaris*) were the test crops while Mucuna (*Mucuna pruriens*) was used as a cover crop with the aim to build up organic. The current cropping practice plus two alternative cropping systems that incorporate soil-building cover crops were studied. The current cropping system termed as Current Practice (CP) was Maize-Beans intercropping all seasons. One cropping system referred to as Rotation 1 (ROT 1) was built from a current cropping system and it involved intercropping Maize-Beans with Mucuna cover crop relay after bean harvest. Alternative cropping system Rotation 2 (ROT 2) involved strip cropping having six rows each of maize, beans and an annual cover crop *Mucuna pruriens*. Nitrogen fertilizer application served as a split-split, with only one side of the half of the experimental plot (5m by 10m area) receiving the nitrogen fertilizer.

Certified hybrid maize seed H502 and H505 were used in Bungoma and Tororo sites respectively, while H6210 was planted in both Kitale and Kapchorwa. Certified bean seed Rosecoco were bought from Kenya Seed Company and used for planting. Mucuna black seed was acquired from Appropriate Technology (AT) Uganda.

Normal land management practices e.g. weeding, pest control was carried out on the experimental plots at appropriate stages of plant growth in the respective treatments. Bullock pesticide was used to control weeds in the no till/zero tillage (NT/ZT) system, while scratching using a hoe was done to control weeds in the minimum tillage (MT) practice plots. Harvesting was done at physiological maturity for maize and pod yellowing for beans, and yield data obtained. Maize and beans from each experimental plot were dried and shelled, representative samples air dried for laboratory analysis.

3.2.4 Treatment application

Application of phosphorus and starter nitrogen (30kg N/ha) was done at planting using Diammonium Phosphate (DAP) fertilizer to each plot. Maize monocrop received 26kg P/Ha and 30kg N/Ha (FURP, 1994). At planting, beans monocrop received 40kg P/Ha and 30kg N/Ha (FURP, 1994). Additional 30kg N/Ha was applied as a split-plot treatment to +N plots at vegetative stage of the crop. This was applied on one side of the plot (+N) to make a 60kg N/ha. An area of 5 m by 10 m received the N while the other 5 m by 10 m did not. No fertilizer was added to *Mucuna pruriens* crop during planting as the crop was only meant for soil biomass build up studies.

Fertilizers were applied at the time of sowing by banding close to the seed row in order to enhance contact between the fertilizer and the roots early in the growing season for enhanced nutrient uptake by plants. Crop residue from previous cropping season was incorporated back in their respective plots as a means to recycle nutrients.

3.2.5 Crop harvesting procedures

A simple random sampling method was adopted. Sample size of Ten (10) selected plants for both maize and beans were collected for the yield data for each of the treatments in a marked central area in the experimental plots. To eliminate the "edge effects" a central area of 8 m by 7 m was used to obtain the representative sample of ten plants (both maize and beans). However for Rotation 2 there was minus N (-N) and plus N(+N) split put across the rows, only one border row and sampling the central plants (both beans and maize) was done, while for mucuna a 1m x 1m quadrat area was harvested for biomass measurement done in two spots in each experimental unit. The rest of mucuna crop in rotation 2, rotation 1 and in current practice plots was incorporated back in the soil for both organic matter content build up and nutrient recycling. The plant population was taken for the central area marked for collecting biometric observations both for maize and beans in all rotations. For yield data the several yield parameters were measured. For maize:- total plant population, number of cobs, cobs weight (kg), weight of 10 cobs, total maize stover yield (kg) in the harvest area; Beans:- weight of plants harvested in a plot, weight of 15 plants randomly sampled from the total crop from the harvest area, Number of pods/plant for the 15 plants, fresh and dry weight of the 15 plants, dry weight of the grains from the 15 plants, 100 grains test weight, grain yield; while for Mucuna:- biomass production per unit area (2 sites are taken using a 1 m2 quadrat, but only for rotation 2).

The yield component method is based on the premise that one can estimate grain yield from estimates of the yield components that constitute grain yield. These yield components include number of ears per area, number of kernel rows per ear, number of kernels per row, and weight per kernel. Final weight per kernel is measured at harvest moisture and at oven drying for realistic results. The above data were used in yield estimation using equation I and II:

$$\text{Yield/plot} = \frac{\text{total fresh weight} \times \text{Sample dry weight}}{\text{Sample fresh weight}} \quad \ldots\ldots \text{I}$$

$$\text{Yield (kg/ha)} = \frac{\text{Yield/plot} \times 10{,}000\,m^2}{\text{Effective area } (m^2)} \quad \ldots\ldots \text{II}$$

3.2.6 Soil sampling procedures

Initial soil sampling was done prior to the onset of the experiment across all the four sites, at the following depths;

- 0-10 cm
- 10-30cm

- 30-60cm
- 60-100cm

A 'W' shape was used in every plot to mark four sampling spots, each randomly picked on the four arms of the 'W'. Soil sampling of the soil down the profile were used for better assessment of nutrient status down the profile. Soil samples were collected in to well labeled plastic polythene bags. Sampling errors were reduced by making composite sample (using buckets) at each depth in every plot. Soil samples for microbial, mineral nitrogen and moisture content analysis were transported to the laboratory under reduced temperature conditions in a cooler box and analyzed upon arrival in the laboratory. Soil samples for chemical analysis were air dried and prepared by sieving through a 2mm sieve to remove large clods and organic matter, after which 250 g was obtained for laboratory analysis. Soil chemical analysis including percent organic carbon, soil pH, particle size analysis, total nitrogen and phosphorus, mineral nitrogen and available phosphorus (Olsen Method) were analyzed and determined according to the procedures outlined in Okalebo *et al*., (2002). Soil macrofauna populations (Plate 1) were analyzed from a representative sample of 50 g freshly sampled soil sample using the standard method of the Tropical Soil Biology and Fertility Programme (TSBF) Handbook of methods (Anderson and Ingram, 1993), in which the various groups representing the soil macrofauna are hand-sorted. The sample was a representative sample of a 5 m^2 experimental plot area.

• Beetles 	Earthworms 
• Fly larvae 	• Snails & slugs 
• Centipedes	• Ants
• Termites	Spiders

Plate 1: Representatives groupings of soil macrofauna (Author, 2015)

Soil macrobial population analyses were determined in every cropping season at the vegetative stage. Only the 0-20cm depth was sampled.

3.3 Laboratory methods

3.3.1 Soil analysis

Soil Samples for microbial analysis were transported to the laboratory under 4^0C temperature conditions using a cooler box containing ice and analyzed upon arrival in the laboratory (Anderson and Ingram, 1993; Swift and Bignell, 2001). Soil samples for chemical analysis were air dried and prepared by sieving through 2 mm and 60 mesh sieves. For analysis of soil pH, available phosphorus and soil particle size analysis a 2mm sieve was used, while a <2 mm sieve was used to prepare soils for analysis of organic carbon, total phosphorus and total nitrogen (Okalebo *et al.*, 2002).

3.3.1.1 Soil particle size analysis (Hydrometer method)

This was done in order to estimate the percentage sand, silt and clay contents of the soil by weight of air-dry and organic matter-free soil as described as outlined by Okalebo et al., (2002). The hydrometer method of particle size analysis of a soil estimates the percentage sand, silt and clay contents of the soil and is often reported as percentage by weight of oven-dry and organic matter-free soil. A soil textural category is then assigned to the sample based on the proportions of different particle sizes (Okalebo *et al.*, 2002).

3.3.1.2 Soil pH

Soil pH analysis was done according to the procedure involving use of a ratio 2.5:1 soil water suspension (Okalebo *et al.*, 2002).

3.3.1.3 Total Nitrogen in soil

The content of total nitrogen was measured by the Kjeldahl oxidation method in a digest obtained by treating soil samples with hydrogen peroxide plus sulphuric acid (H_2SO_4), selenium and salicylic acid, and heated at temperatures of 330^0C (Okalebo *et al.*, 2002). The content of total nitrogen and phosphorus is measured in the resulting digest. The principle takes into account the possible loss of nitrates by coupling them with salicylic acid in an acid media to form 3-nitrosalicylic and or 4-nitrosalicylic. The analysis of total nutrients requires complete oxidation of organic matterand was done using colorimetric method (using Reagents N1 and N2) (Okalebo *et al.*, 2002).

3.3.1.4 Extractable soil Phosphorus (P)

The soil was extracted using 0.5 M solution of sodium bicarbonate and available P concentration (Okalebo et al., 2002). P concentration in the solution was measured at a wavelength of 880 nm using a spectrophotometer (Okalebo et al., 2002).

3.3.1.5 Soil Organic Carbon

Organic carbon was determined by the sulphuric acid and aqueous potassium dichromate ($K_2Cr_2O_7$) mixture on a 0.3 g (sample weight) of ground (>2 mm sieve) soil in a block digester tube as outlined by Okalebo et al., (2002).

3.3.1.7 Soil mineral nitrogen (ammonium and nitrates)

The majority of soil nitrogen resides in organic matter, but this N is continuously being mineralized into ammonium (NH_4^+) and nitrates (NO_3^-) ions, the forms assimilated by plants (Okalebo et al., 2002). This reflects the need to measure the forms and subsequent movement patterns of these ions in soils during cropping in order to make informed recommendations on the need and rates of N-bearing fertilizers and organic inputs. NH_4-H and NO_3-N estimates in soil were extracted in fresh soils using 0.5 M K_2SO_4 followed by colorimetric estimates (by use of reagents N1 and N2) using a spectrophotometer at wavelength of 655nm (Okalebo et al., 2002).

3.3.1.7 Soil Earthworm population count

Soil macrofauna were analyzed from a 50g freshly sampled soil sample using a modified standard method of the Tropical Soil Biology and Fertility Programme (TSBF) Handbook of methods (Anderson and Ingram, 1993; Swift and Bignell, 2001). Sampling was done on a 0-20 cm depth, and then brought to the laboratory for hand sorting in polythene bags in a cooler box at 4^0C (Anderson and Ingram, 1993; Swift and Bignell, 2001). Procedures followed a modified Anderson and Ingram (1993) protocol, making use of pitfall traps together with the picking of soil samples at selected points within the area of interest. The number of earthworms were collected and then recorded on the basis of population count per 5 m^2 (Anderson and Ingram, 1993).

3.4 Data collection and analysis

3.4.1 Data collection

Data was collected on maize and beans yield, as well as earthworm’s population counts. Soils data was collected on soil pH, available P, organic carbon, total Nand mineral N (NH_4-H and NO_3-N estimates). Production and input data was collected throughout each season in each site to enable economic analysis.

3.4.2 Data analysis

Data obtained from the experimental variables was analyzed using General Linear Model (GLM) and subjected to analysis of variance (ANOVA) using GENSTAT 12, 2012 statistical package. Means were separated by Duncan New Multiple Range Tests (DNMRT) at 5% level of significance (Gomez and Gomez, 1984). Relationships between crop yields and the treatments were also drawn. Changes in the soil chemical properties and earthworm population counts over time under different tillage, cropping systems and nitrogen application were also determined.

3.4.2.1 The experiment model

The experiment model used for the split-split plot arrangement in an RCBD was as follows;

$$Yijkl = \mu + P\acute{\imath} + Tj + \alpha\acute{\imath}j + Nk + TNjk + \beta\acute{\imath}jk + Cl + CNkl + CTjl + CNTikl + \lambda ijkl$$

Where; Yijkl – Observation

Pí – main plot effect

μ – Overal mean of all observations

Tj – Tillage effect

αíj- Main plot error

Nk – Effect of nitrogen application

TNjk – Tillage * Nitrogen application

βíjk – Split plot error

Cl - Cropping systems effect

CNkl - Cropping systems* Nitrogen application

CTjl - Cropping systems * Tillage

CNTikl - Tillage * Nitrogen application * Cropping systems

λijkl – Split split Plot Error

Table 3.6: Skeleton ANOVA Table for all four sites and treatments

Source of Variation	**df**
Replicate	3
Tillage	2
Error (a)	6
Nitrogen Application	1
Tillage * Nitrogen Application	2
Error (b)	9
Cropping System	2
Tillage * Cropping Systems	4
Cropping Systems * Nitrogen Application	2
Tillage*Cropping Systems*Nitrogen Application	4
Error	36
Total	71

3.4.3 Economic analysis

Several economic indicators were estimated and used to compare the benefits of producing the intercrops under the different tillage systems, cropping systems and fertilizer application at each site. Input data consisted of: labour requirements for land preparation, planting, weeding, application of herbicides and pesticides, harvesting and shelling of maize and bean grains (Chikowo *et al*., 2004; CIMMYT, 1988; Low, 1989). The labour was valued using the prevailing wage rate for each site and calculated for each activity per plot and then converted to a unit hectare basis. Prices of inputs such as maize, mucuna and beans seeds, DAP, CAN, pasagran herbicide and stalkborer dust were obtained from nearby markets locally. Opportunity cost of capital was estimated as 10% per person, which is the commonly used rate for studies involving resource-poor smallholder farmers (Jama et al., 1998).

The production cost was the product of the prevailing prices of maize/beans/mucuna in that particular season. The most economically acceptable treatments were determined by partial budgeting analysis to estimate the gross value of grain by using the adjusted yield at the market value of grain inputs during the cropping year. Here, only costs that vary from the control are used referred to as total costs that vary (TCV).

Table 3.7: Values used for costs and benefits analysis (Ksh) during the years 2011 and 2012.

Year	Year 2011		Year 2012	
Parameters	Bungoma & Trans-zoia	Tororo & Kapchorwa	Bungoma & Trans-Nzoia	Tororo and Kapchorwa
DAP Kg/ha applied	132.29	128.22	130.29	130.00
CAN Kg/ha	143.21	141.78	143.21	141.78
Price DAP/kg	126.18	122.21	126.18	122.21
Price CAN/ha	89.15	76.78	89.15	76.78
Transporting 50 kg of fertilizer to the experimental farm	23.00	24.00	23.00	24.00
Cost of sacks for grain storage	25.00	21.77	25.00	22.00
Labour costs				
Planting and application of DAP or CAN fertilizer/ha	150.00	100.00	160.00	120.00
Cost of harvesting 1 bag of maize cobs or beans	30.00	20.00	30.00	20.00
Cost of shelling one bag of maize or beans grains	45.00	35.00	45.00	38.00
Price of maize grain/ kg	40.00	30.00	45.00	30.00
Opportunity cost of Capital (%)	10.00	10.00	10.00	10.00

Yield data were adjusted downward by 10% since research has found out that farmers using the same technologies would obtain 10% yield lower than those obtained by researchers (Kipkoech *et al*., 2002; Zeddies *et al*., 2001). The discounted rate of capital was determined at the rate of 10 and 20% per season and year, respectively and was applied to cash costs only. The discounted rate reflects the farmer's preference to receive benefits as early as possible and to postpone costs. All costs and benefits were converted to monetary values in Kenya Shilling (Ksh) and reported on a per hectare basis (CIMMYT, 1988; Low, 1989).

The net accrued net financial benefits (NFBs) and TCV were then compared across the treatments dominance analysis the formula:

$$\mathbf{NFBs = (Y * P) - TCV}$$

Where;

$(Y * P)$ = Gross Field Benefit (GFB),

Y=Yield per ha and

P=Field price per unit of the crop.

Treatment with less than or equal to treatment with lower TCV are dominated (CIMMYT, 1988; Low, 1989). Treatments with higher NFB than the treatments and lower TCV are undominated. Since the control treatments (conventional tillage and continuous maize-bean intercropping without N fertilizer application) had no input of fertilizers, TCV of the treatments was compared to the TCV of the control. This was done to determine the most economical treatment.

CHAPTER FOUR

Results

4.1 Rainfall information for the four sites in the year 2011 and 2012

Figure 5.1 and 5.2 shows monthly rainfall for the study sites. Rainfall in all the four sites Bungoma, Tororo, Trans-Nzoia and Kapchorwa was measured daily using rain gauges installed on every experimental farm. Bungoma and Tororo have a bimodal rainfall pattern between March to July, and August to September, while Trans-Nzoia and Kapchorwa have unimodal rainfall distribution.

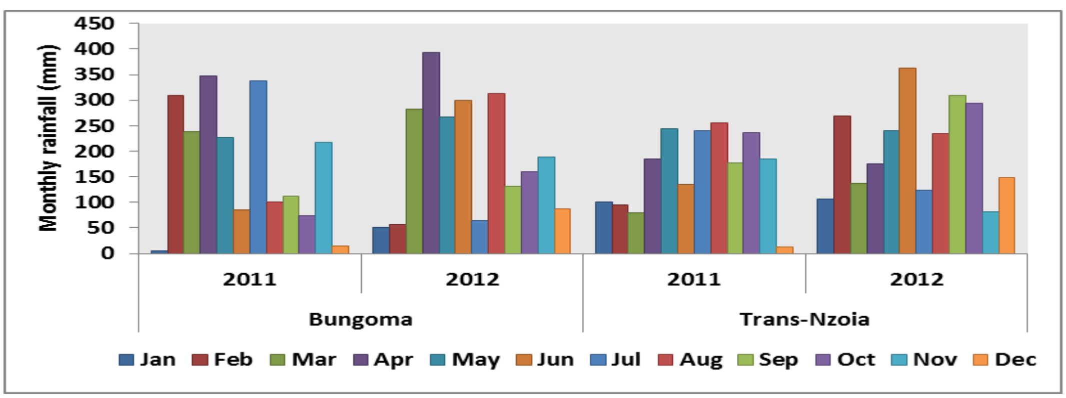


Fig 4.1: Rainfall data for Bungoma and Trans-Nzoia in the year 2011 and 2012

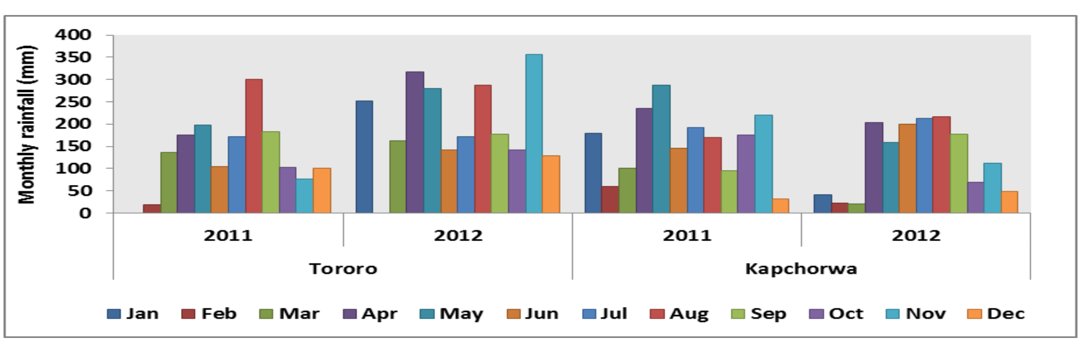


Fig 4.2: Rainfall data for Tororo and Kapchorwa in the year 2011 and 2012

Rainfall levels varied in the rain days within the cropping seasons. This varied between the sites and cropping seasons (Fig 5.1 and 5.2).

4.2 Initial soil characterization for the four sites

The initial soil analysis data shows the depleted status of the soils across all the four sites

Table 4.1: Initial soil chemical analysis data for the four sites

		Kenya		**Uganda**	
	Adequate Levels (Okalebo et al., 2002)	**Bungoma**	**Trans-Nzoia**	**Tororo**	**Kapchorwa**
Soil pH (1:2.5H_2O)	***5.5 - 6.0***	4.54	5.01	4.49	4.41
Av. P (mgKg^{-1})	***13 - 15***	6.457	8.453	6.045	5.435
% O. C	***1.5 - 3.0***	1.48	1.32	1.43	1.40
% N	***0.2 - 0.3***	0.168	0.131	0.185	0.143
NH_4-H (cmol/kg soil)		487.9	509.2	596.3	498.2
NO_3-N(cmol/kg soil)		356.3	403.1	429.9	373.8
Earthworms/5m^2 area		1	0	1	0

(Source: Okalebo *et al*., 2002)

The levels of phosphorus were below the required adequate levels for crop production, with the lowest levels recorded in Kapchorwa (Tables 1a and 1b). The soils across the four sites indicate acidic soils with the soil pH ranging from 4.61 to 5.37. The percent organic carbon levels of the soils across the sites were low ranging between 1.09-1.40%.

4.3 Effects of Tillage, Cropping Systems and Nitrogen application on selected soil chemical properties during cropping.

4.3.1 Effects of Tillage, Cropping Systems and Nitrogen application on soil pH

There was a significant increase ($p \leq 0.05$) in soil pH in Bungoma soils as a result of the tested treatments. The interaction between MT and ROT 2 (under +N) resulted into the highest overall soil pH mean of 5.07 in Bungoma up from the initial soil pH of 4.54 (Fig 4.5). Nitrogen application however had no significant effect ($p \leq 0.05$) on soil pH overall, with MT by ROT 2 interaction recording soil pH 4.84 under N1, and 5.11 under N0.

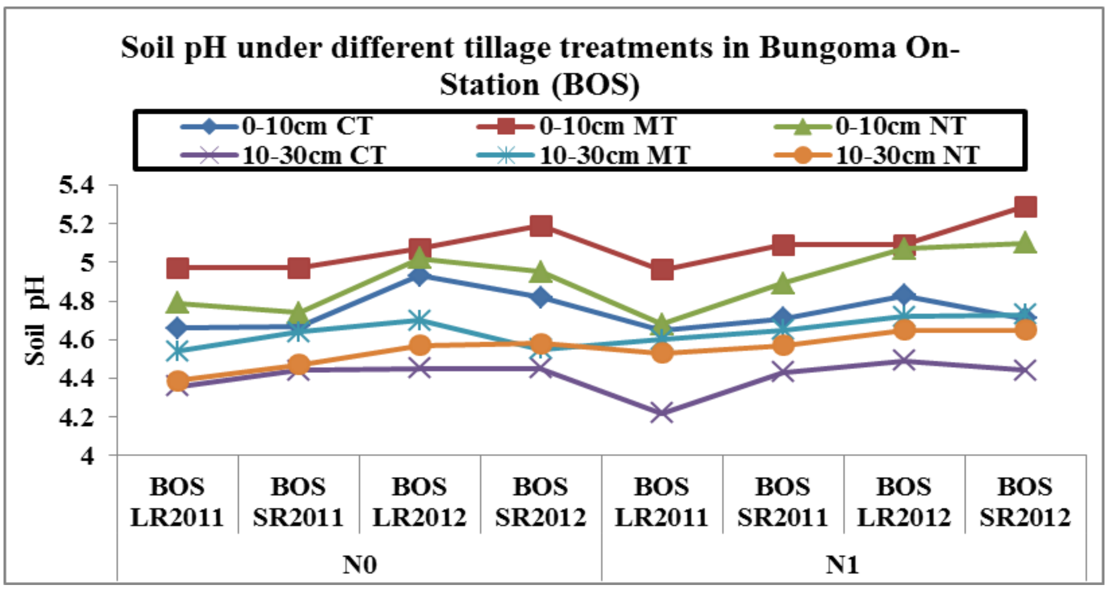


Fig 4.3: Soil pH under different tillage systems

Among the tillage systems, MT recorded highest levels of soil pH (Fig 4.3). This was followed by Nt and CT in that order. There was a general increase in soil pH across the seasons from LR2011-SR2012, indicating a progressive improvement. Also, ROT 2 resulted into a higher soil pH mean under NT, recording 4.85.

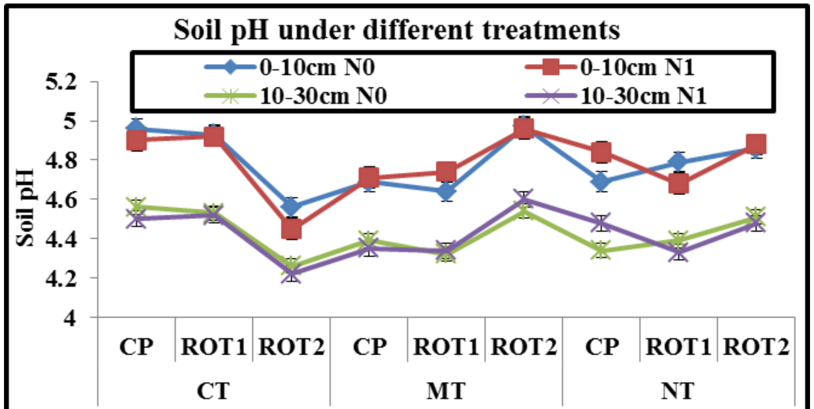


Fig 4.4: Soil pH in Bungoma LR2011

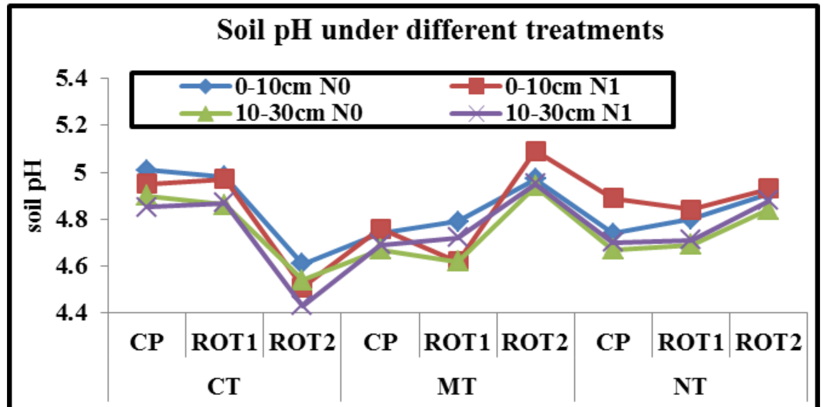


Fig 4.5: Soil pH in Bungoma SR2011

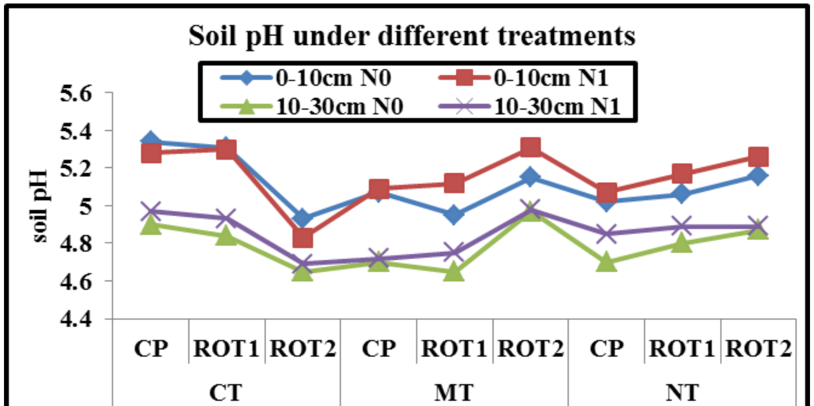


Fig 4.6: Soil pH in Bungoma LR2012

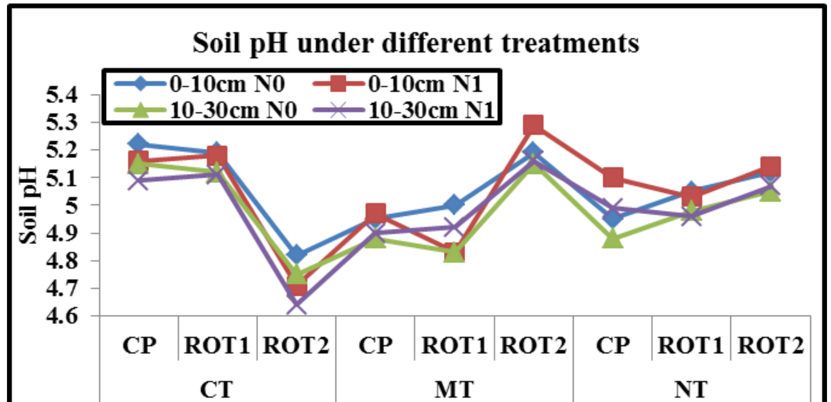


Fig 4.7: Soil pH in Bungoma SR2012

Among the tested cropping systems, ROT 2 recorded the highest means in all cropping seasons irrespective of the tillage systems and nitrogen ffertilizer application. Overal, soil pH was higher at 0-10cm depth than 10-30cm, with soil pH 5.16 and 4.99 being recorded for 0-10cm and 10-30cm respectively. Conventional tillage recorded the lowest soil pH means both in Trans-Nzoia and Kapchorwa, across all cropping seasons (Table 4.3 and 4.4).

In Trans-Nzoia, there was an increase in soil pH across the two cropping seasons in general (Fig 5.2). This resulted in a rise in soil pH from 4.80 to 5.18 in LR2011 and LR2012 respectively. Tillage systems had a significant effect ($p \leq 0.05$) on soil pH, with MT recording the highest overall mean of 5.23 and 5.22 both under ROT 2 in N1 and N0 respectively. NT followed closely with a mean of 5.12. Nitrogen application did not have a significant effect ($p \leq 0.05$) on the resulting soil pH. The recorded high values of soil pH of 5.22 and 5.23 under N0 and N1 respectively did not differ significantly ($p \leq 0.05$) (Fig 4.8 and 4.9).

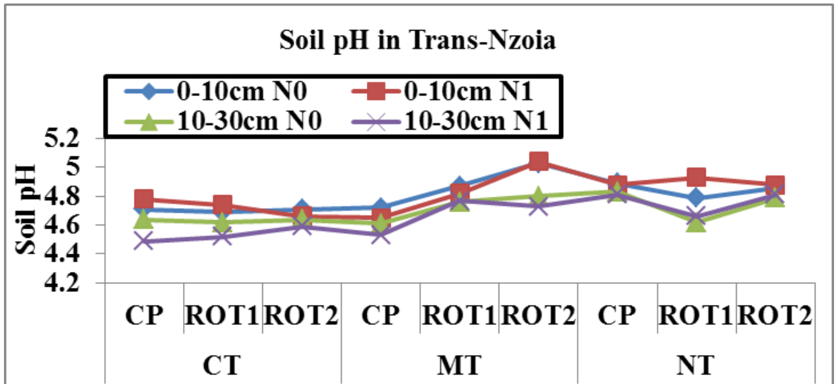


Fig 4.8: Soil pH changes in Trans-Nzoia in LR2011

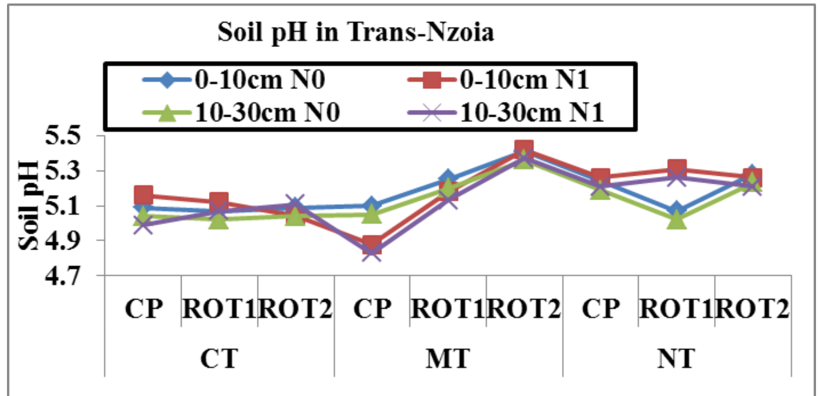


Fig 4.9: Soil pH changes in Trans-Nzoia LR2012

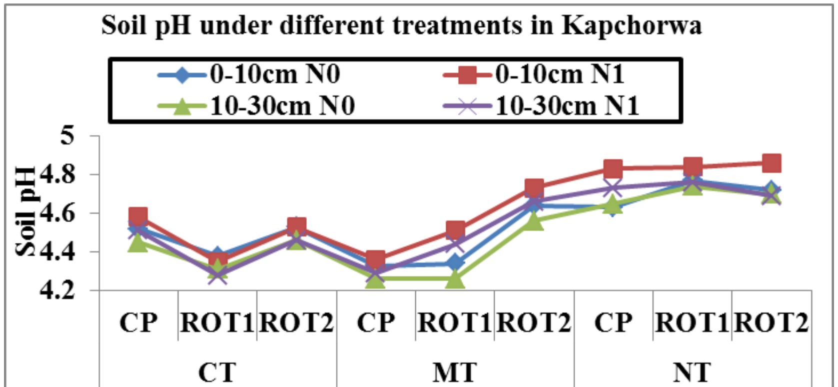


Fig 5.0: Soil pH changes in Kapchorwa in LR2011

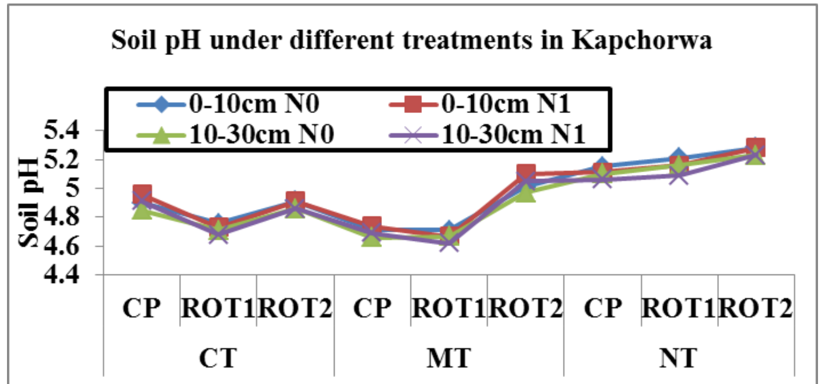


Fig 5.1: Soil pH changes in Kapchorwa in LR2012

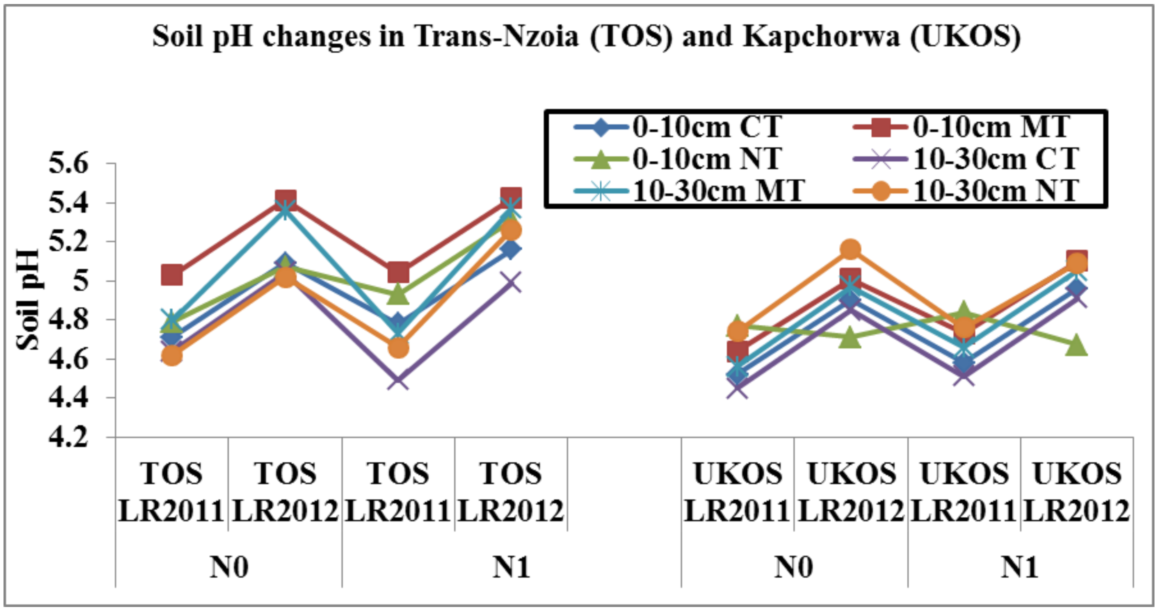


Fig 5.2: Soil ph in Trans-Nzoia (TOS) and Kapchorwa (UKOS)

Generally, soil pH slightly improved from a mean of 4.59 to 4.78 in Kapchorwa (Fig 5.2). The soil pH overall was 4.90 at the beginning of the experiment revealing an acidic soil. Minimum tillage yielded the highest soil pH mean as followed by NT and CT. under cropping systems, ROT 2 recorded the highest mean of 5.02 and 5.06 under N1 and N0 respectively (Fig 5.0 and 5.1). The difference between N0 and N1 was however not significant ($p \leq 0.05$).

In Tororo, there was a recorded increase in soil pH across all cropping seasons. A general soil pH mean of 5.20 and 5.18 was recorded under CT and MT respectively (Fig 5.3).

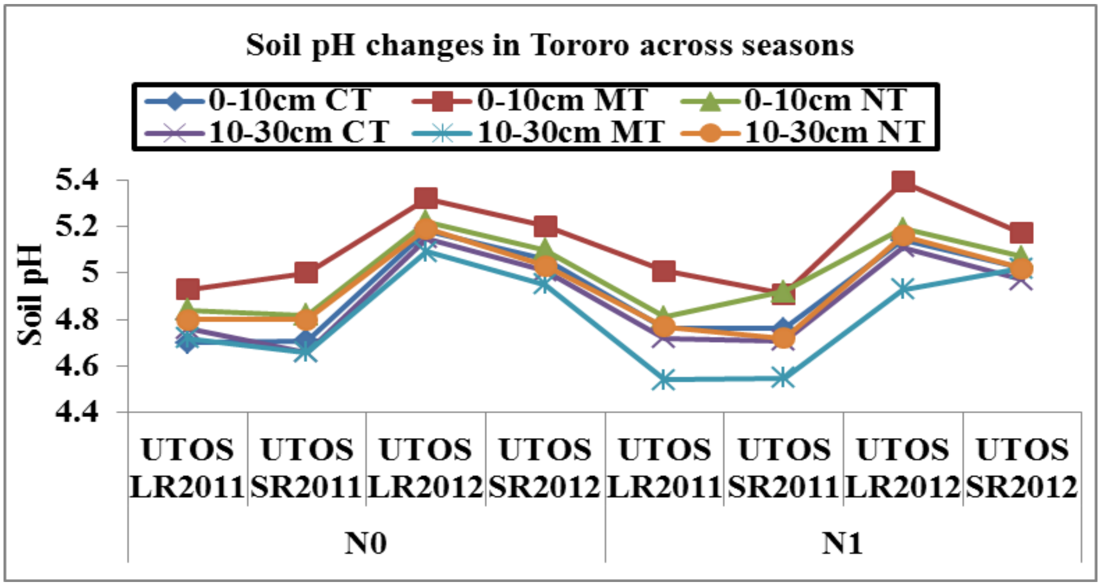


Fig 5.3: Soil pH change in Tororo

Under cropping systems, ROT 2 resulted into an increase in soil ph irrespective of the tillage systems. However, Nitrogen application resulted into higher soil pH (Figures 5.4-5.7).

In all the four sites, the treatments of tillage, N-application and cropping systems had an effect on soil pH in general. This resulted to a rise in soil pH, with the highest means being recorded under MT by ROT 2 by N1 interaction

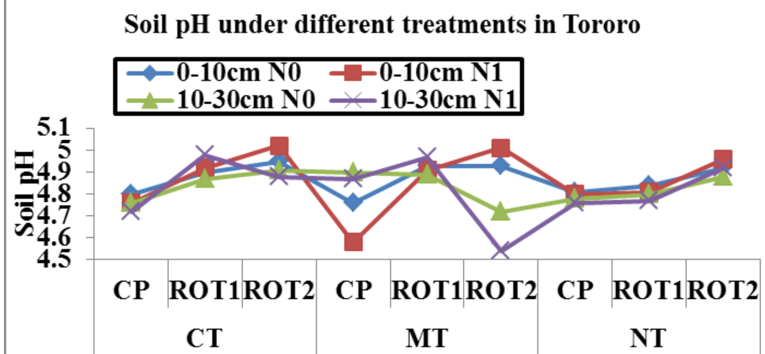


Fig 5.4: soil pH in Tororo LR2011

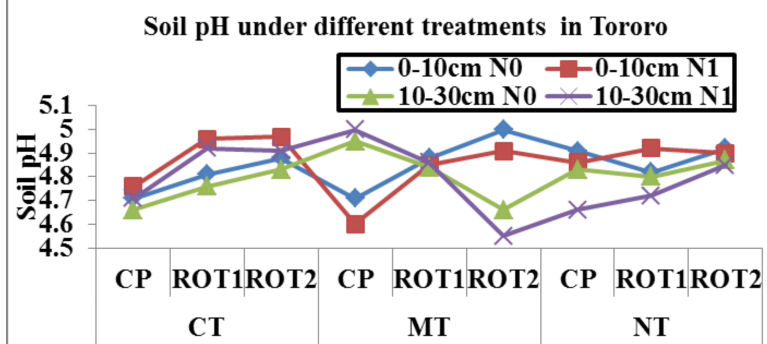


Fig 5.5: Soil pH in Tororo SR2011

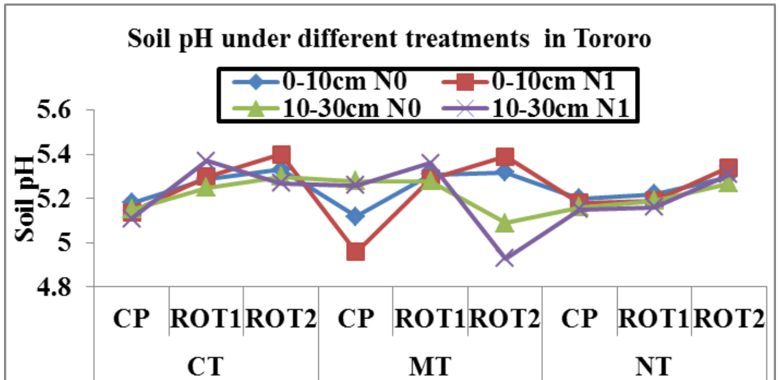


Fig 5.6: Soil pH in Tororo LR2012

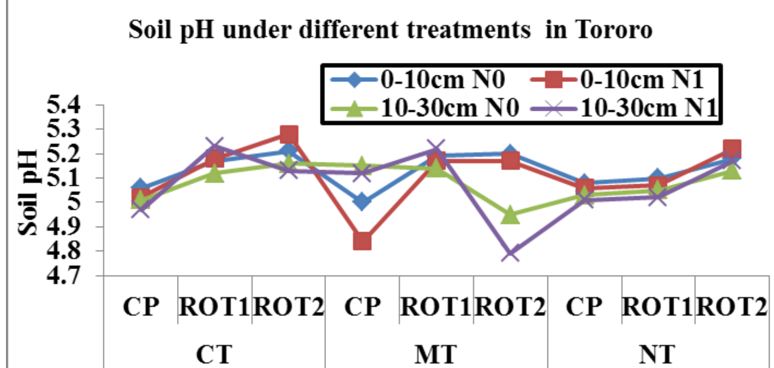


Fig 5.7: Soil pH in Tororo SR2012

4.3.2 Effects of Tillage, Cropping Systems and Nitrogen application on available soil Phosphorus (Sodium Hydrogen Carbonate extractable Phosphorus)

The resulting available phosphorus levels were high under ROT 2 cropping system in Bungoma as compared to ROT 1 and CP (Fig 5.8). However, there was no significant difference between MT and CT in the levels of available P (Fig 5.8). NT resulted into the lowest mean of available P in comparison to MT and CT. Higher levels of available P were recovered from N1 treatment as compared to N0. This was irrespective of the treatments being applied.

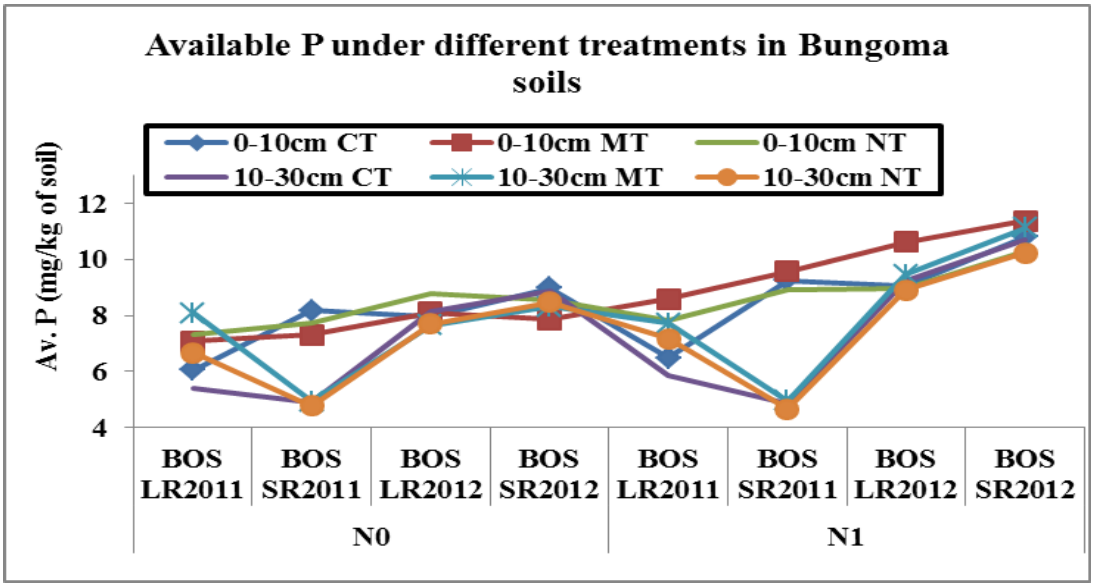


Fig 5.8: Available P in Bungoma soils

Across the cropping seasons, the results reveal a progressive increase in available P, with the highest mean of 9.03mg P kg^{-1} being recorded in SR2011. This was under the treatments of MT and ROT 2 with nitrogen application. In general, the treatments had an effect on the P levels, realizing an increase to 10.46 mg kg^{-1} of soil up from the initial level at 6.46 mg kg^{-1} of soil (Fig 5.9-5.12).

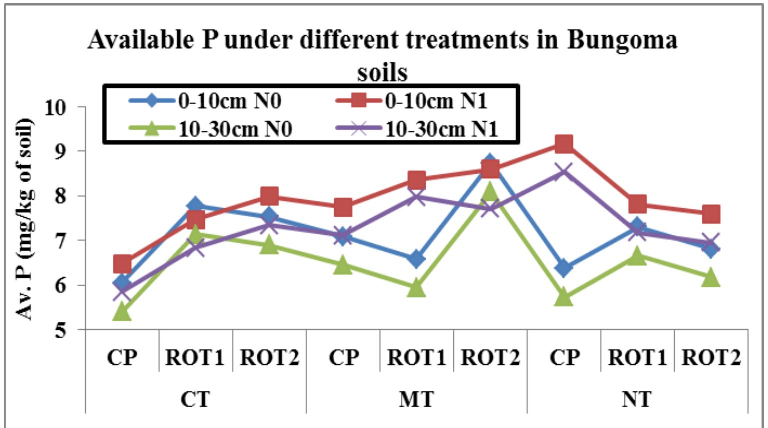


Fig 5.9: Available P in Bungoma in LR2011

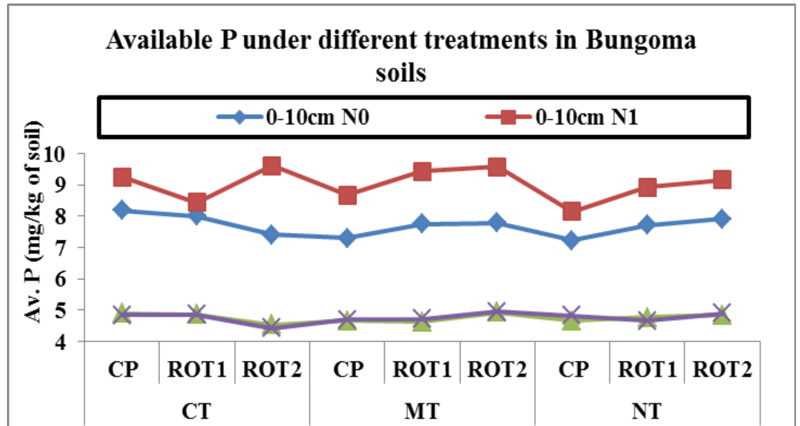


Fig 5.10: Available P in Bungoma in SR2011

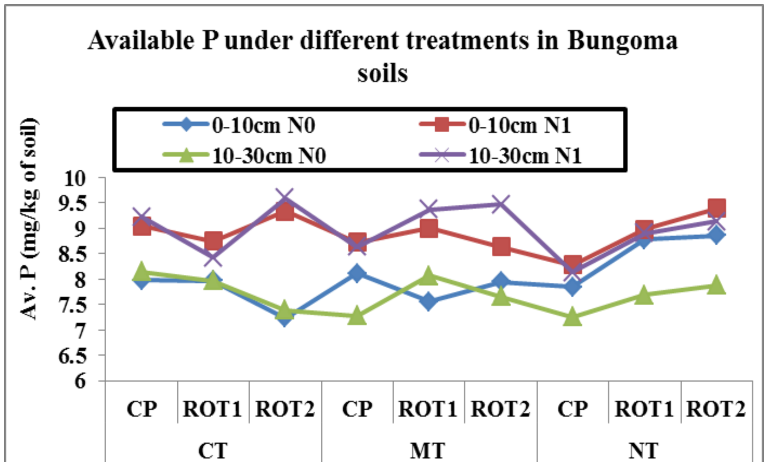


Fig 5.11: Available P in Bungoma LR2012

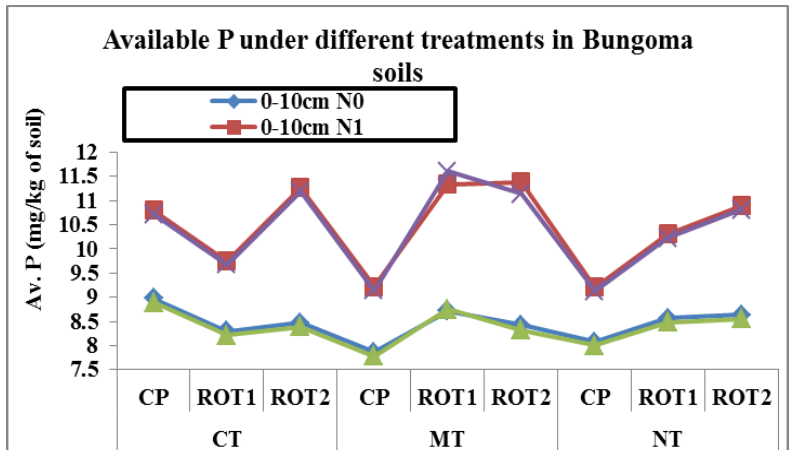


Fig 5.12: Available P in Bungoma SR2012

In Trans-Nzoia, there was a general increase in available P levels to 8.45 mg kg^{-1} of soil up from 10.46 mg kg^{-1} of soil (Fig 5.13). The increase was however not significant ($p \leq 0.05$). Under cropping systems, ROT 2 resulted to increased levels of available P recording a highest mean of 8.90 mg P kg^{-1} under MT. N application had a significant ($p \leq 0.05$) effect on soil P levels in Trans-Nzoia in LR2012.

In comparison to the other tillage systems, NT recorded higher levels of available P than CT in Trans-Nzoia. Higher levels of available P were available in Trans-Nzoia soils under ROT 2 cropping systems. This was the same case for all the tillage systems in interaction with N application. However, ROT 1 performed better than CP in terms of available P in Trans-Nzoia soils (Fig 5.14).

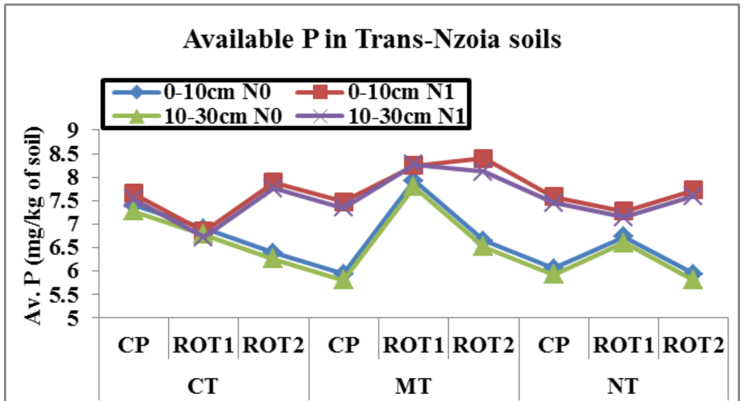


Fig 5.13: Available P in Trans-Nzoia LR2011

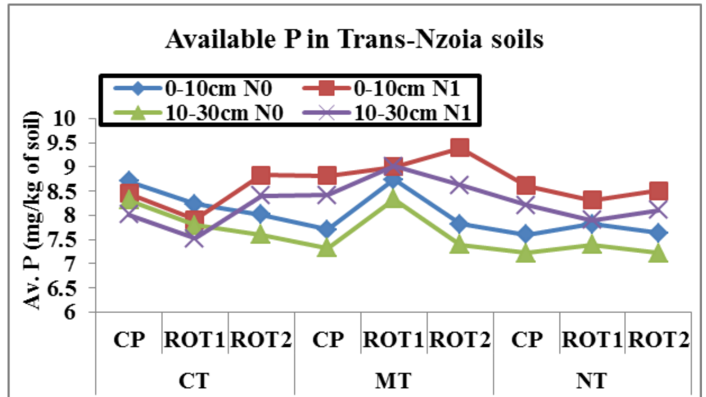


Fig 5.14: Available P in Trans-Nzoia LR2012

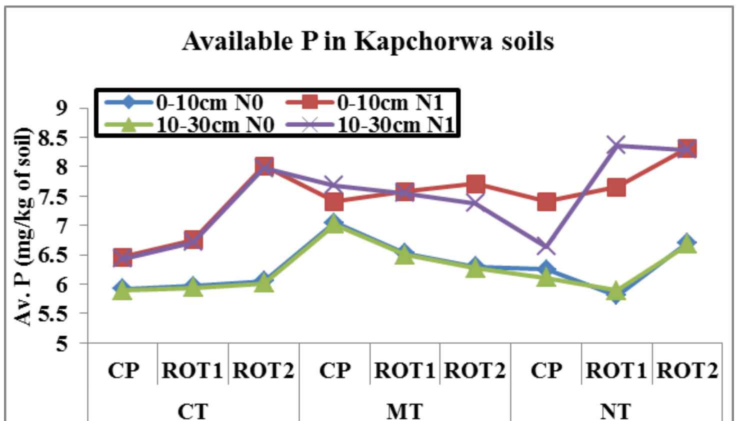


Fig 5.15: Available P in Kapchorwa LR2011

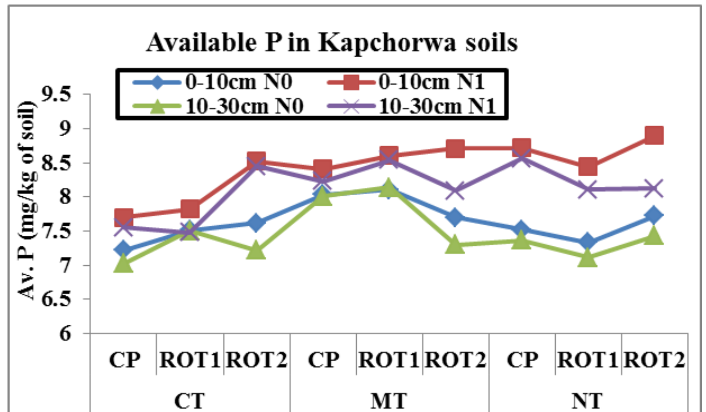


Fig 5.16: Available P in Kapchorwa LR2012

In Kapchorwa, there were higher levels of available P in ROT 2 cropping system with N application. This was consistent in all the three tillage systems MT, NT and CT. However, more levels of P were recovered under ROT 1, followed by ROT 2 and CP in that order. There was a general increase in available P levels in Kapchorwa as a result of the tillage, nitrogen application and cropping systems treatments. The recorded mean at end of LR2012 was 8.42 mg kg^{-1} of soil, up from 5.44 mg kg^{-1} of soil at onset of the experiment (Fig 5.15 and 5.16).

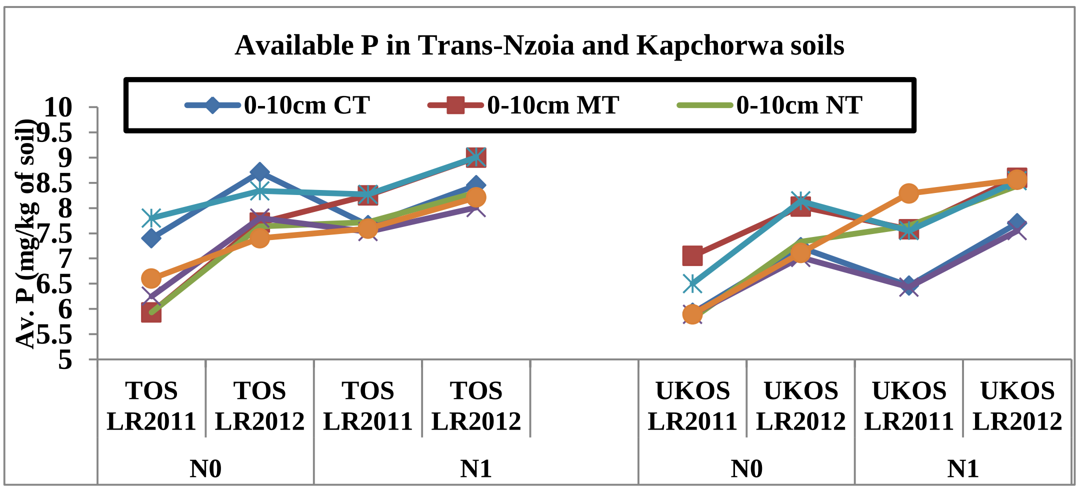


Fig 5.17: Available P in Trans-Nzoia and Kapchorwa soils

Generally, there was an increase in available phosphorus in Trans-Nzoia and Kapchorwa from LR2011 to LR2012 cropping seasons (Fig 5.17).

There was a general increase in available P in Tororo soils up to 9.43 mg kg^{-1} of soil at the end of the experiment. This was up from the initial P levels at 6.05 mg kg^{-1} of soil (Fig 5.18).

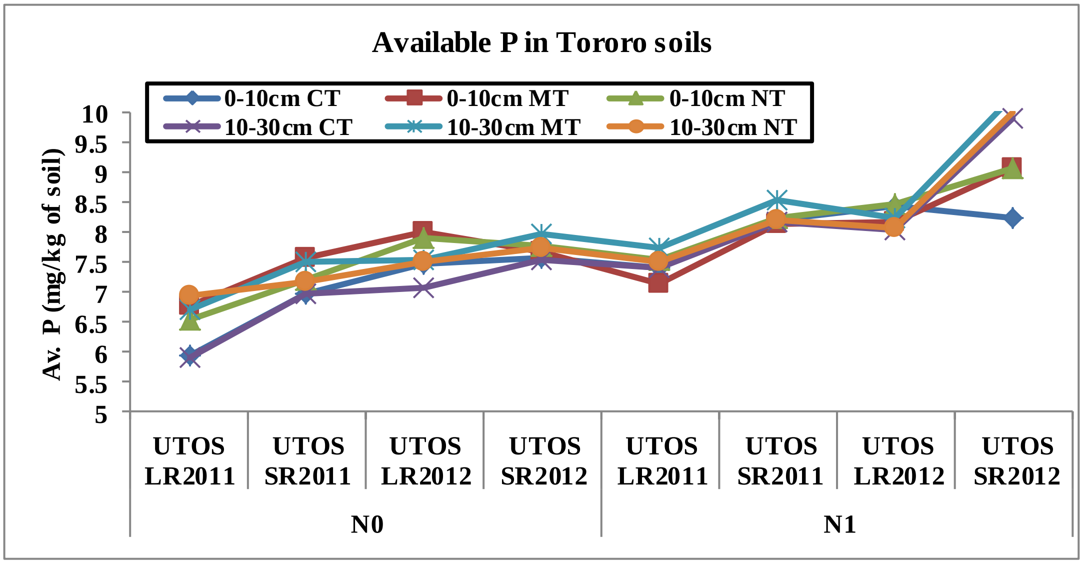


Fig 5.18: Available P in Tororo across seasons

This represented a 55% increase. Irrespective of the tillage system tested, ROT 2 realized higher P levels as compared to ROT 1 and CP in Tororo soils. The ROT 2 cropping systems recorded the highest value of available P under MT.

This was followed by ROT 2 under NT and CT (Fig 5.19-5.22). There was a high level of available P recovered under N1 as compared to N0.

.

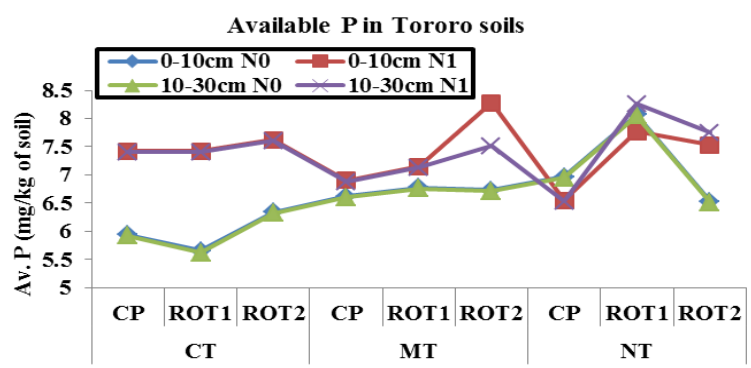


Fig 5.19: Available P in Tororo LR2011

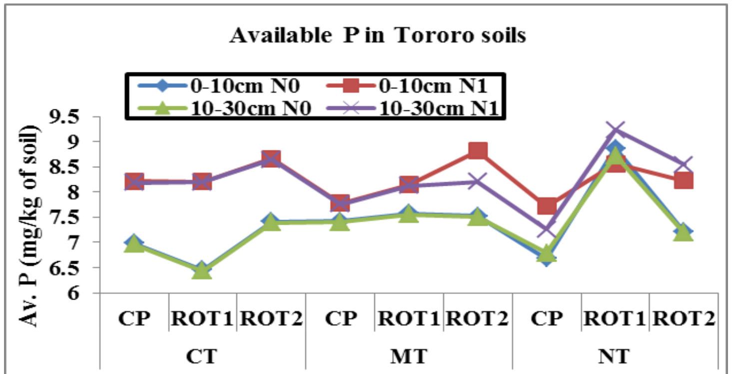


Fig 5.20: Available P in Tororo SR2011

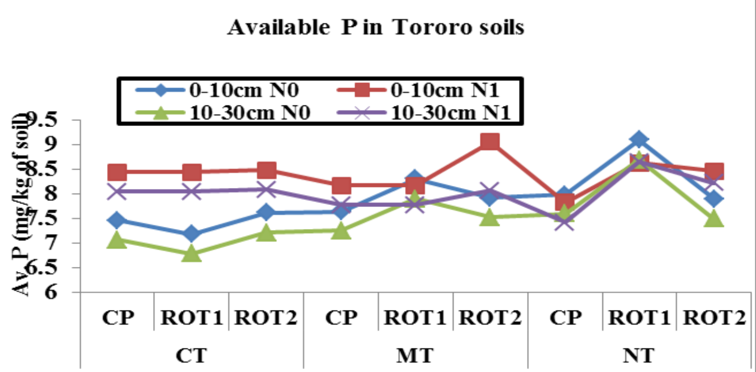


Fig 5.21: Available P in Tororo LR2012

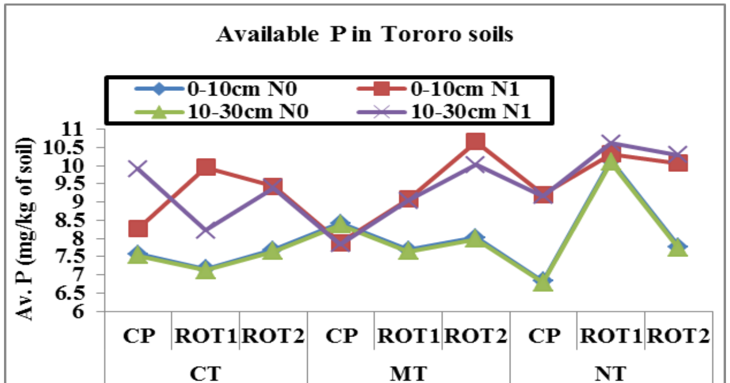


Fig 5.22: Available P in Tororo SR2012

Generally, nitrogen application resulted into an increase in available soil phosphorus in all the four sites- Bungoma, Trans-Nzoia, Kapchorwa and Tororo. There were higher levels of available phosphorus in N1 treatment as compared to N0. Under cropping systems, higher levels of available phosphorus were recovered from minimum tillage treatment.

These were however not significantly different ($p \leq 0.05$) from the levels of available phosphorus under NT. Conventional tillage realized lower levels of available phosphorus. The interaction of minimum tillage by ROT 2 with nitrogen application realized a higher level of available phosphorus across all the four sites as compared to the other treatments' interactions.

4.3.3 Effects of Tillage, Cropping Systems and Nitrogen application on soil organic carbon (SOC)

There was a rise in the levels of SOC in Bungoma in the 0-10cm depth. The initial soil characterization revealed soils in Bungoma with percentage organic levels below the minimum required levels of 1.5% according to Okalebo *et al* (2002) (Fig 5.23).

Overall, nitrogen application resulted into a higher increase in SOC levels as compared to N0. Under cropping systems, ROT 2 yielded the highest SOC means followed by ROT 1 and lastly CP in Bungoma soils. Minimum tillage (MT) contributed highly to a rise in SOC followed by NT and CT.

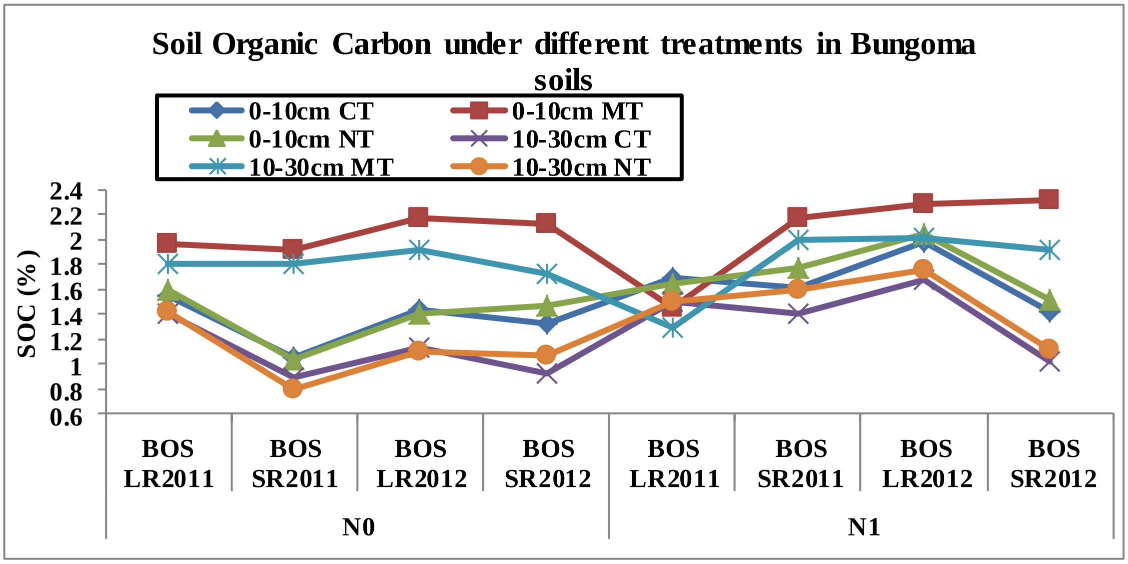


Fig 5.23: Soil organic carbon in Bungoma soils across seasons

The highest recorded percent SOC was 2.09% (Fig 5.23). This highest means recorded were from the interactions involving ROT 2 by MT under N1. This was however not significantly different ($p \leq 0.05$) from NT by ROT 2 under N1. The ROT 2 yielded higher levels of percent SOC both under N1 and N0 in Bungoma soils (Fig 5.24-5.27). Minimum tillage by ROT 2 under N1 recorded 2.29% in LR2012, at a 0-10cm depth (Fig 5.26). This was not significantly different ($p \leq 0.05$) from 2.17% recorded under the same interactions in combination with N0.

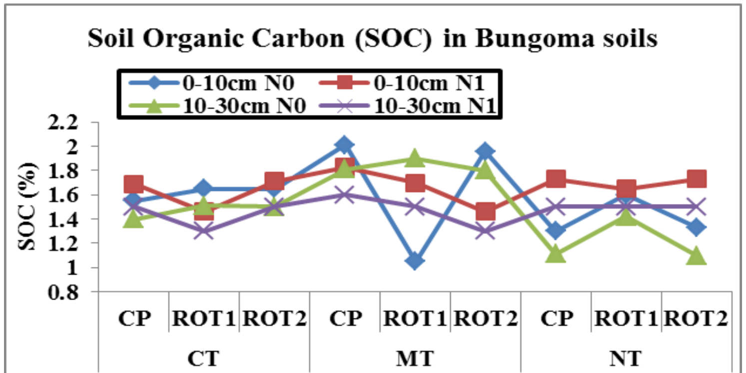


Fig 5.24: SOC in Bungoma in LR2011

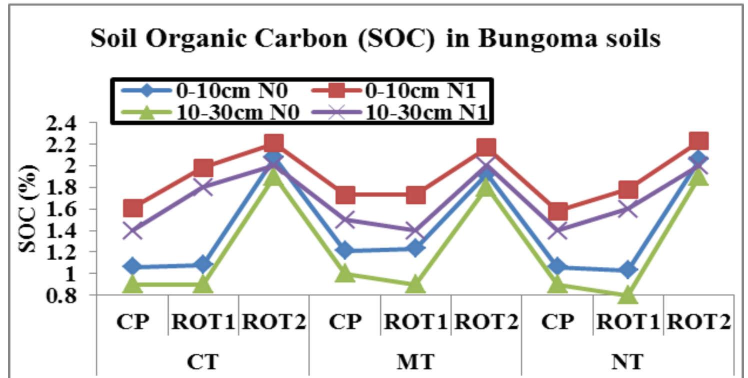


Fig 5.25: SOC in Bungoma in SR2011

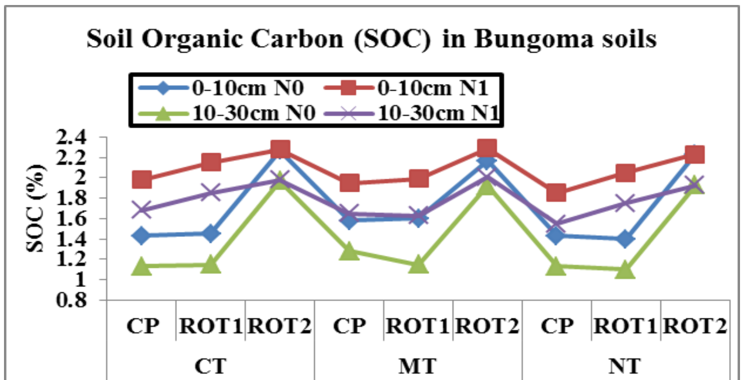


Fig 5.26: SOC in Bungoma in LR2012

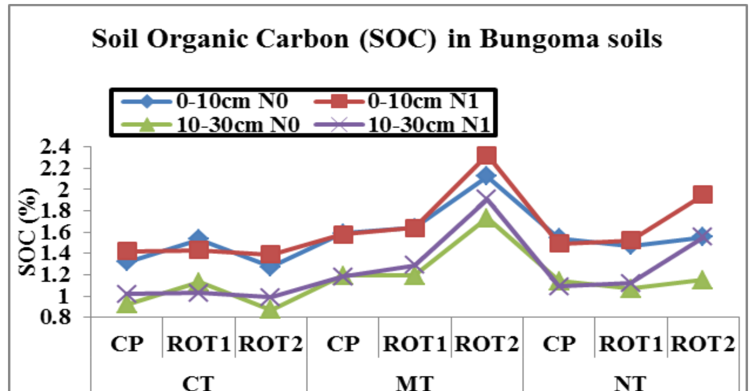


Fig 5.27: SOC in Bungoma in SR2012

Trans-Nzoia, the levels of SOC were high under MT in the 0-10cm depth. This was in combination with MT, ROT 2 cropping system and N1. The highest mean recorded was 2.20%. No-till and conventional tillage recorded the second highest SOC means under ROT 2 by N1 treatment (Fig 5.28). The %SOC levels recorded under ROT 2 in the 10-30cm depth were highest under NT followed by MT and CT. Generally, nitrogen application had a significant influence on the resulting SOC levels in Trans-Nzoia soils. Cropping systems differed significantly ($p \leq 0.05$) with ROT 2 having a higher influence on %SOC in Trans-Nzoia soils as compared to ROT 1 and CP. There was however no significant difference ($p \leq 0.05$) between tillage systems on the resulting %SOC levels (Fig 5.29).

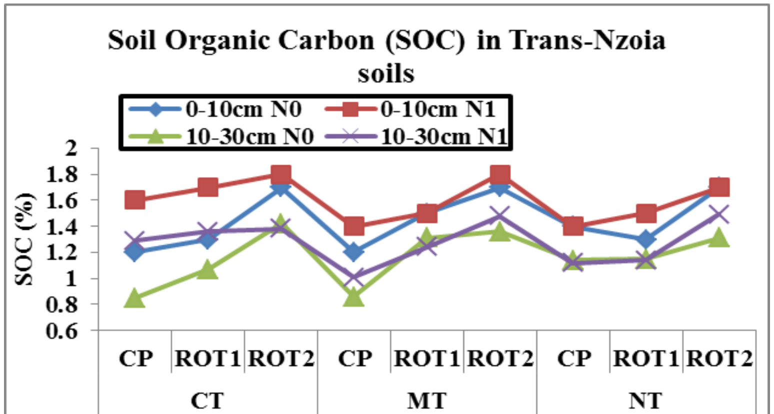


Fig 5.28: SOC in Trans-Nzoia in LR2011

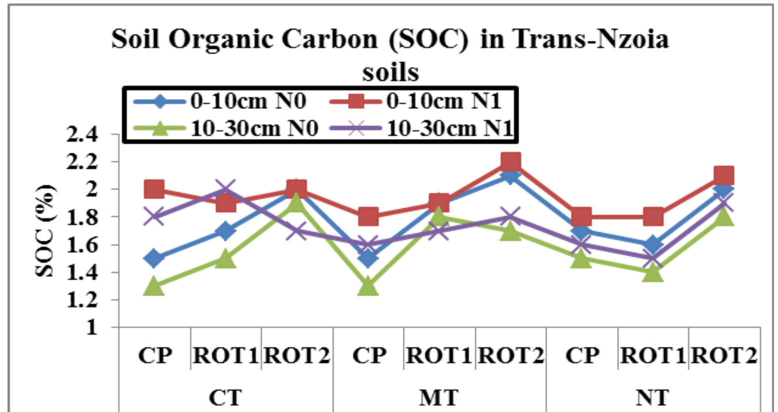


Fig 5.29: SOC in Trans-Nzoia in LR2012

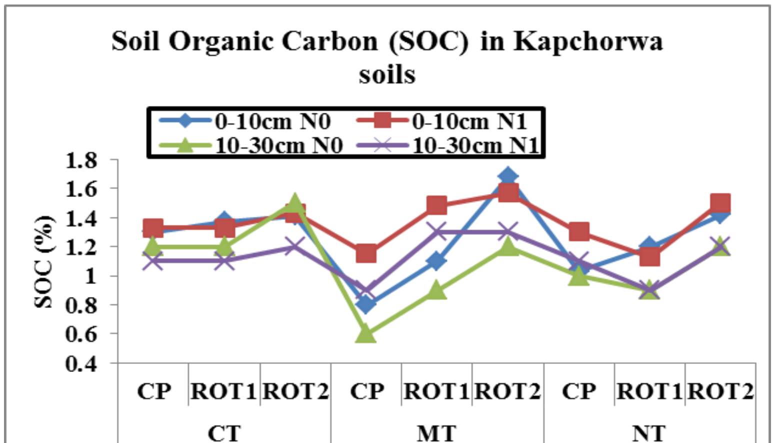


Fig 5.30: SOC in Kapchorwa in LR2011

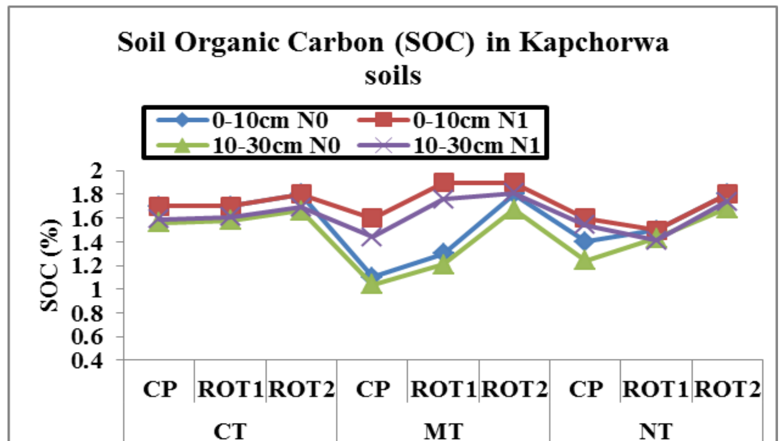


Fig 5.31: SOC in Kapchorwa in LR2012

In Kapchorwa soils, ROT 2 had a significant effect ($p \leq 0.05$) on SOC recording the highest mean of 1.90% in the 0-10cm depth (Fig 5.30). This was under MT and N1 interaction. The means were significantly higher than ROT 1 and CP. Minimum tillage had a significant effect on %SOC recording higher values in comparison to NT and CT. At 10-30cm, the levels of %SOC were high still under MT by ROT 2 interaction (Table 4.12). However, the levels of % soil organic carbon were generally high under 0-10cm as compared to 10-30cm depths, with a mean of 1.72% and 1.62% respectively (Fig 5.31).

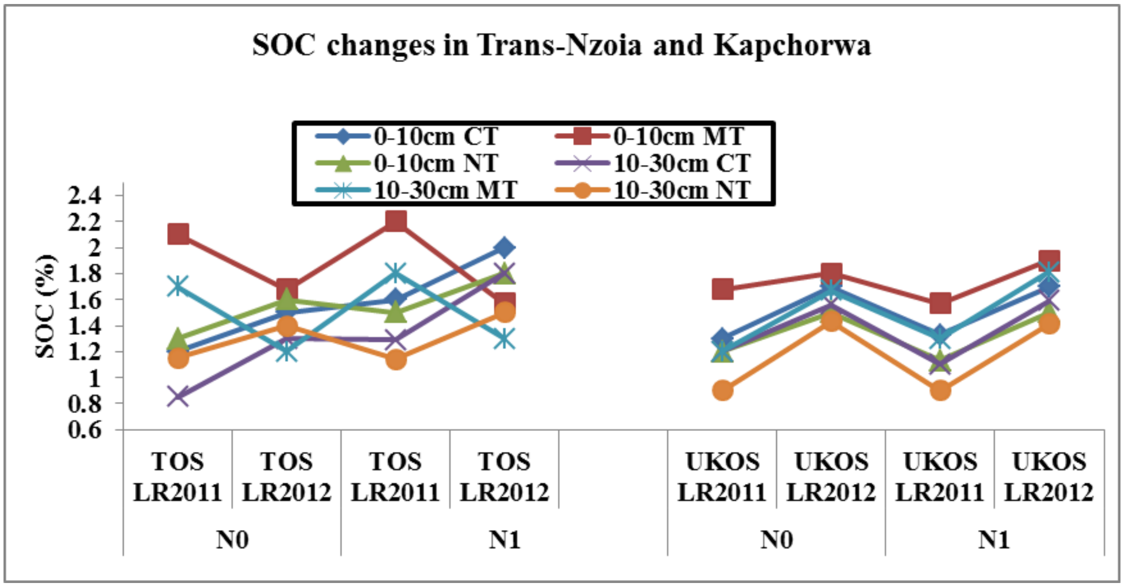


Fig 5.32: Soil Organic Carbon changes in Kapchorwa and Trans-Nzoia

Generally, SOC was highest under MT and ROT 2 in both Kapchorwa and Trans-Nzoia (Fig 5.32).

There was a significant difference ($p \leq 0.05$) in the resulting SOC levels between MT and NT in Tororo soils under 0-10cm. Percent SOC under ROT 2 were significantly higher than ROT 1 and CP (Fig 5.33 to Fig 5.36).

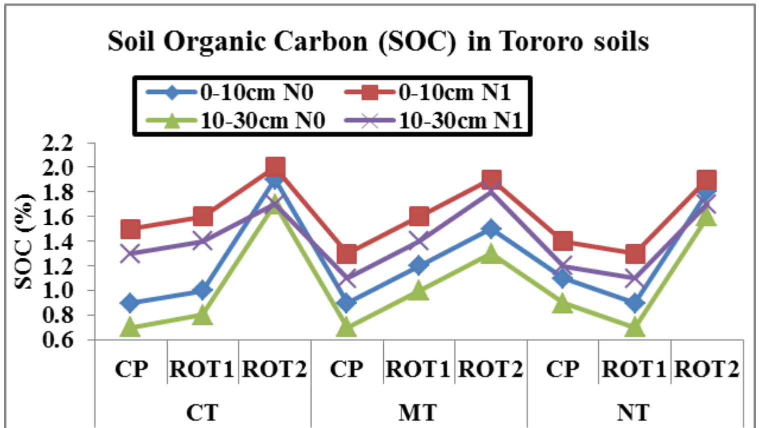


Fig 5.33: SOC in Tororo in LR2011

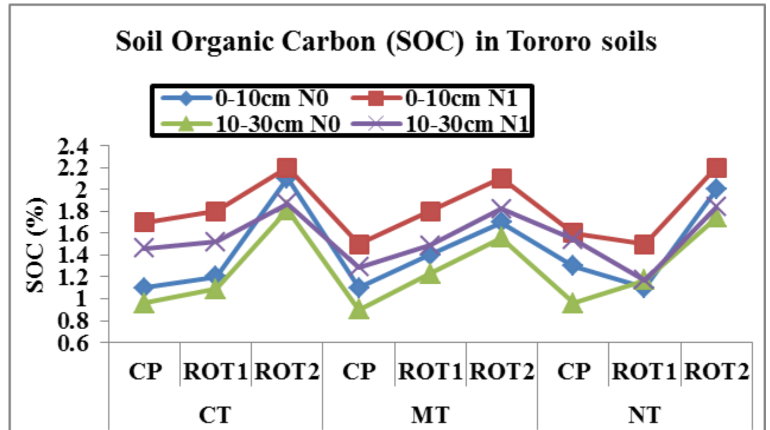


Fig 5.34: SOC in Tororo in SR2011

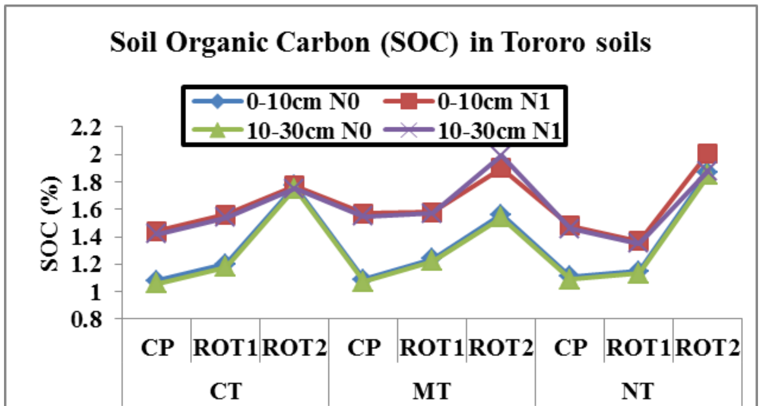


Fig 5.35: SOC in Tororo in LR2012

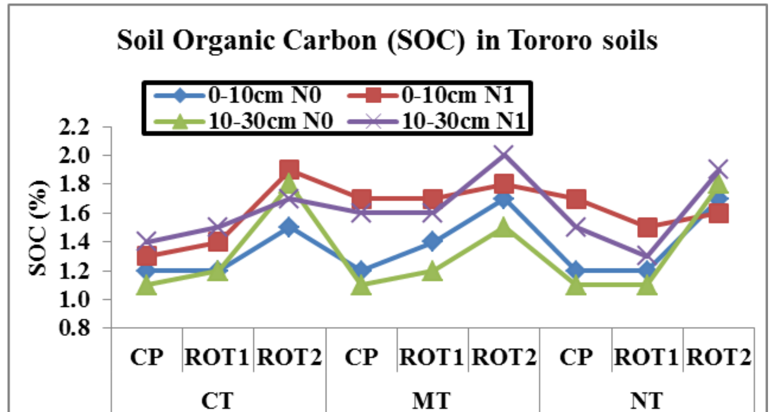


Fig 5.36: SOC in Tororo in SR2012

Nitrogen application had a significant effect on the resulting percent SOC in Tororo soils (Fig 5.33 to Fig 5.36). Nitrogen application realized a percent soil organic carbon level of 1.82%, as compared to 1.61% SOC under N0 (Fig 5.33 to Fig 5.36).

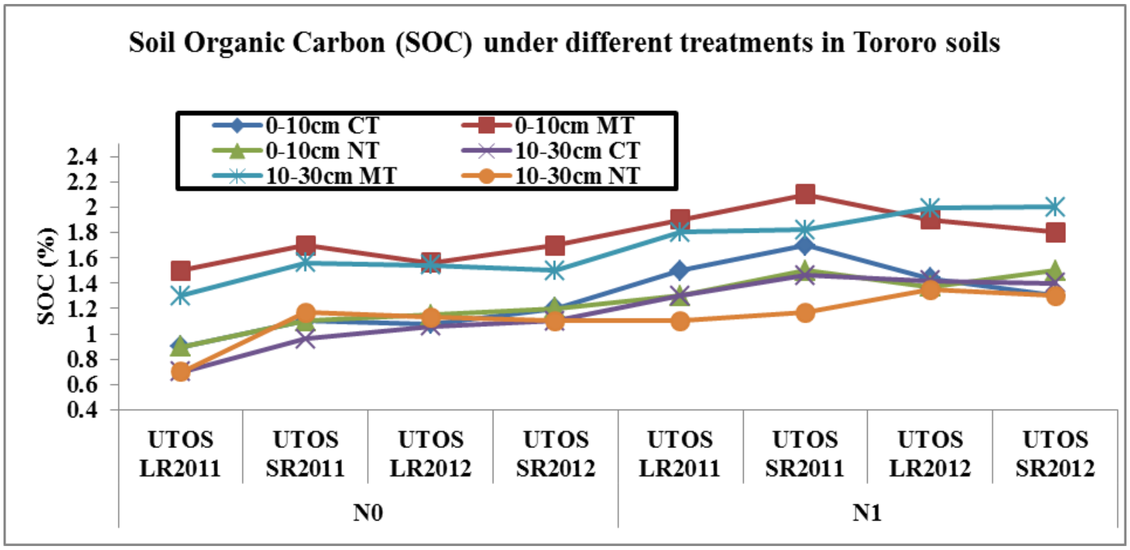


Fig 5.37: Soil Organic Carbon (SOC) in Tororo across seasons

Rotation 2 recorded the highest mean of 1.90% SOC under N1 in both MT and NT. A higher SOC mean was also recorded under ROT 2 in 10-30cm depth 2.00% in combination with MT and N1 (Fig 5.37).

4.3.4 Effects of Tillage, Cropping Systems and Nitrogen application on soil total nitrogen (N)

The levels of total N in Bungoma soils as aresult of the tested treatments were high under ROT 2 cropping system. This was in combination with minimum tillage (MT) with N application. There was an increase in N levels in Bungoma with N application in comparison to N0. Total N levels under MT were significantly high ($p \leq 0.05$) in Bungoma soils as compared to NT and CT (Tables 4.14.1 and 4.14.2). Rotation 2 resulted into increased levels of total nitrogen in Bungoma soils in all the three tillage systems.

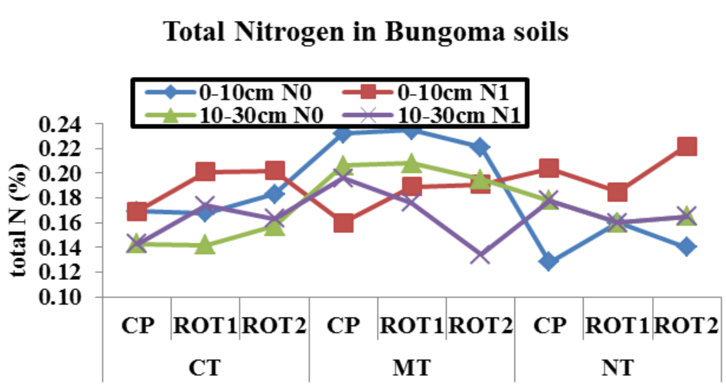


Fig 5.38: % Nitrogen in Bungoma in LR2011

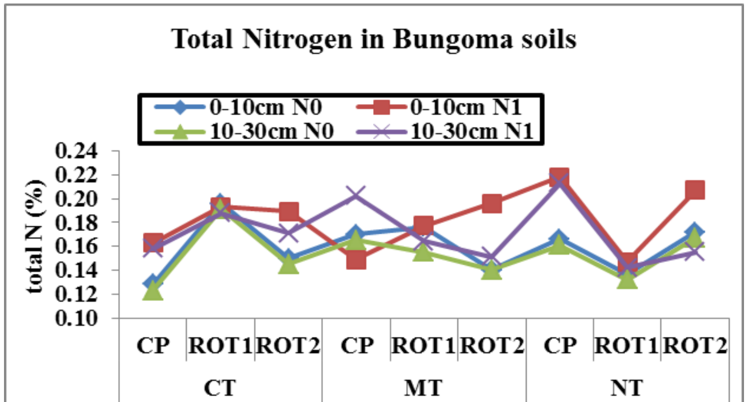


Fig 5.39: % Nitrogen in Bungoma in SR2011

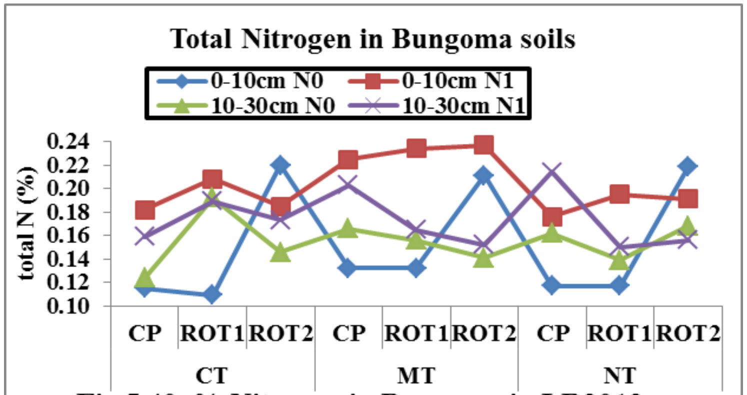


Fig 5.40: % Nitrogen in Bungoma in LR2012

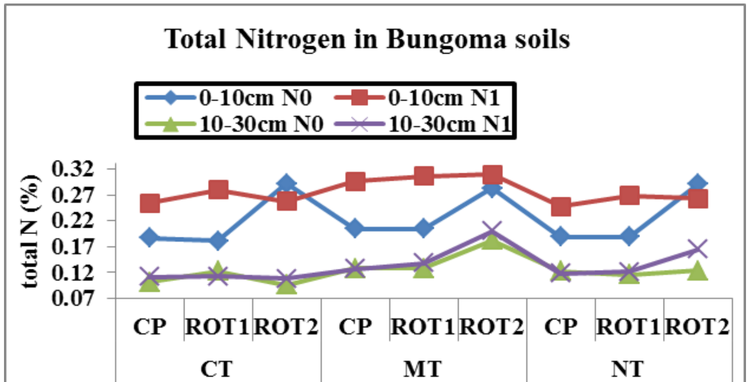


Fig 5.41: % Nitrogen in Bungoma in SR2012

Similar to Bungoma, total N in soils of Trans-Nzoia were also significantly influenced by tillage (Fig 5.42-5.43). Minimum till recorded the highest means of total N under ROT 2 cropping system (Fig 5.42). ROT 2 recorded high total N levels irrespective of nitrogen fertilizer application. This was followed by ROT 1 and CP. However, the total N in soils treated with N1 recorded higher percentage of total N in Trans-Nzoia soils. There was a general increase in total N to 0.162%, up from 0.154% in Trans-Nzoia soils. Nitrogen application had a significant effect ($p \leq 0.05$) on the levels of total nitrogen in Trans-Nzoia soils (Fig 5.43).

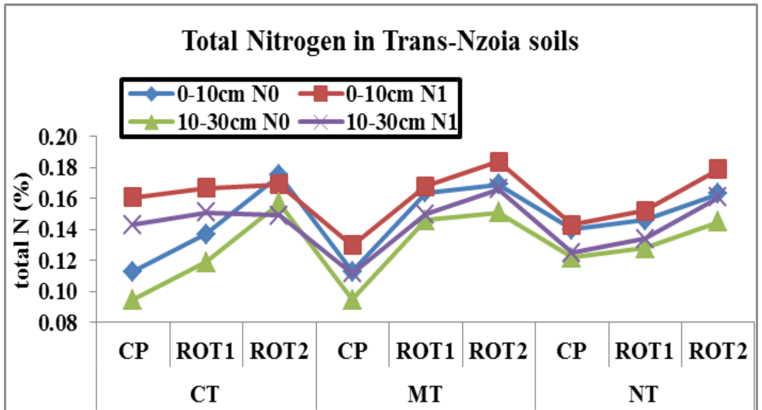


Fig 5.42: % Nitrogen in Trans-Nzoia in LR2011

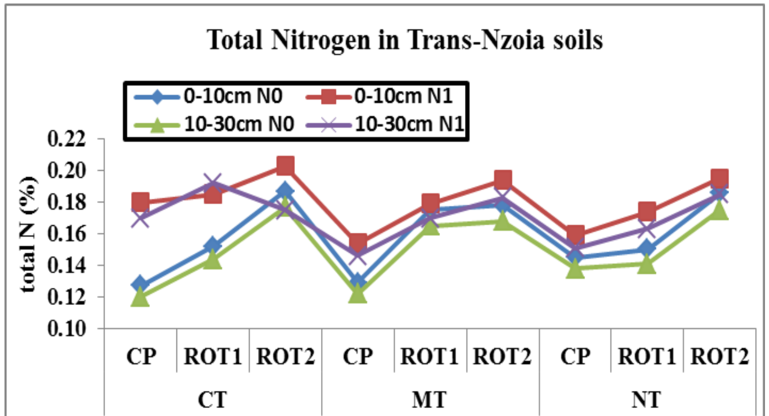


Fig 5.43: % Nitrogen in Trans-Nzoia in LR2012

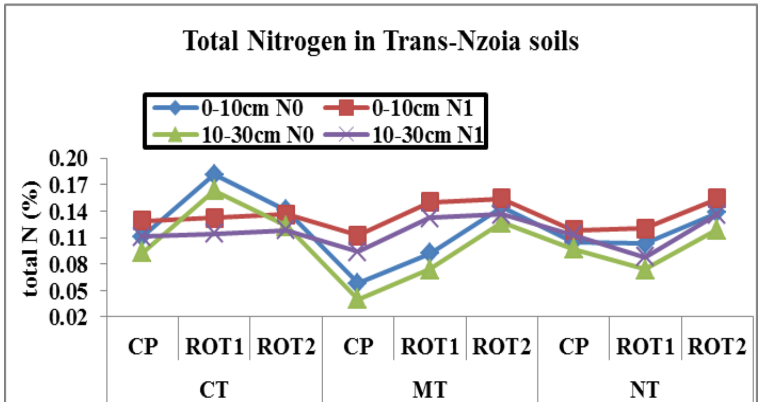


Fig 5.44: % Nitrogen in Kapchorwa in LR2011

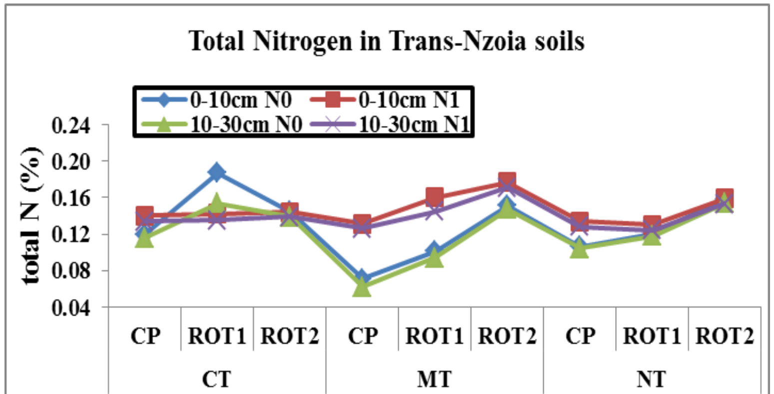


Fig 5.45: % Nitrogen in Kapchorwa in LR2012

In Kapchorwa soils, total N levels increased from 0.134% in LR2011, to 0.146% at end of LR2012 season (Fig 5.44). The highest total N mean recorded was under ROT 2 cropping system. This was then followed by ROT 1 (Fig 5.45).

All these were under N1, and were significantly high above the N0 treatment (Fig 5.46). Generally, higher levels of total N were recorded under MT, followed by NT and lastly CT. Under cropping systems, the least total N level was recorded under CP. The highest means were recorded under ROT 2. Nitrogen application had a significant influence ($p \leq 0.05$) on the total N levels in Kapchorwa soils (Fig 5.46- 5.49). This resulted into higher means of total N being recorded in this site.

The resulting total N levels were high under minimum tillage in Tororo soils, as compared to NT. The least of the three was CT. Rotation 2 yielded the highest levels of soil total N in Tororo. This was followed by ROT 1. Nitrogen application had a significant influence ($p \leq 0.05$) on total N levels in Tororo soils (Fig 5.48). This resulted into increased total nitrogen levels in soils under N1 in general. The interaction of MT by ROT 2 under N1 recorded the highest total N levels (0.225%) in Tororo soils (in 0-10cm depth). This was followed by ROT 1 under NT in combination with nitrogen application at 0.215%. Conventional tillage realized a high amount of total nitrogen in Tororo soils. This was in interaction involving rotation 2 and nitrogen application.

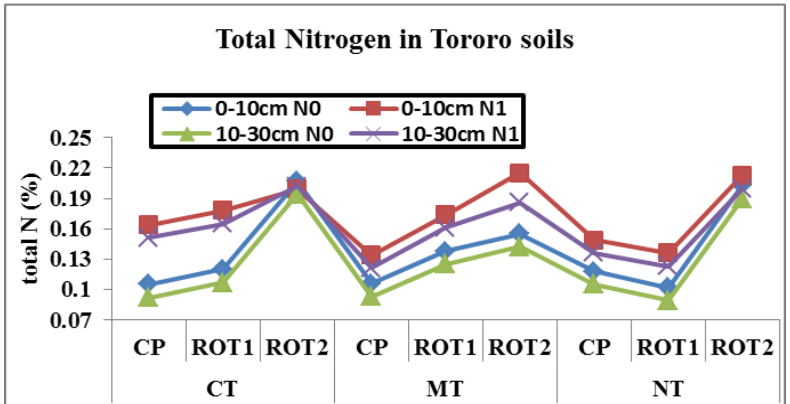


Fig 5.46: % Nitrogen in Tororo in LR2011

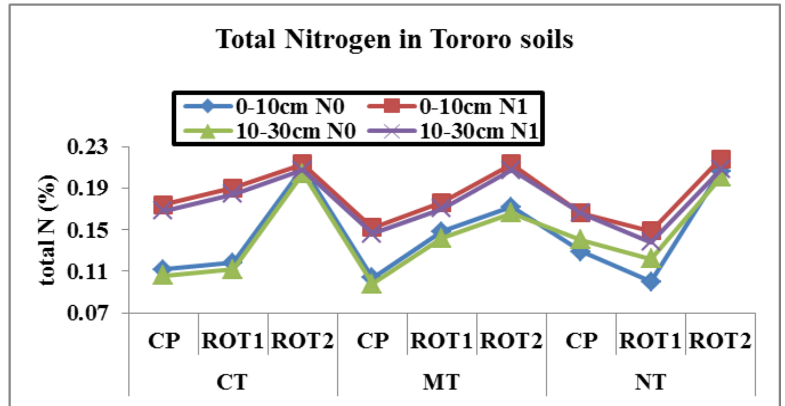


Fig 5.47: % Nitrogen in Tororo in SR2011

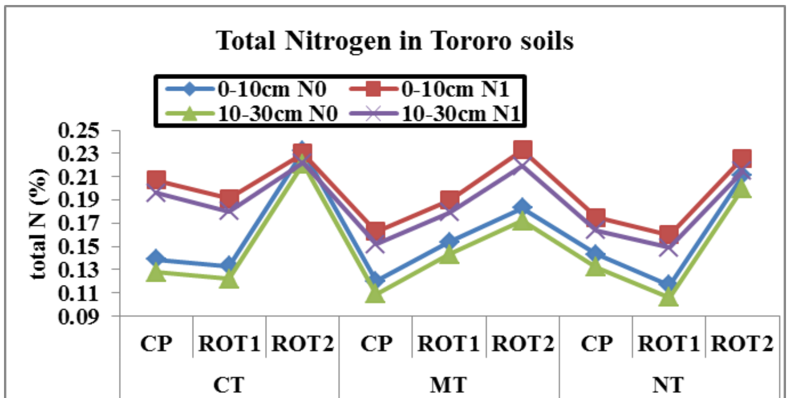


Fig 5.48: % Nitrogen in Tororo in LR2012

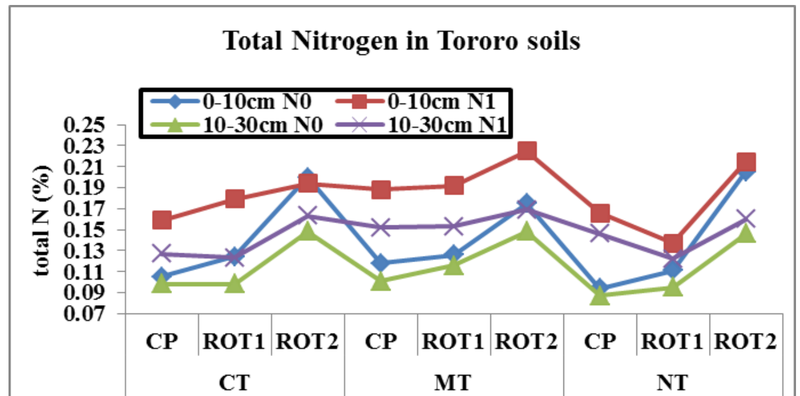


Fig 5.49: % Nitrogen in Tororo in SR2012

Overall, there was a general increase in the total N levels in Tororo soils (Fig 5.48).

Generally, in all the four sites- Bungoma, Trans-Nzoia, Tororo and Kapchorwa- nitrogen application resulted into an increase in total N levels. Under cropping systems, the levels of total N under CP were the least with ROT 2 recording the highest. Minimum tillage resulted into increased levels of total N across all the four sites. Conventional tillage recorded the least percent total N levels of the three tillage systems.

4.4 Effects of Tillage, Cropping Systems and Nitrogen application on earthworm population

In Bungoma, the high number of earthworms was recorded under ROT 2 in combination with nitrogen application (Fig 5.50 and 5.51).

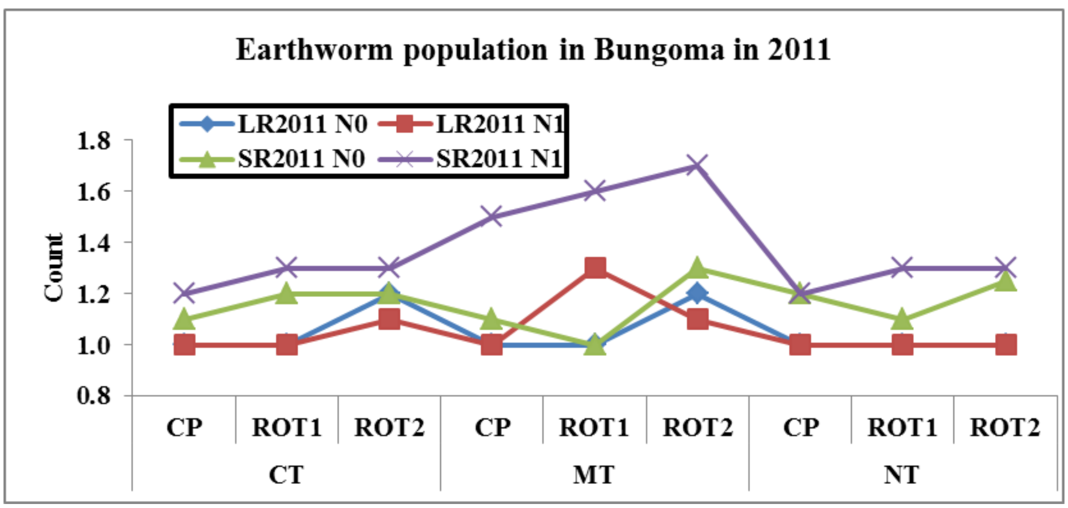


Fig 5.50: Earthworms count in LR2011 and SR2011 in Bungoma

The highest mean of 4.8 was recorded in LR2012 cropping season (Fig 5.51). This however did not differ significantly ($p \leq 0.05$) with ROT 1. Nitrogen application had no significant effect ($p \leq 0.05$) on the population of earthworms in Bungoma soils. Minimum tillage recorded the highest number of earthworms followed by NT. However MT and

NT did not differ significantly (p≤0.05). Current practice recorded significantly low number of earthworms in Bungoma County (Fig 5.51).

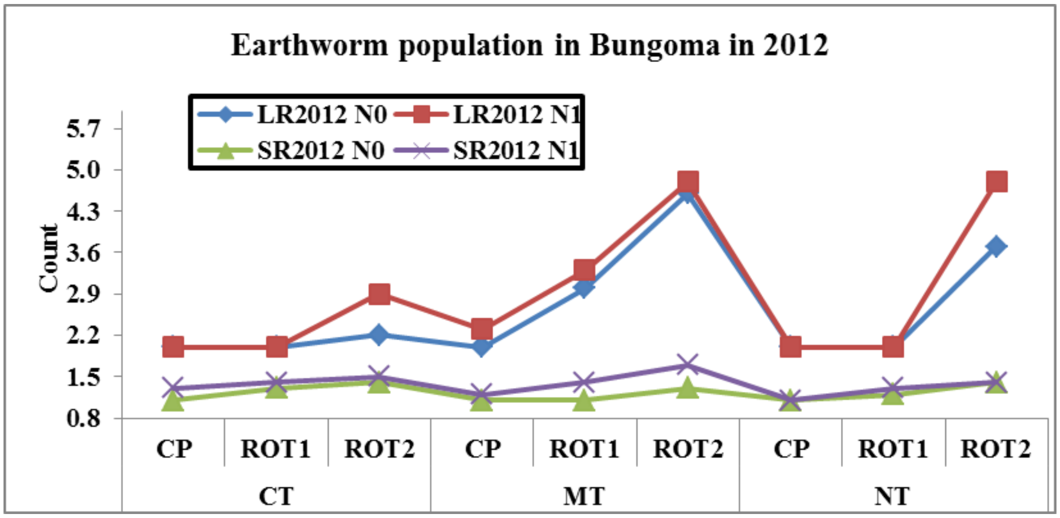


Fig 5.51: Earthworms count in LR2012 and SR2012 in Bungoma

In Trans-Nzoia County, the highest number of earthworms was recorded under MT. This was significantly high (p≤0.05) above NT (which was second highest) and CP. Rotation 2 scored the highest irrespective of the tillage systems (Fig 5.52).

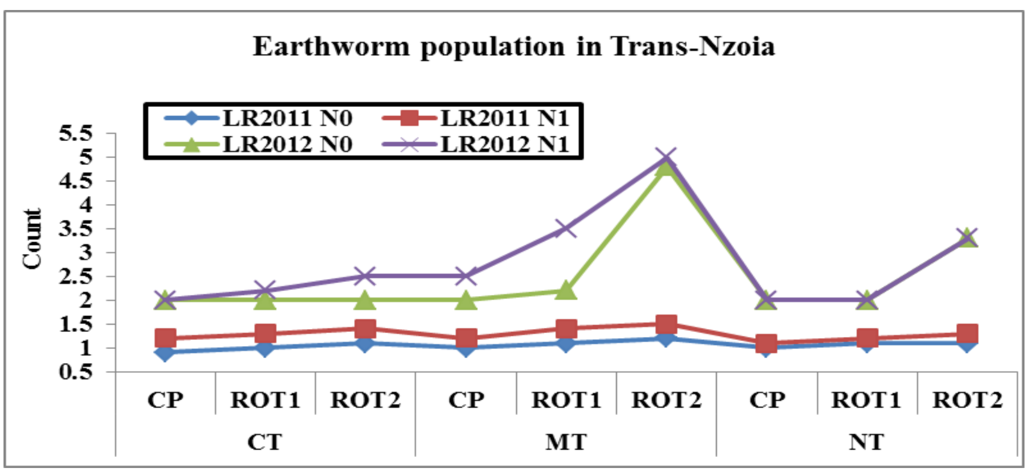


Fig 5.52: Earthworms count in LR2011 and LR2012 in Trans-Nzoia

This was significantly high (p≤0.05) above ROT 1 and CP. The number of earthworms under ROT 1 was higher than in CP even though ANOVA showed no significant difference (p≤0.05) between the two. Nitrogen application had a significant effect (p≤0.05) on the earthworms' population in Trans-Nzoia county soils (Fig 5.52).

The high number of earthworms was counted from ROT 2 treated plots in Tororo (Table 4.20.1 and 4.20.2). This had the highest overall mean of 2.9 under MT (Fig 5.53).

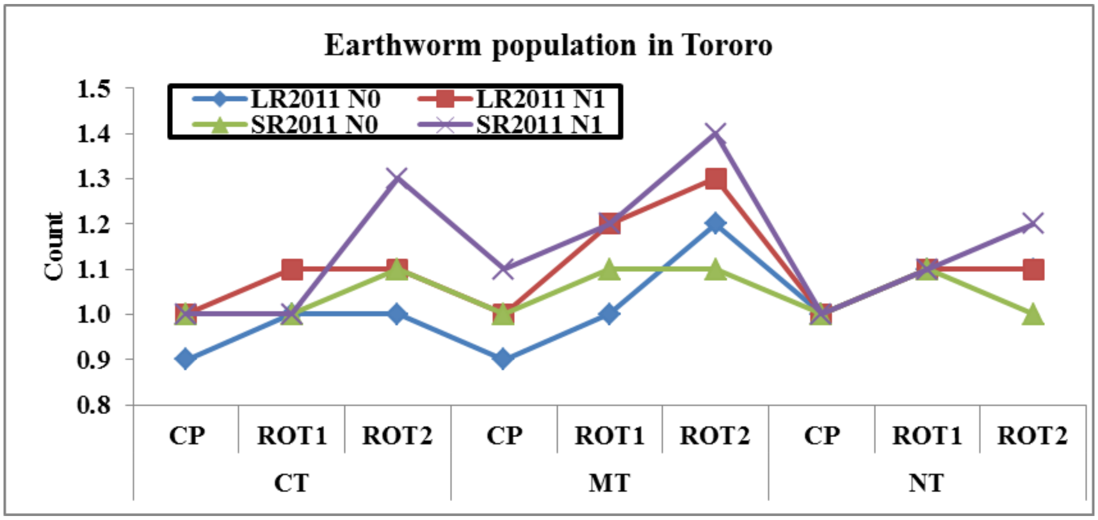


Fig 5.53: Earthworms count in LR2011 and SR2011 in Tororo

The high number of earthworms was counted in LR2012 among the cropping seasons. There was however no significant difference (p≤0.05) between N1 and N0 treatments with a mean of 2.3 and 2.5 respectively. The mean of 4.8 under MT by ROT 2 with nitrogen application was not significantly different (p≤0.05) from that of the similar treatment under N0 with 4.2. No-till scored the second highest earthworm means after minimum tillage (Fig 5.54). Under cropping systems, ROT 2 recorded the highest number of earthworms that differed significantly (p≤0.05) with the other two systems.

There was no significant difference (p≤0.05) between ROT 1 and CP in the number of counted earthworms.

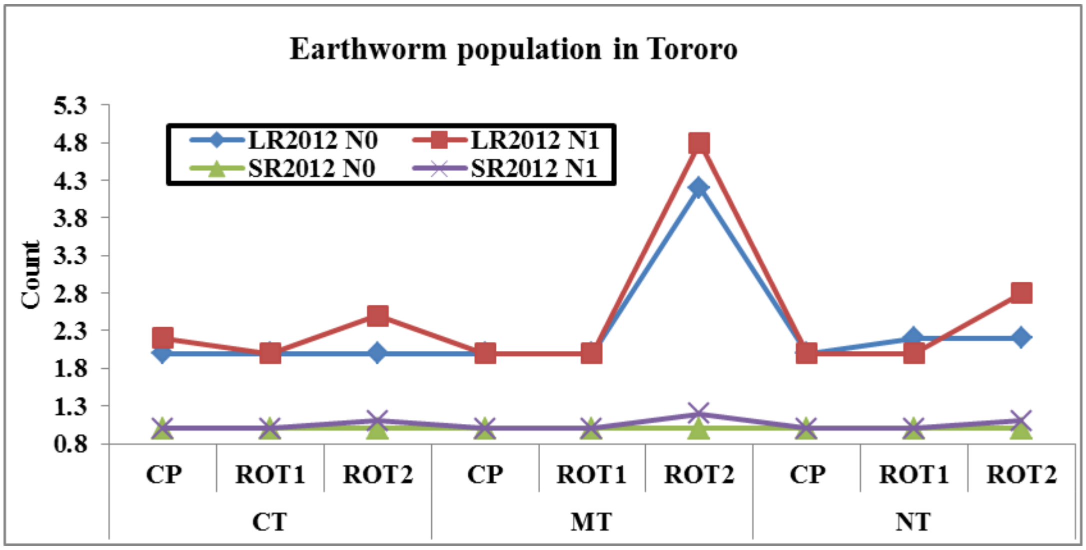


Fig 5.54: Earthworms count in LR2012 and SR2012 in Tororo

In Kapchorwa, there was no significant difference (p≤0.05) between the three tillage systems tested.

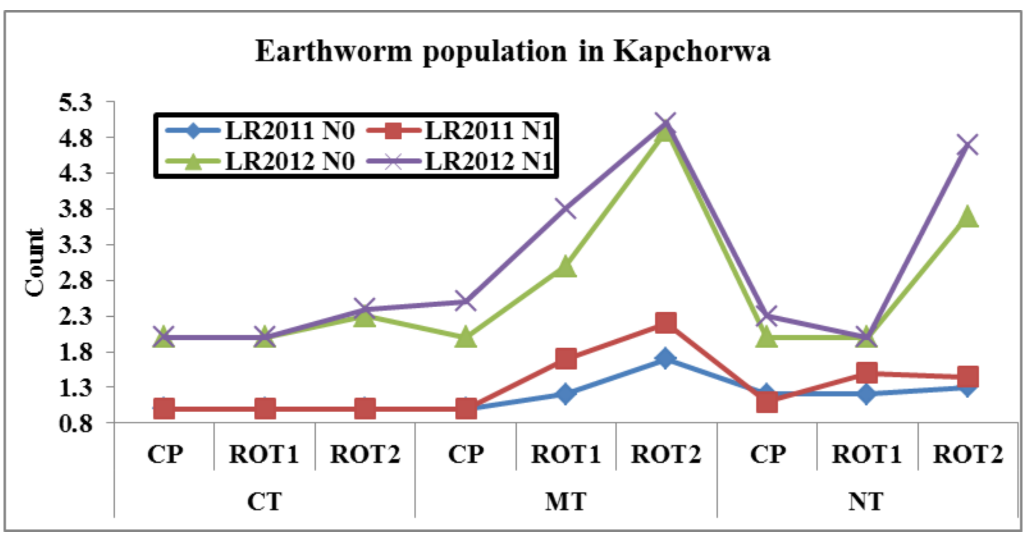


Fig 5.55: Earthworms count in LR2011 and LR2012 in Kapchorwa

This is despite the fact that MT recorded the highest number of earthworms (5.0 in LR2012 under ROT 2) followed by NT (Fig 5.55). Nitrogen application had a significant effect ($p \leq 0.05$) on the resulting earthworms' population in Kapchorwa soils. The overall mean of earthworm count under N1 and N0 was 2.7 and 3.0 respectively (Fig 5.55). There was a significant difference ($p \leq 0.05$) between N0 and N1. There was significant difference ($p \leq 0.05$) between the ROT 2 and ROT 1 cropping systems in LR2012, having a mean of 5.0 and 4.7 respectively. However, CP recorded significantly low ($p \leq 0.05$) earthworm population counts overall (Fig 5.55).

In general, the earthworm population was significantly ($p \leq 0.05$) affected by cropping systems. This was evident with the higher number of earthworms counted under ROT 2. In some cases, these were significantly high above ROT 1 and CP e.g. in LR2012 under N0. Tillage systems had a significant effect ($p \leq 0.05$) on earthworms' population. Minimum tillage had the highest number of earthworms above NT and CT. This was significantly different from those under no-till and conventional tillage.

The level of earthworms counted was high in ROT 2 under *Mucuna* crop. This was followed by beans with the least population count under maize crop (Fig 5.56).

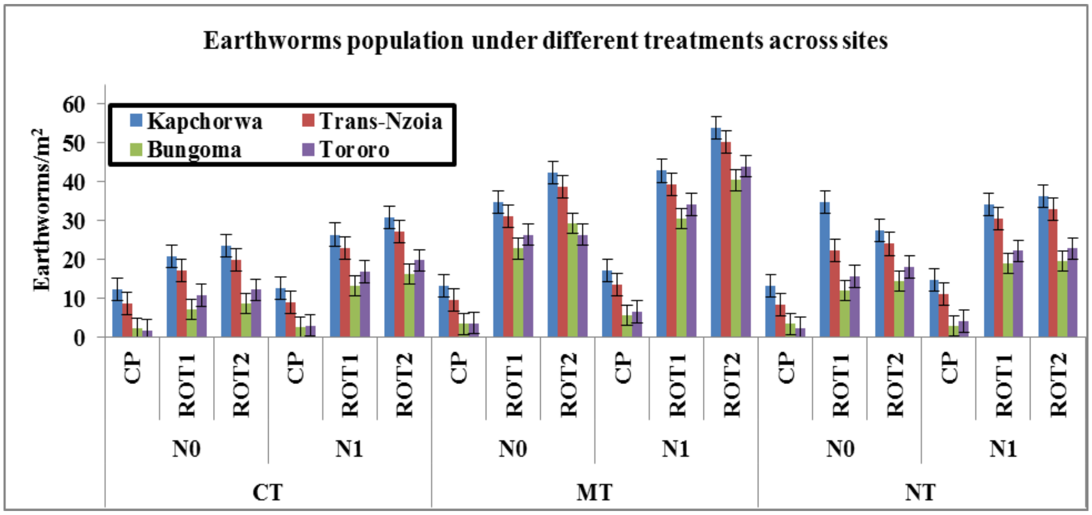


Fig 5.56: Earthworm population count under different tillage systems, cropping systems and nitrogen application across sites

A higher number of earthworms were counted under MT, with CT recording the least number. The soil chemical status of the soil in terms of available P, soil organic carbon and pH was better than the initial stage under different tillage systems. The levels of available phosphorus and percent soil organic carbon were higher under minimum tillage, followed by no-till. CT recorded the least of the the three tillage systems.

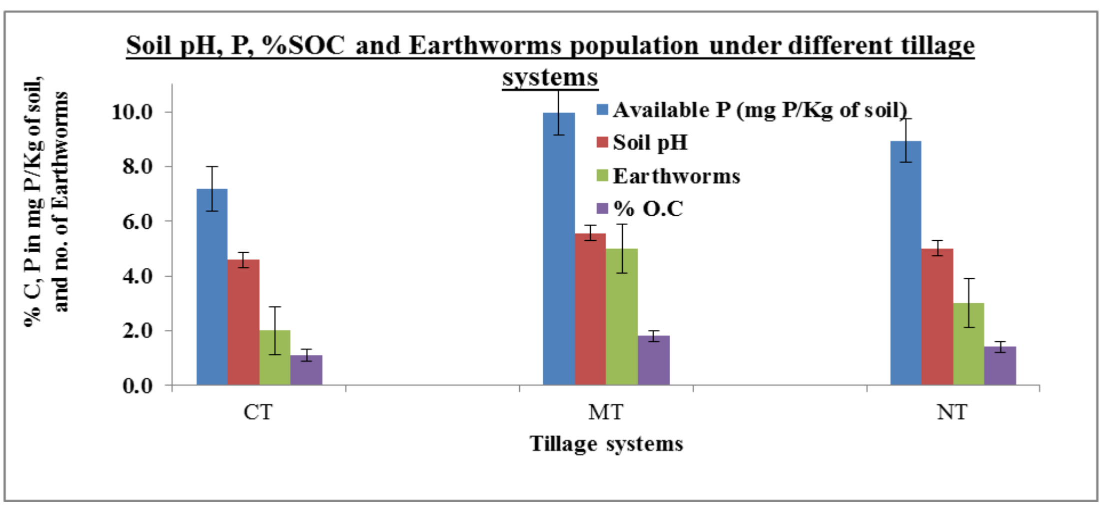


Fig 5.57: The status of the soil chemical parameters and earthworm population

count under different crops in LR2012 cropping season at Tran-Nzoia

The levels of available phosphorus under minimum tillage were significantly high ($p \leq 0.05$) above conventional tillage. Overall, tillage systems had no significant effect ($p \leq 0.05$) on soil pH (Fig 5.57). The levels of soil pH were high under minimum tillage. No-till treatment recorded the second highest levels of soil pH with conventional tillage recording the least.

4.5 Effects of Tillage, Cropping Systems and Nitrogen application on crop yield

4.5.1 Effects of Tillage, Cropping Systems and N application on Maize grain yield

In Bungoma, ROT 2 had the highest maize grain yield mean of 2.77 t/ha among the cropping systems under minimum tillage and N1 at the end of the experiment (Fig 5.58a). It was significantly high above ROT 2 under no-till and conventional tillage (1.42 and 1.91 t/ha respectively). Nitrogen application resulted into an increase in maize grain yield above N0 (Fig 5.58a and 5.58b).

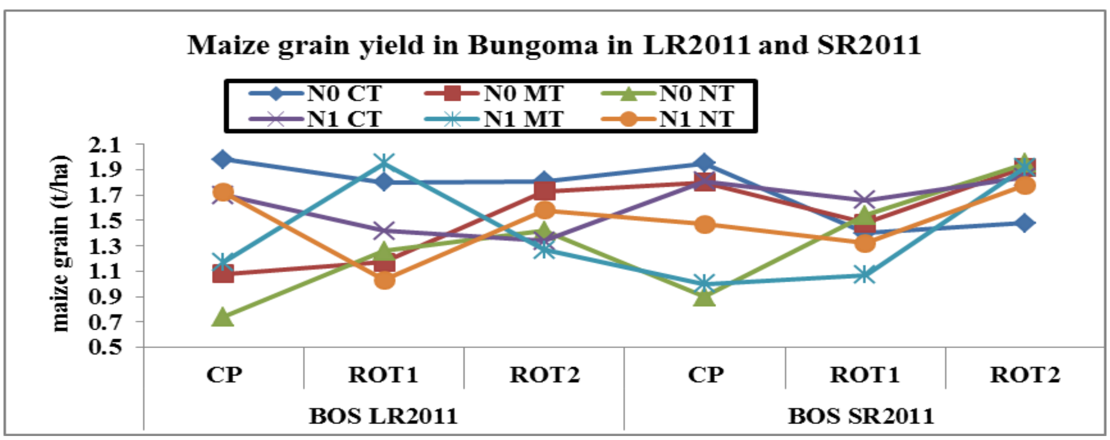


Fig 5.58a: Maize grain yield (t/ha) in Bungoma in LR2011 and SR2011 seasons

This was however not significantly different (p≤0.05) from N0. Overall, minimum tillage recorded the highest maize grain yield, followed by conventional tillage, with no-till recording the least. The treatments tested resulted into an increase in the maize grain yield by above 60% (Fig 5.58a and 5.58b). The highest mean was recorded in LR2012.

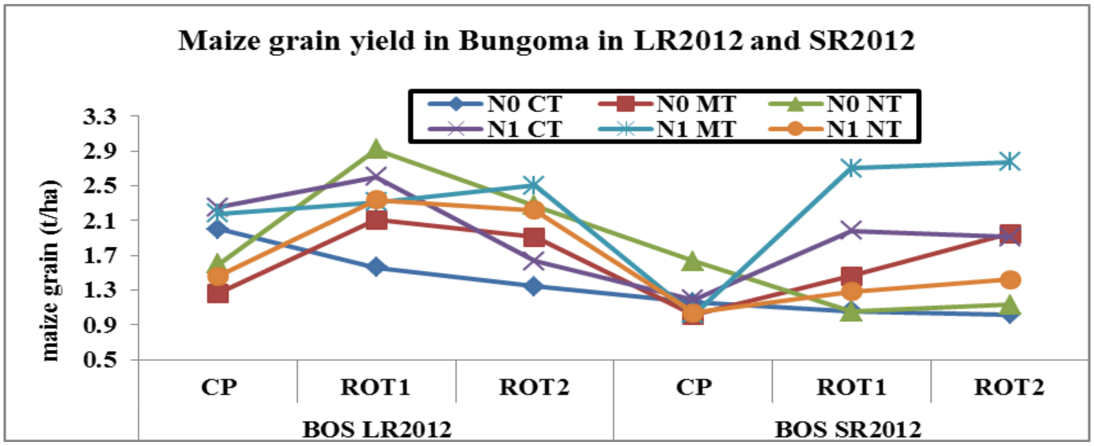


Fig 5.58b: Maize grain yield (t/ha) in Bungoma in LR2012 and SR2012 seasons

Among tillage systems, minimum tillage recorded the highest maize grain yield of 6.11 t/ha in Trans-Nzoia in LR2012 (Fig 5.59). It was significantly high (p≤0.05) above no-till and conventional tillage that recorded the least.

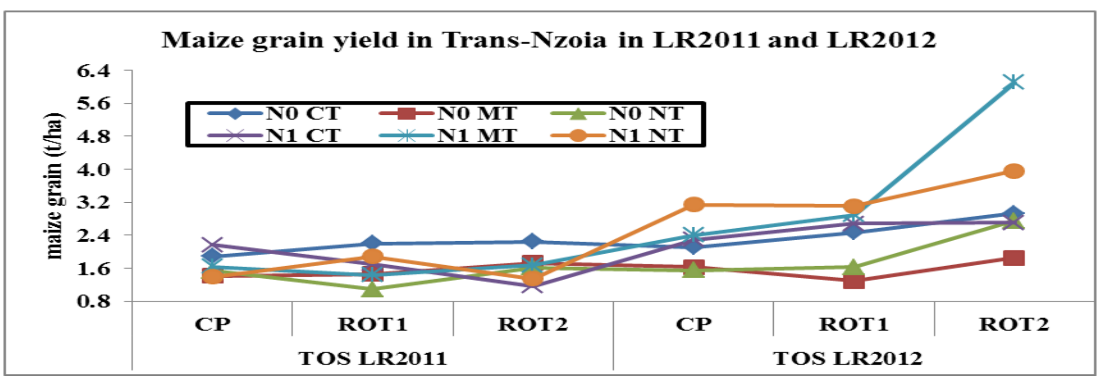


Fig 5.59: Maize grain yield (t/ha) in Trans-Nzoia in LR2011 and LR2012 seasons

Nitrogen application had a significant effect on the resulting maize yield. The grand mean maize yield 0f 2.14 t/ha indicated a 29% increase from 1.65 t/ha in LR2012. Rotation 2 recorded the highest maize grain yield of 3.89 t/ha, followed by ROT 1 and CP (2.17 t/ha and 2.03 t/ha) under minimum tillage. This was in combination with nitrogen application in Trans-Nzoia (Fig 5.59).

Rotation 2 scored the highest maize grain yield of 3.11t/ha in Tororo (Fig 5.60). Similar to Bungoma, minimum tillage recorded the highest means of maize grain yield in Trans-Nzoia. The application of nitrogen too had a significant effect ($p \leq 0.05$) on the resulting maize grain yield in Tororo. The overall increase in maize grain yield from 2.21 t/ha to 2.67 t/ha, represented a 20% increase in Tororo (Fig 5.60).

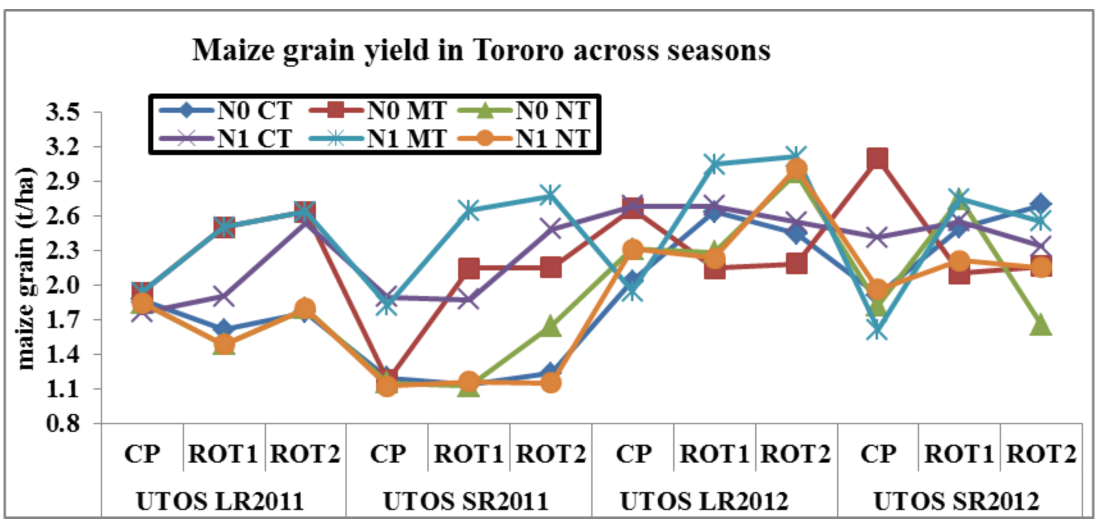


Fig 5.60: Maize grain yield (t/ha) in Tororo in LR2011 and LR2012 seasons

Kapchorwa recorded a significantly high ($p \leq 0.05$) maize grain yield of 3.80t/ha up from 1.43 representing a 165% increase. ROT 2 and ROT 1 resulted into a maize grain mean yield of 4.19 t/ha and 4.06 t/ha respectively (Fig 5.61). This was under minimum tillage and No-till by nitrogen application interaction. There was however no significant difference (p≤0.05) between minimum tillage and no-till. Nitrogen application with a mean of 3.80 t/ha was significantly high (p≤0.05) above N0 that recorded 2.54 t/ha (Fig 5.61).

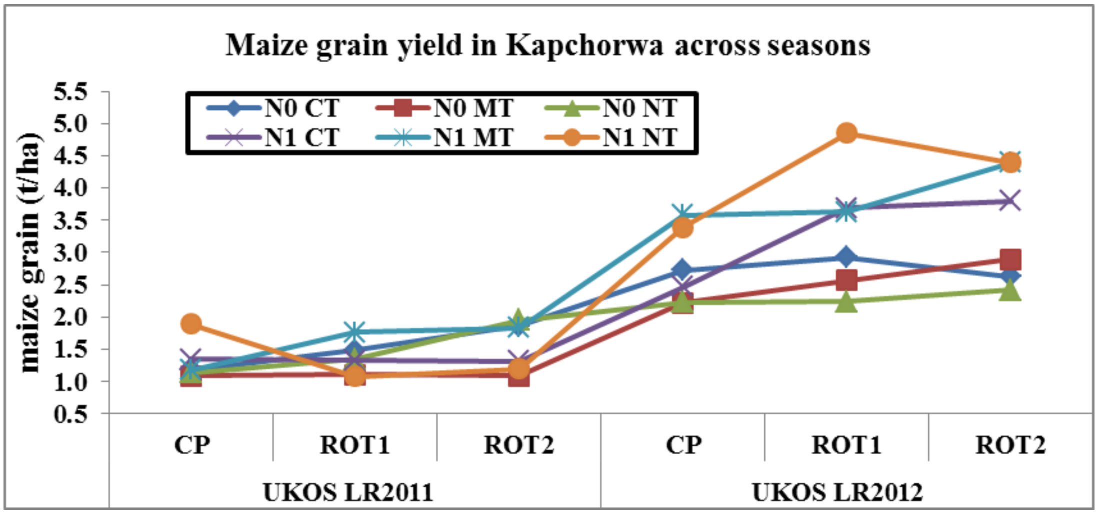


Fig 5.61: Maize grain yield (t/ha) in Kapchorwa in LR2011 and LR2012 seasons

Generally, there was a general increase in the yield of maize across all the four sites as a result of tillage, crooping systems and nitrogen application treatments. The highest maize grain yield was recorded under minimum tillage in rotation 2 with strips of maize, mucuna and beans. This was in combination with nitrogen application.

4.5.2 Effects of Tillage, Cropping Systems and Nitrogen application on Beans grain yield

A mean of 0.39 t/ha beans grain yield was recorded under conventional tillage and ROT 2 with nitrogen application in Bungoma. This was high compared to MT and NT. However, at the end of the experiment in 2012, MT and CT both recorded a mean of 0.34 t/ha under ROT 2 (Fig 5.62). There was no significant difference between ROT 2 and ROT 1 under MT by N-application.

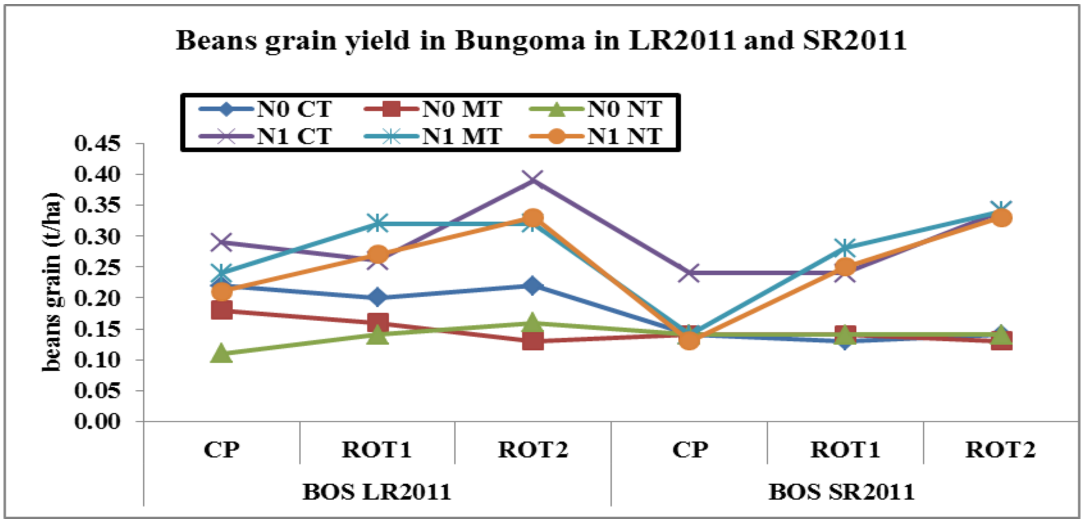


Fig 5.62: Beans grain yield (t/ha) in Bungoma in LR2011 and SR2011 seasons

Minimum tillage performed better than NT in terms of beans grain yield recording a mean of 0.31 t/ha. NT also recorded a similar amount of beans grain yield at 0.31 t/ha

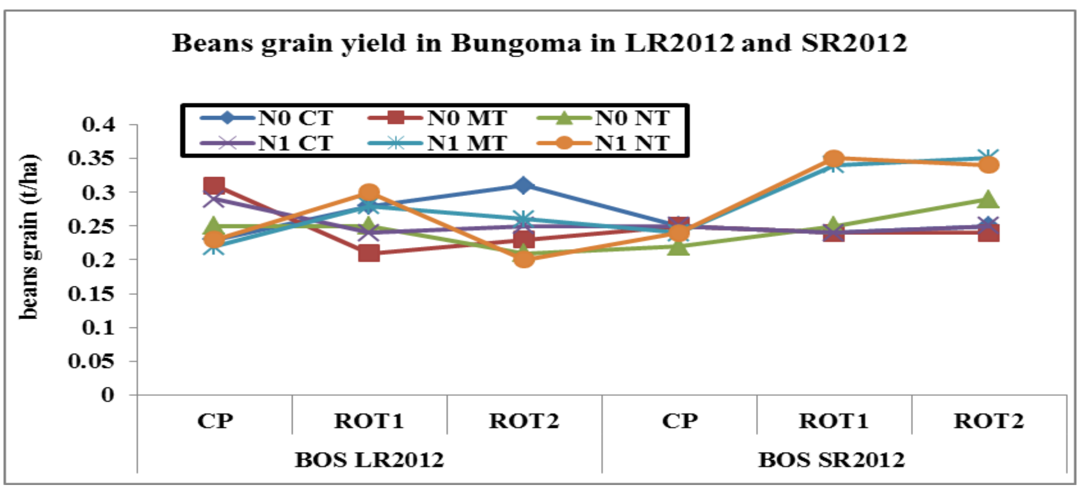


Fig 5.63: Beans grain yield (t/ha) in Bungoma in LR2012 and SR2012 seasons

Conventional tillage was second highest with a mean of 0.25 t/ha. However, the increase in beans grain yields from 0.29 t/ha to 0.31 t/ha was not significant ($p \leq 0.05$) (Fig 5.63).

In Trans-Nzoia, 0.72 t/ha of dry bean grains was recorded as the highest (Table 4.27). This was still under minimum tillage as was the case in Bungoma. This was under MT and ROT 1 interaction coupled with N application (Fig 5.64).

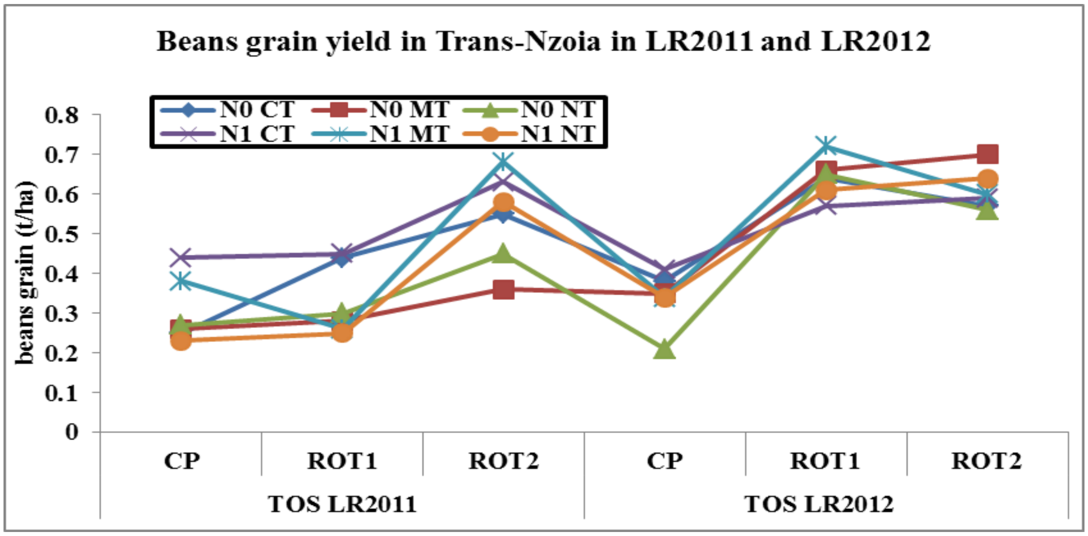


Fig 5.64: Beans grain yield (t/ha) in Trans-Nzoia in LR2011 and LR2012 seasons

This was similar to the yield by ROT 2 under NT and nitrogen application (Table 4.27). Nitrogen application had no significant effect ($p \leq 0.05$) on beans yield in Trans-Nzoia. There was a general increase in bean yield by 17% in Trans-Nzoia County. This was after a rise in bean grain yield from 0.35 t/ha in LR2011 to 0.54 t/ha in LR2012 (Fig 5.64).

There was no significant difference ($p \leq 0.05$) between ROT 2 and ROT 1 under conventional tillage in N0 in Tororo (Fig 5.65 and 5.66). The treatments recorded a mean of 0.24 t/ha. This was high as compared to the highest mean of 0.26 t/ha under the best performing treatment involving nitrogen application and MT by ROT 2 (Fig 5.65 and 5.66). There was no significant difference ($p \leq 0.05$) between N0 and N1 in terms of beans grain yield in Tororo.

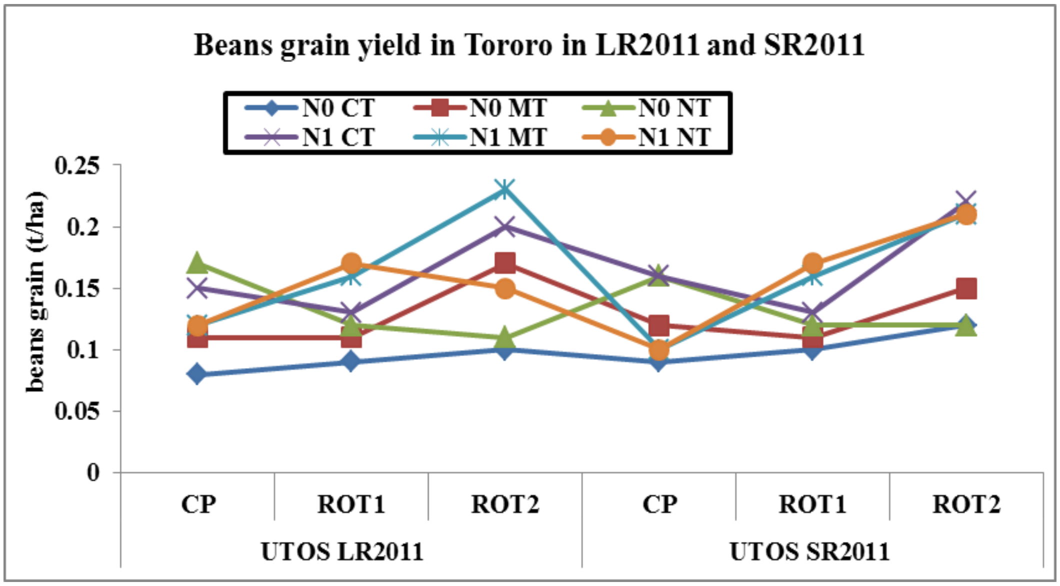


Fig 5.65: Beans grain yield (t/ha) in Tororo in LR2011 and SR2011 seasons

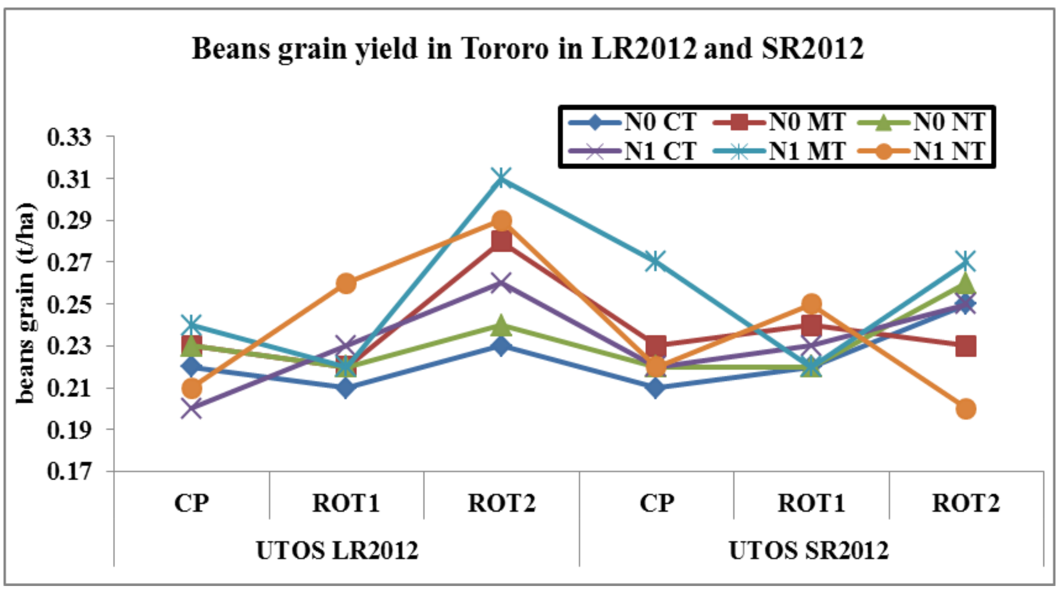


Fig 5.66: Beans grain yield (t/ha) in Tororo in LR2012 and SR2012 seasons

There was no significant difference ($p \leq 0.05$) between N1 and N0 in terms of beans grain yield in Tororo. There was a significant difference ($p \leq 0.05$) between Tororo (with the highest beans yield mean of 0.24 t/ha) (Fig 5.66) and Kapchorwa in terms of beans yield, with the latter recording a beans yield of 0.30 t/ha (Fig 5.67).

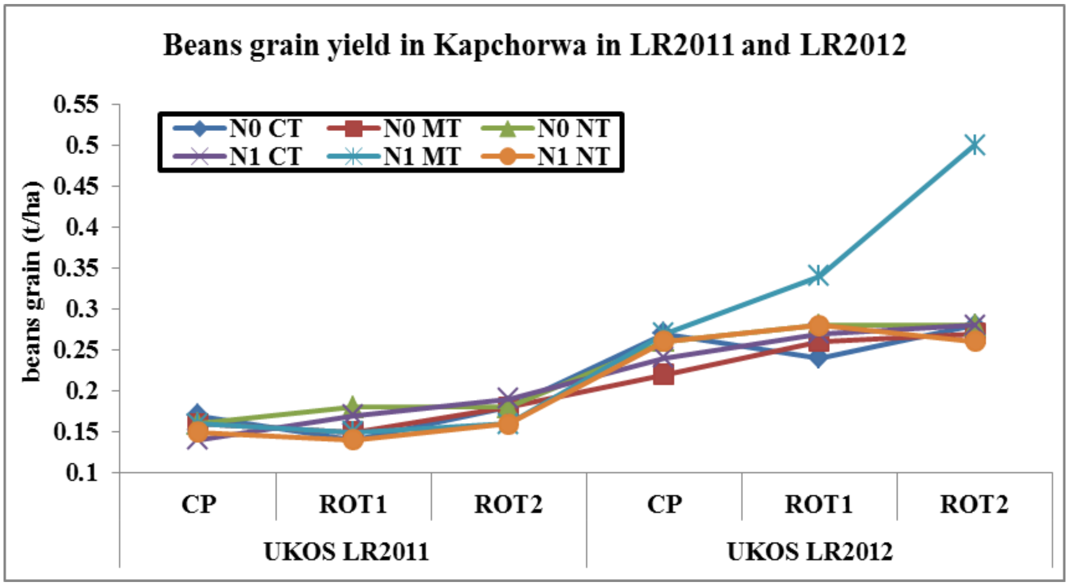


Fig 5.67: Beans grain yield (t/ha) in Kapchorwa in LR2011 and LR2012 seasons

An 87.5% increase in beans yield (from 0.16 to 0.30 t/ha) was recorded in Kapchorwa at the end of LR2012 (Fig 5.67). The highest mean was recorded under MT and ROT 2 in Kapchorwa. This was a mean of 0.50 t/ha under N1 treatment (Fig 5.67).

4.6 Effects of Tillage, Cropping Systems and Nitrogen application on soil nitrate-N (NO3-N) and ammonium-N

4.6.1 Effects of Tillage, Cropping Systems and Nitrogen application on soil nitrate-N

In Trans-Nzoia, there was a significant difference ($p \leq 0.05$) in the levels of nitrates recovered from soils under different cropping systems. More nitrates were recovered under ROT 2, followed by ROT 1 and CP in that order. ROT 2 under minimum tillage realized a greater mean of nitrates at 1254.0 cmol kg^{-1} soil with nitrogen application

(Table 4.30). This was under 0-10cm depth and N1. The counter part treatment under 10-30cm depth however, recorded the highest mean of soil nitrates at 1262.0 cmol kg^{-1} soil.

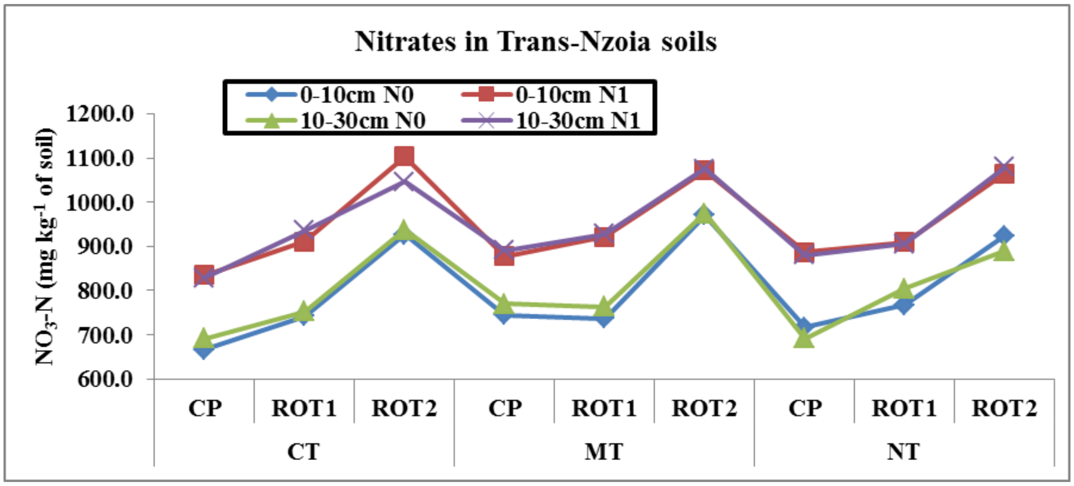


Fig 5.68: Nitrates in Trans-Nzoia soils in LR2011

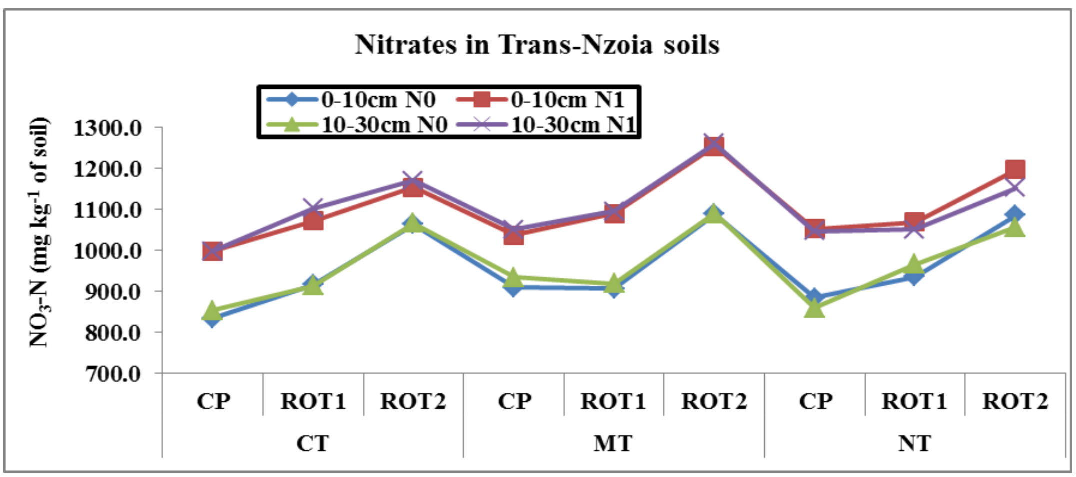


Fig 5.69: Nitrates in Trans-Nzoia soils in LR2012

Nitrogen application significantly influenced a rise in nitrates levels. This saw a higher level of nitrates extracted from Trans-Nzoia soils under N1 (Fig 5.68). Minimum tillage recorded the highest mean of nitrates among tillage systems. There existed no significant difference ($p \leq 0.05$) between 0-10cm and 10-30cm depths in the levels of nitrates recovered in Trans-Nzoia soils. The soil nitrates levels under CT were high in the 10-30cm depth as compared to 0-10cm (Fig 5.69).

There was a significant difference ($p \leq 0.05$) in the nitrates levels between N0 and N1 in Kapchorwa (Fig 5.70). The N1 treatment realized a higher level of nitrates from these soils recording a mean of 981.0 cmol kg^{-1} soil (Fig 5.70).

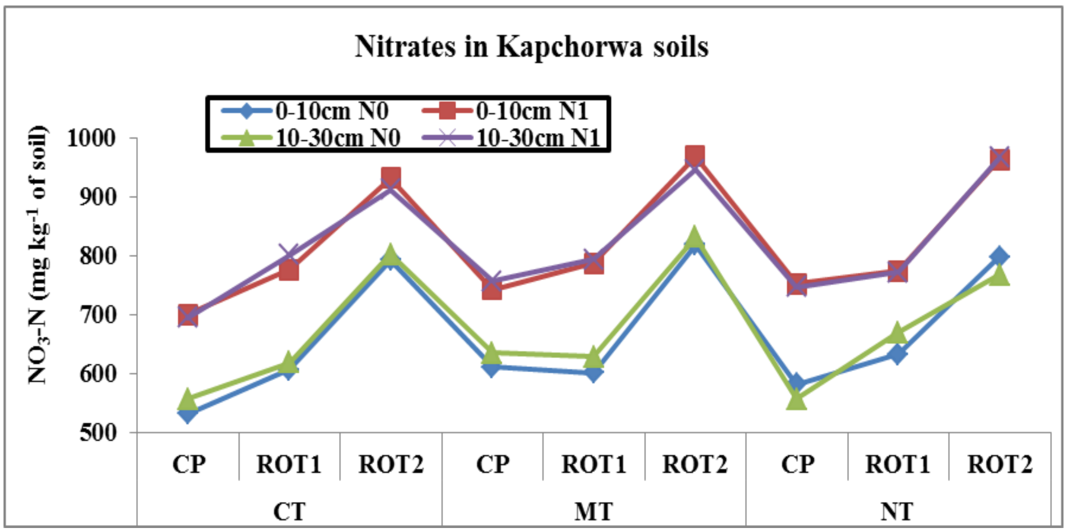


Fig 5.70: Nitrates in Kapchorwa soils in LR2011

The interaction between ROT 2 and minimum tillage recorded the highest mean of 1101.2 cmol kg^{-1} soil among the interactions. This was followed by ROT 2 by no-till interaction with a mean of 1078.0 cmol kg^{-1} soil (Fig 5.71). Under nitrogen application, tillage systems differed significantly ($p \leq 0.05$) in their levels of nitrates in Kapchorwa soils (Fig 5.71). Minimum tillage realized a high level of nitrates followed by no-till, with conventional tillage recording the least (973.5 cmol kg^{-1}soil) (Fig 5.71).

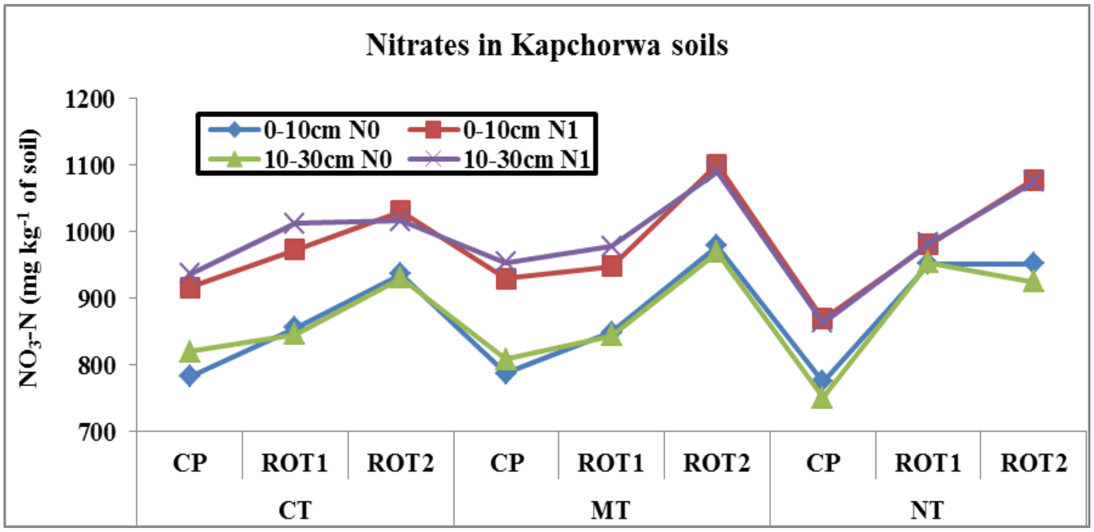


Fig 5.71: Nitrates in Kapchorwa soils in LR2012

There was no significant difference in the nitrates levels between 0-10cm and 10-30cm in Bungoma (Fig 5.72 to 5.75). Strip cropping involving mucuna, maize and beans in ROT 2 realized a recovery of more nitrates levels higher than ROT 1 and CP. Nitrogen application significantly ($p \leq 0.05$) influenced an increase in nitrates levels in Bungoma soils (Fig 5.72 and 5.73). There was a significant difference ($p \leq 0.05$) between MT and CT in the nitrates levels recovered in Bungoma soils. There was however no significant difference ($p \leq 0.05$) between MT and NT, even though nitrates levels were higher under MT (Fig 5.74 and 5.75).

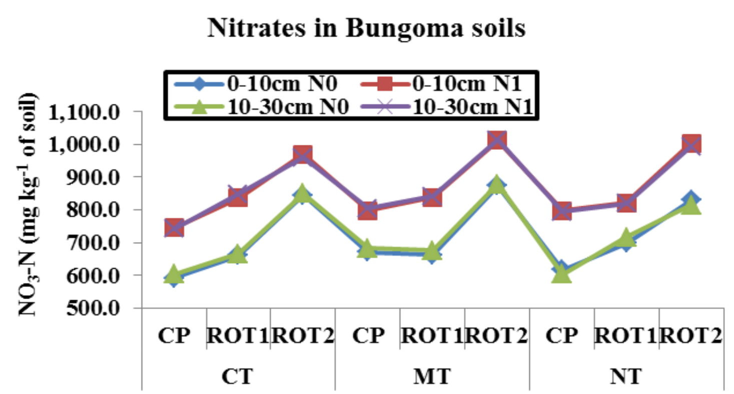


Fig 5.72: Nitrates in Bungoma soils in LR2011

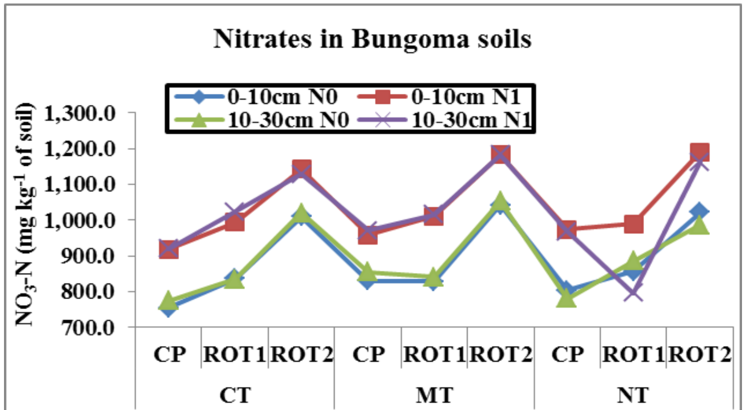


Fig 5.73: Nitrates in Bungoma soils in SR2011

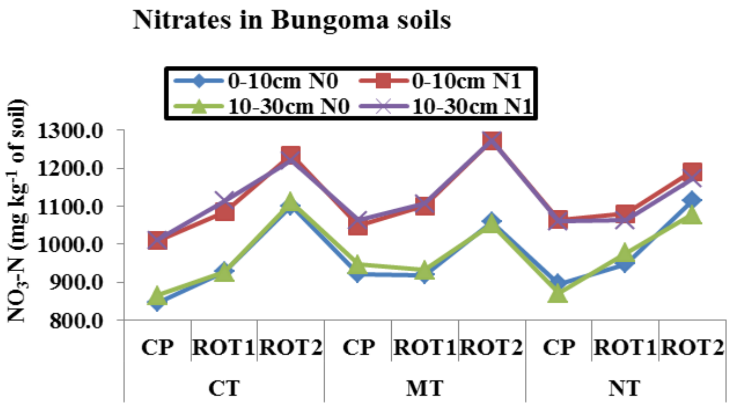


Fig 5.74: Nitrates in Bungoma soils in LR2012

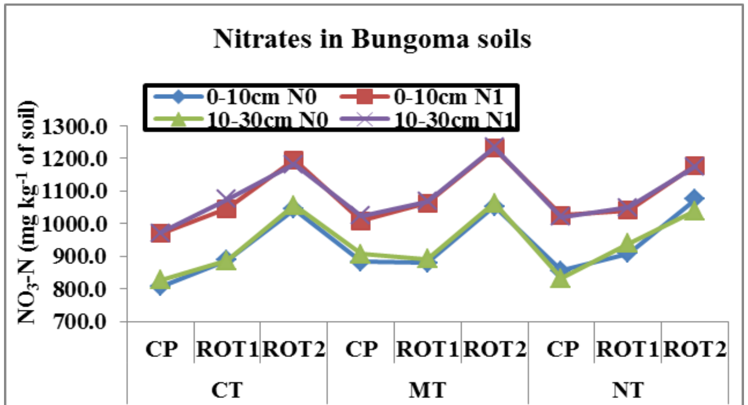


Fig 5.75: Nitrates in Bungoma soils in SR2012

This was under 10-30cm depth. There was however no significant difference ($p \leq 0.05$) in nitrates levels between 0-10 and 10-30cm sampling depths in Bungoma (Fig 5.72–5.75).

In Tororo, a mean of 1117.0 cmol kg^{-1} soil nitrates were recovered (Fig 5.76–5.79). This was the highest amongst the treatments. It was under ROT 2 by NT by N1 interaction at 10-30cm depth (Fig 5.77). These nitrates level was not significantly different ($p \leq 0.05$) from ROT 2 by NT by N1 interaction at 0-10cm depth. It was also not significantly different ($p \leq 0.05$) from MT by ROT 2 by N1 interaction with 1112.9 cmol kg^{-1} soil. This was significantly influenced ($p \leq 0.05$) by nitrogen application, as N0 recorded least amount of nitrates. There was no significant difference ($p \leq 0.05$) between MT and NT. However, CT recorded the least amount of nitrates. These were significantly low ($p \leq 0.05$) as compared to MT and NT (Fig 5.78–5.79). There was a general rise in soil nitrates in Tororo soils at the end of the experiment.

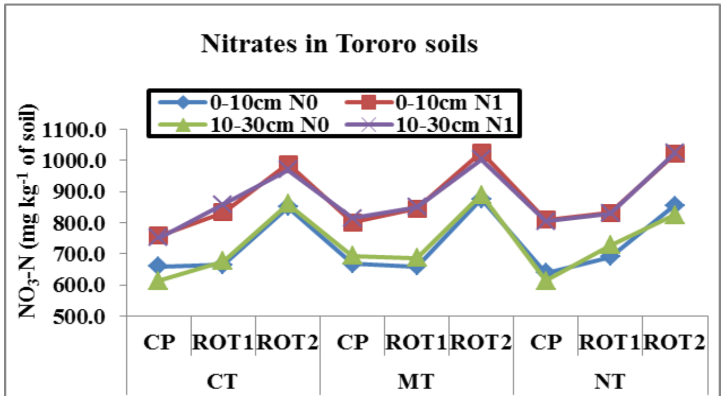


Fig 5.76: Nitrates in Tororo soils in LR2011

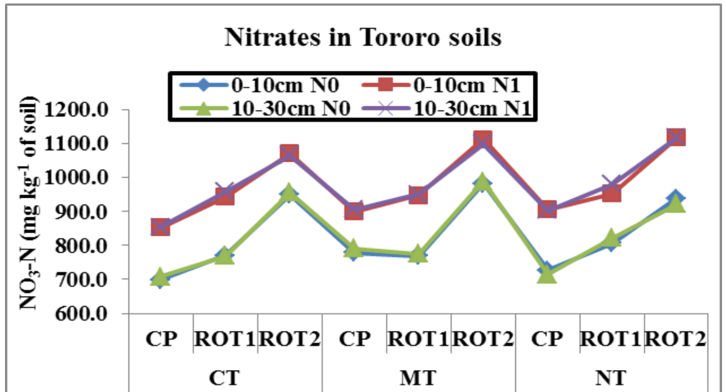


Fig 5.77: Nitrates in Tororo soils in SR2011

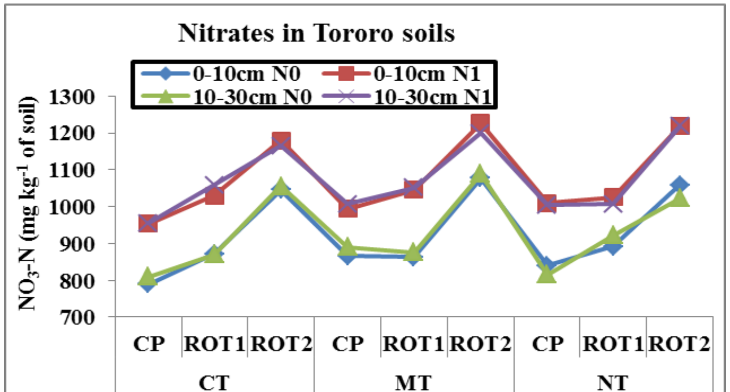


Fig 5.78: Nitrates in Tororo soils in LR2012

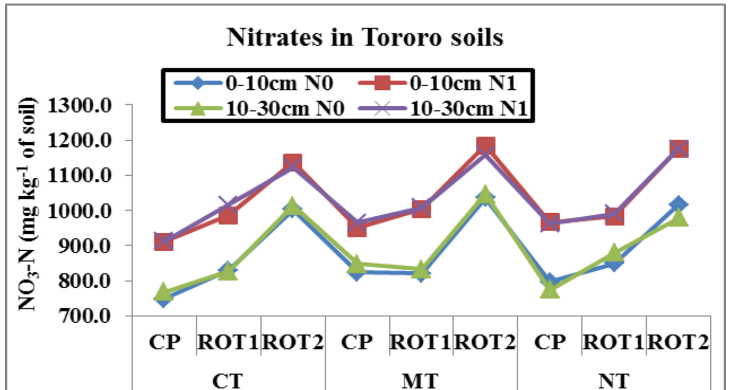


Fig 5.79: Nitrates in Tororo soils in SR2012

The treatments resulted into a 37% increase between LR2011 and SR2012 in Tororo (Fig 5.78–5.79). The highest means of nitrates were recovered mainly in the long rain seasons. The LR2012 cropping season however recorded the highest means of nitrates amongst the two long rain seasons (Fig 5.76–5.79). This was the same case both under 0-10cm and 10-30cm depth (Fig 5.78–5.79).

In general, there was an increase in the level of soil nitrates in all the four sites-Bungoma, Kapchorwa, Trans-Nzoia and Tororo. Cropping systems significantly influenced ($p \leq 0.05$) this rise, with ROT 2 resulting into higher levels of nitrate. Even though minimum tillage scored higher in terms of the recovered soil nitrates, in most cases it was not significantly different ($p \leq 0.05$) from NT. In all sites however, conventional tillage did not result in a significant ($p \leq 0.05$) rise in soil nitrates.

4.6.2 Effects of Tillage, Cropping Systems and Nitrogen application on soil ammonium-N (NH4+-N)

The levels of ammonium-N (NH_{4+}-N) in Bungoma were significantly ($p \leq 0.05$) higher in the 0-10cm than in 10-30cm depth (Fig 5.80–5.83). Results of the recovered ammonium in Bungoma soils indicate NT by ROT 2 by N1 interaction as being the highest. This had a mean of 1007.0 cmol kg^{-1} soil under 0-10cm depth (Fig 5.82–5.83). It was significantly different from MT by ROT by N1 having 989.0 cmol of NH_4-N/kg soil (Fig 5.82). There was no significant difference ($p \leq 0.05$) between minimum tillage and no-till in the ammonium levels in Bungoma soils. However, the two conservation agriculture tillage systems (MT and NT) recorded higher levels of ammonium that was significantly different ($p \leq 0.05$) from conventional tillage (CT) practice (Fig 5.80–5.83).

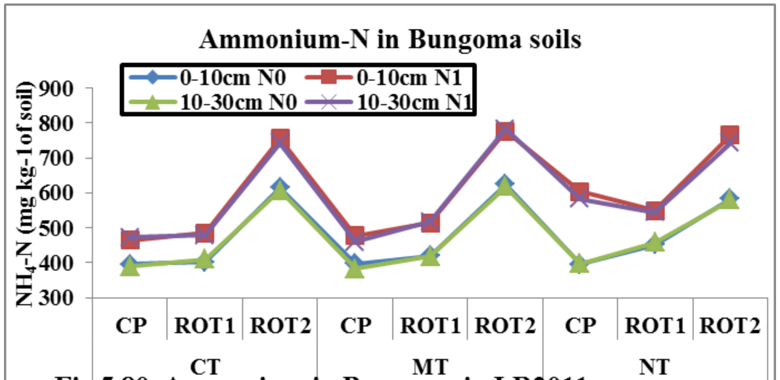


Fig 5.80: Ammonium in Bungoma in LR2011

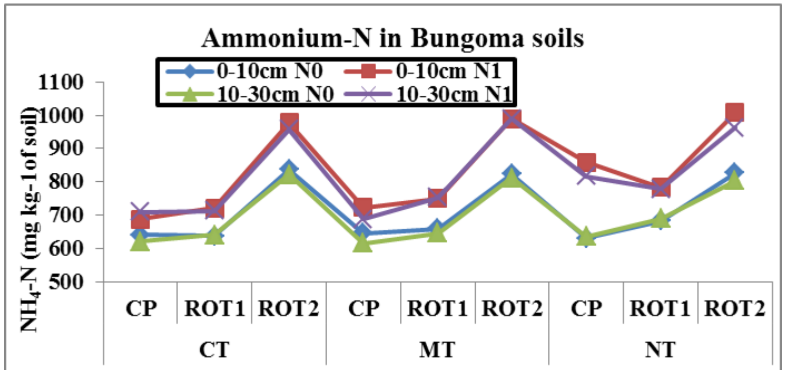


Fig 5.81: Ammonium in Bungoma in SR2011

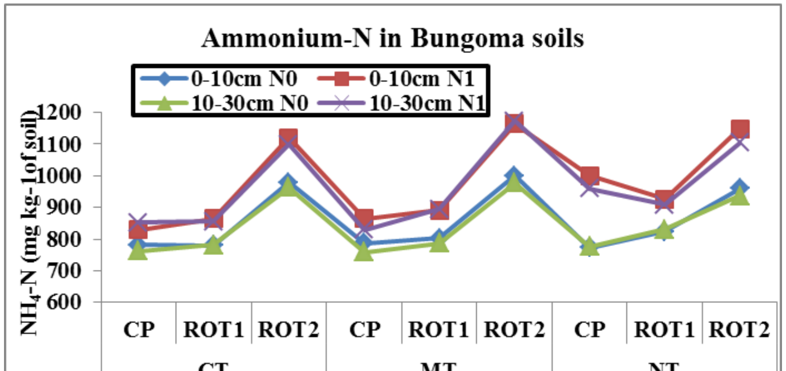


Fig 5.82: Ammonium in Bungoma in LR2012

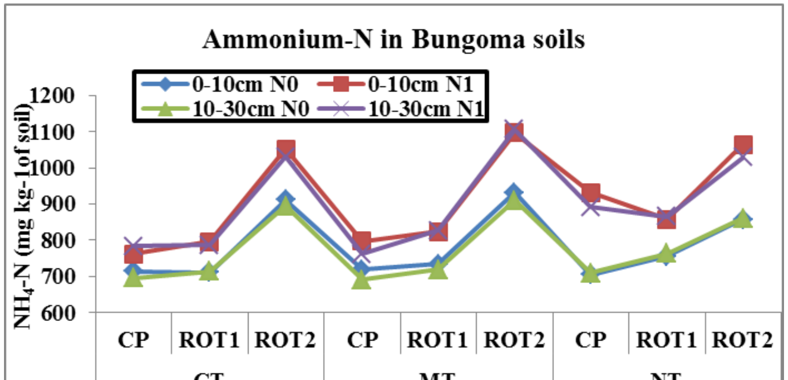


Fig 5.83: Ammonium in Bungoma in SR2012

Nitrogen application had a significant effect ($p \leq 0.05$) on ammonium levels. The means of ammonium under N1 were high as compared to N0 in Bungoma. This was high under 0-10cm in comparison to 10-30cm depth (Fig 5.80–5.83). Rotation 2 had the highest means of soil ammonium-N in Tororo soils having 1079.0 cmol of NH_4-N/kg soil at 0-10cm. The levels of ammonium were however higher under 10-30cm sampling depths in MT by N1 by ROT 2 treatment interaction.These were similar to ROT 2 by N1 under NT (Fig 5.84-5.87). The two cropping systems (ROT 1 and ROT 2) were however significantly different ($p \leq 0.05$) from current practice (CP) that recorded the least means of ammonium-N (Fig 5.84-5.87). N application yielded more ammonium in Tororo soils as compared to N0. N1 and N0 differed significantly in their ammonium levels in Tororo soils (Fig 5.84-5.87).

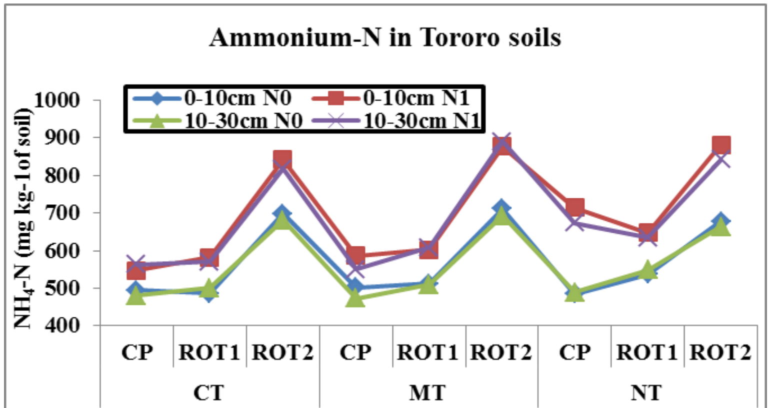


Fig 5.84: Ammonium in Tororo in LR2011

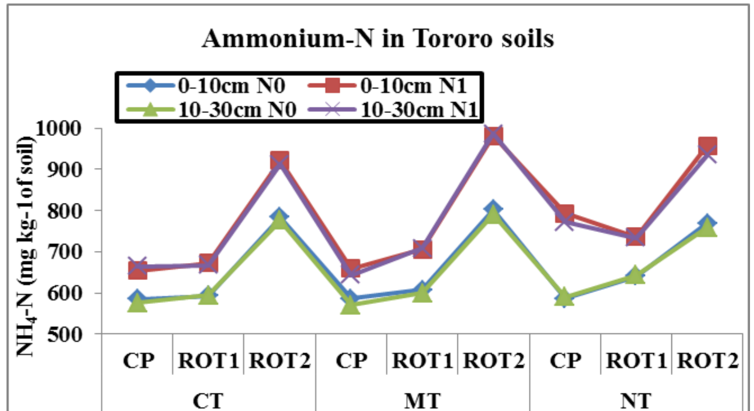


Fig 5.85: Ammonium in Tororo in SR2011

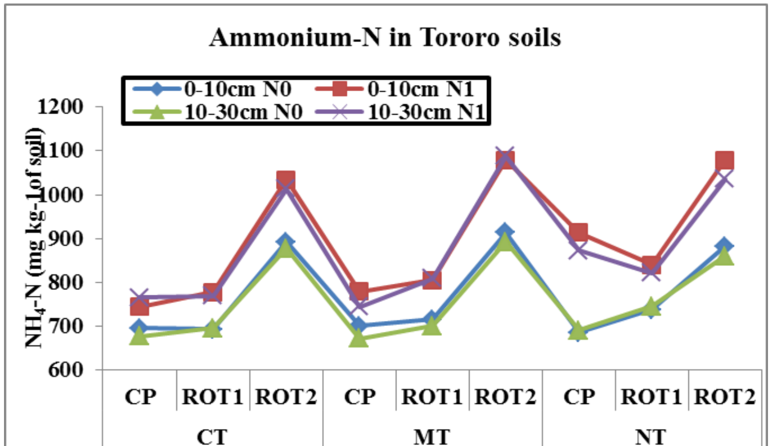


Fig 5.86: Ammonium in Tororo in LR2012

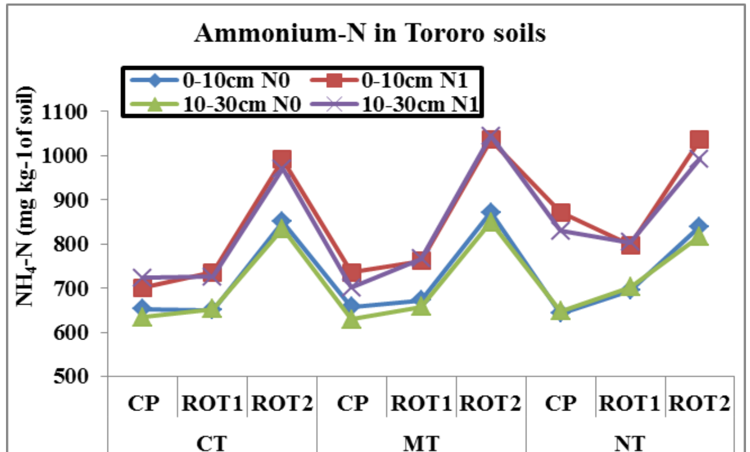


Fig 5.87: Ammonium in Tororo in SR2012

This was evident with the lower levels recorded under N0 as compared to N1 (Fig 5.84-5.87). There were higher levels of ammonium in the 0-10cm depth as compared to 10-30cm (Fig 5.86). The two sampling depths were significantly different ($p \leq 0.05$) in terms of soil ammonium levels.

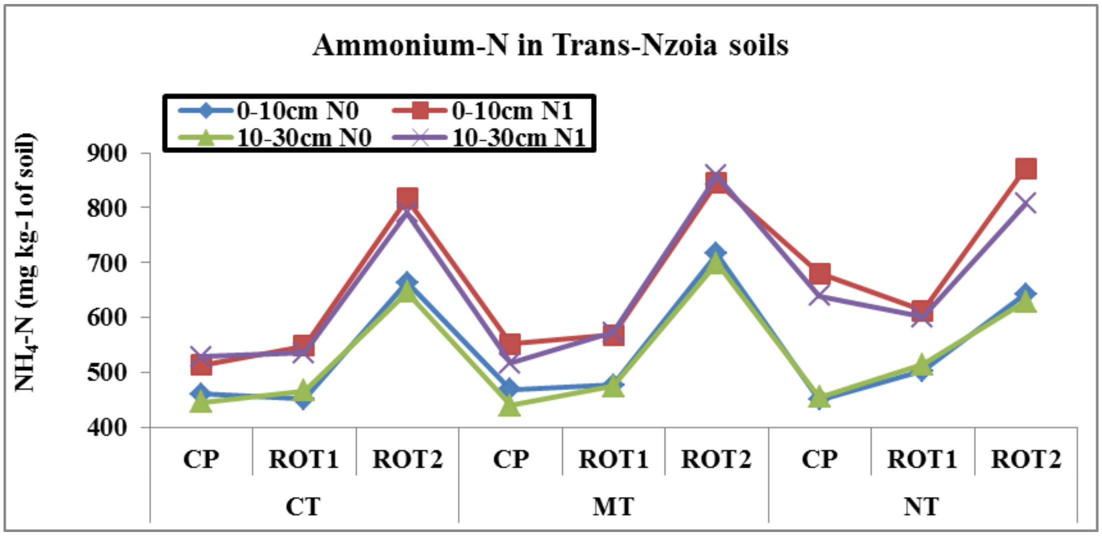


Fig 5.88: Ammonium-N in Trans-Nzoia soils in LR2011

Trans-Nzoia realized 1017.0 cmol kg^{-}1of soil under ROT 2 by MT interaction (at 0-10cm) with this being the highest means. This was in interaction with N1 (Fig 5.88). The levels of ammonium-N under ROT 2 in combination with NT were second highest at 1001.0 cmol kg^{-1} soil (Fig 5.89). Overall, there was a significant effect ($p \leq 0.05$) by N application on ammonium-N in Trans-Nzoia soils. This was evident with the higher levels of ammonium-N recovered under N1 (Fig 5.89).

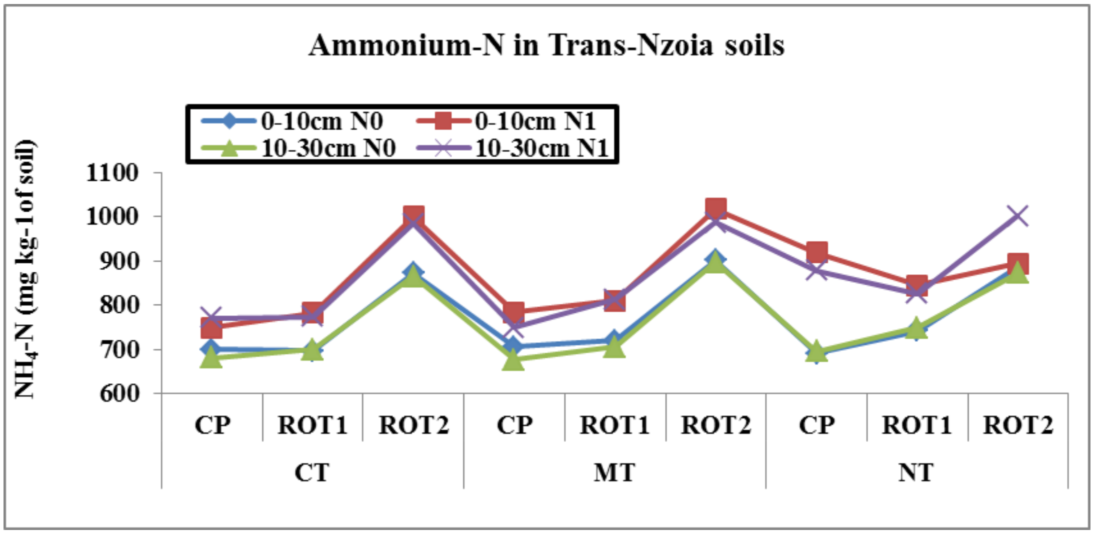


Fig 5.89: Ammonium-N in Trans-Nzoia soils in LR2012

Similar to Trans-Nzoia, nitrogen application had a significant effect ($p \leq 0.05$) on ammonium-N in Kapchorwa soils (Fig 5.90). Rotation 2 in interaction with minimum tillage recorded the highest mean of 983.0 cmol kg^{-1} soil. This was followed closely with 953.0 cmol kg^{-1} soil in the NT by ROT 2 interaction all under 0-10cm depth (Fig 5.90). The two interactions however were not significantly different ($p \leq 0.05$) in terms of ammonium-N in Trans-Nzoia soils. There was a significant increase in ammonium levels from 597.0 cmol kg^{-1} soil in LR2011 to 826.0 cmol kg^{-1} of soil in LR2012 in Trans-Nzoia (Fig 5.91).

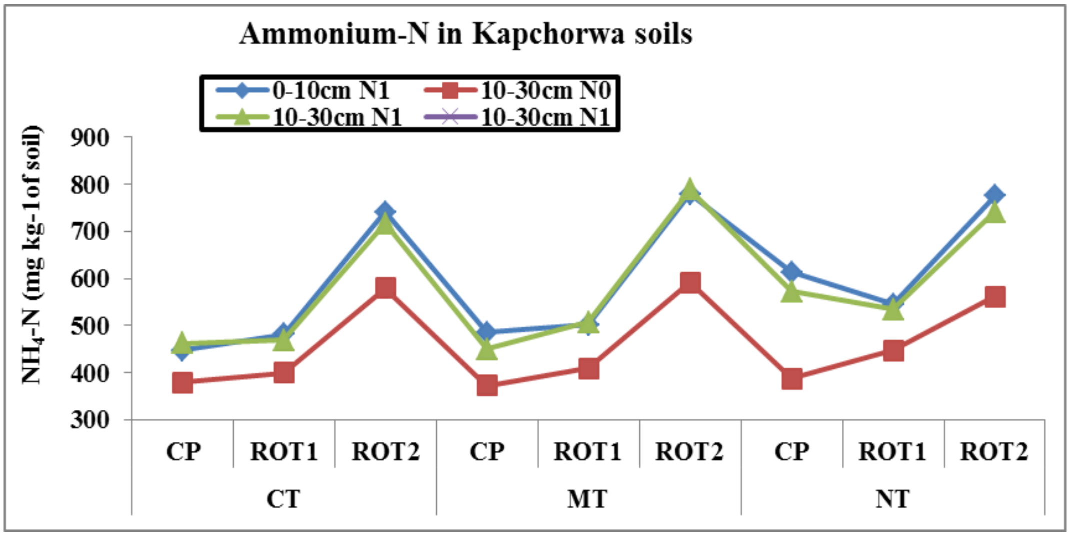


Fig 5.90: Ammonium-N in Kapchorwa in LR2011

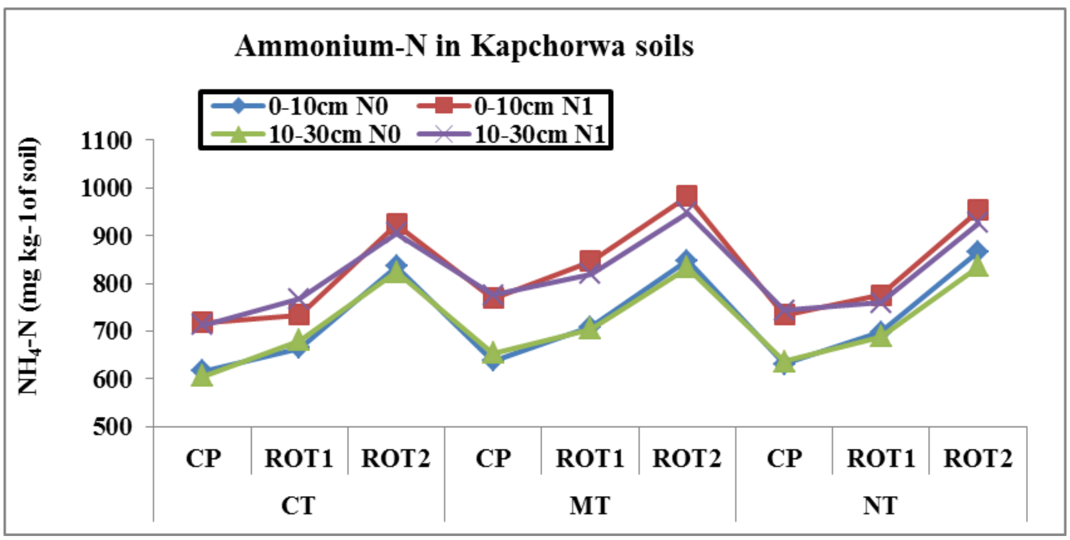
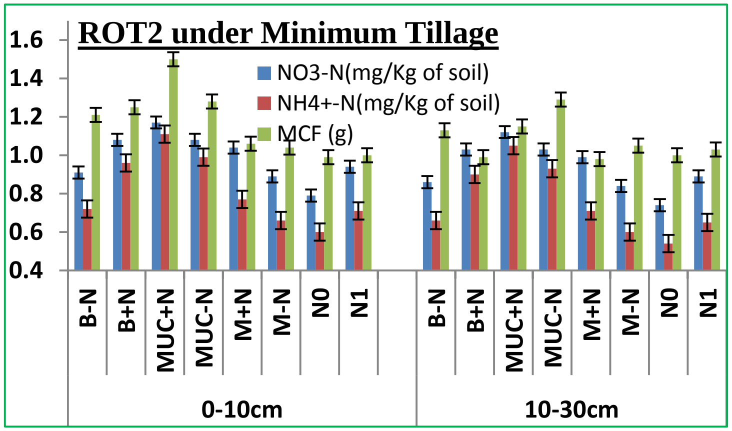


Fig 5.91: Ammonium-N in Kapchorwa in LR2012

In general, application of nitrogen had a significant effect ($p \leq 0.05$) on ammonium-N levels in all the four sites. The ammonium levels were high under N1 in all the sites. Amongst cropping systems, ROT 2 had significantly high levels of ammonium-N above ROT 1 and CP. Tillage systems (CT, MT and NT) had a significant effect ($p \leq 0.05$) on ammonium-N levels in all the four sites- Bungoma, Kapchorwa, Trans-Nzoia and Tororo.



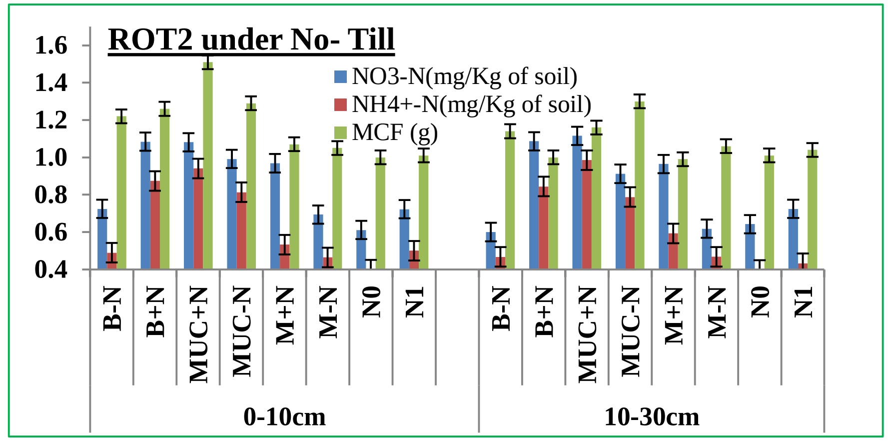
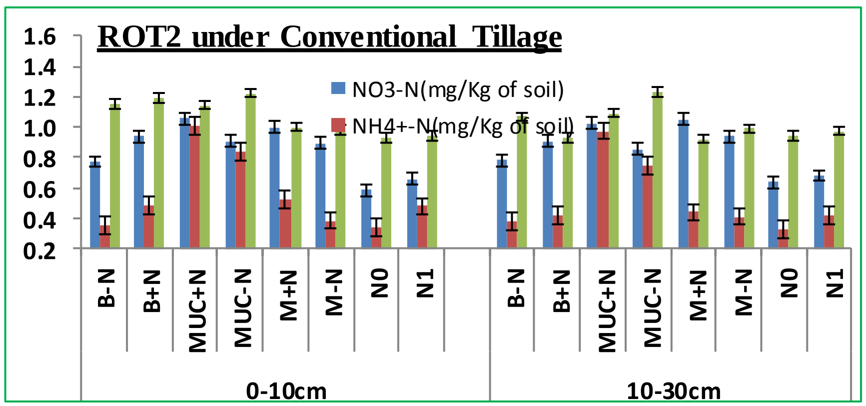


Fig 5.92: Miimum Tillage vs ROT2 in LR2012 in Bungoma

Fig 5.93: No-Till vs ROT2 in LR2012 in Kapchorwa



KEY:
B-N: **Beans without Nitrogen Application**
B+N: **Beans with Nitrogen Application**
MUC+N: **Mucuna without Nitrogen Application**
MUC-N: **Mucuna with Nitrogen Application**
M+N: **Maize with Nitrogen Application**
M-N: **Maize without Nitrogen Application**
N0: **No Nitrogen Application**
N1: **Nitrogen Application**

Fig 5.94: Conventional Tillage vs ROT2 in LR2012 in Trans-Nzoia

Minimum tillage recorded higher levels of ammonium-N as compared to no-till and conventional tillage. In some sites however, there was no significant difference between NT and MT, but CT recorded the least. Conventional tillage recorded significantly ($p \leq 0.05$) low ammonium-N levels in all the four sites (Fig 5.92-5.94).

Additionally, there was high Moisture content under Mucuna cover crop as compared to maize and beans, or their intercrops (Fig 5.92-5.94). Mucuna covered most of the plot area where it was grown as shown in plates 1 and 2.

Plate 2: ROT2 cropping system with maize-beans-mucuna strips

Plate 3: ROT1 cropping system with maize-beans intercrop, with mucuna to be introduced after harvest of beans.

There was a greater percentage of land cover under mucuna cover crop than maize beans intercrops (plate 2 and 3).

4.7 Economic analysis

The inputs for the experiment in all the four sites were all acquired once in 2011 before planting. None of the treatments proved to be economical in Bungoma. Minimum tillage proved to be economically viable in Trans-Nzoia. This in combination with ROT 2 cropping system yielded an MRR of 76% and 24 under +N and –N respectively. However, MT by CP resulted into the highest percent MRR at 196% (Table 4.39).

Table 4.2; Added cost of production (Ksh) for Bungoma and Trans-Nzoia in the year 2011

Site	Nitrogen Application	Tillage system	Cropping systems	Inorganic inputs	Labour and others	TCV	Inorganic inputs (%)
Bungoma	**-N**	CT	ROT 1	13948	3733	17681	79
		CT	CP	13409	4073	17482	77
		CT	ROT 2	13256	3181	16437	81
		MT	CP	13343	2906	16249	82
		MT	ROT 2	13009	3953	16962	77
		MT	ROT 1	13751	3720	17471	79
		NT	CP	15744	1483	17227	91
		NT	ROT 2	15203	2187	17390	87
		NT	ROT 1	15750	2334	18084	87
	+N	NT	ROT 2	14148	3242	17390	81
		CT	ROT 1	13619	2032	15651	87
		CT	CP	13234	2985	16219	82
		MT	ROT 1	13472	2038	15510	87
		MT	ROT 2	13209	1094	14303	92
		MT	CP	13854	3090	16944	82
		NT	ROT 1	13644	2170	15814	86
		NT	ROT 2	13209	2333	15542	85
		NT	CP	13254	2276	15530	85
Trans-Nzoia	**-N**	CT	ROT 1	13148	2350	15498	85
		CT	CP	13209	2927	16136	82
		CT	ROT 2	13656	2906	16562	82
		MT	CP	13733	2191	15924	86
		MT	ROT 2	13169	3037	16206	81

		MT	ROT 1	13551	3267	16818	81
		NT	ROT 2	15684	3490	19174	82
		NT	CP	15173	3318	18491	82
		NT	ROT 1	15670	2728	18398	85
	+N	CT	ROT 2	13128	3418	16546	79
		CT	ROT 1	13619	3430	17049	80
		CT	CP	13334	2269	15603	85
		MT	CP	13478	2732	16210	83
		MT	ROT 1	13523	2318	15841	85
		MT	ROT 2	13694	2800	16494	83
		NT	ROT 1	13554	2440	15994	85
		NT	ROT 2	13229	2872	16101	82
		NT	CP	13154	2826	15980	82

GFB=Gross field benefits, TCV = Total variable cost, NFB = Net financial benefits, MRR = Marginal rate of return, D = dominated treatment (i.e. with less than or equal to treatment with lower TVC that were eliminated from further consideration since no farmer choose a treatment(s) with higher TVC and receive lower NFB), bold and coloured indicate economically viable treatment.

Table 4.3; Gross field benefits, TCV, NFB and MRR analysis of treatments for Bungoma and Trans-Nzoia in 2011

Site	Nitrogen Application	Tillage system	Cropping systems	GFB (KES)	TCV	NFB	MRR (%)
Bungoma	**-N**	CT	ROT 1	23954	17681	6273	
		CT	CP	19596	17482	2114	D
		CT	ROT 2	19390	16437	2953	-
		MT	CP	17342	16249	1093	D
		MT	ROT 2	17888	16962	926	-
		MT	ROT 1	18381	17471	910	-
		NT	CP	23979	17227	6752	-
		NT	ROT 2	19835	17390	2445	D
		NT	ROT 1	19556	18084	1472	-
	+N	NT	ROT 2	19835	17390	2445	-
		CT	ROT 1	19603	15651	3952	-
		CT	CP	18766	16219	2547	-
		MT	ROT 1	18399	15510	2889	-
		MT	ROT 2	19465	14303	5162	-
		MT	CP	17625	16944	681	-
		NT	ROT 1	17716	15814	1902	-
		NT	ROT 2	18619	15542	3077	-
		NT	CP	19559	15530	4029	-
Trans-Nzoia	**-N**	CT	ROT 1	18674	15498	3176	D
		CT	CP	18398	16136	2262	-
		CT	ROT 2	19408	16562	2846	137
		MT	CP	19287	15924	3363	-
		MT	ROT 2	19636	16206	3430	24
		MT	ROT 1	18307	16818	1489	-
		NT	ROT 2	19352	19174	178	-

		NT	CP	18820	18491	329	-
		NT	ROT 1	19601	18398	1203	-
	+N	CT	ROT 2	19119	16546	2573	-
		CT	ROT 1	19598	17049	2549	-
		CT	CP	16801	15603	1198	93
		MT	CP	18598	16210	2388	196
		MT	ROT 1	18403	15841	2562	-
		MT	ROT 2	19550	16494	3056	76
		NT	ROT 1	19587	15994	3593	-
		NT	ROT 2	18509	16101	2408	-
		NT	CP	18498	15980	2518	-

GFB=Gross field benefits, TCV = Total variable cost, NFB = Net financial benefits, MRR = Marginal rate of return, D = dominated treatment (i.e. with less than or equal to treatment with lower TVC that were eliminated from further consideration since no farmer choose a treatment(s) with higher TVC and receive lower NFB), bold and coloured indicate economically viable treatment.

In Tororo and Kapchorwa, nitrogen application (+N) proved to be more economical than -N treatment (Table 4.41). Minimum tillage combined with ROT 1 recorded the highest percent MRR of 107% in Tororo. Minimum tillage combined with ROT 2 recorded the second highest MRR of 17% in Tororo. MT treatment dominated in Tororo and Kapchorwa all through the experimental period. This was under N0.

MT without N-application was also economically viable in Tororo and Kapchorwa with 64% MRR (Table 4.41).

Under cropping systems, ROT 2 was the most dominant treatment in all the four sites. It was the followed by ROT 1, with CP being the least. ROT 1 recorded the highest NFB across all the sites. CP in interaction with MT and NT was also an economical treatment in both Tororo and Kapchorwa.

Table 4.4; Added cost of production (Ksh) for Tororo and Kapchorwa in the year 2011

Site	Nitrogen Application	Tillage System	Cropping systems	Inorganic inputs	Labour and others	TCV	Inorganic inputs (%)
Tororo	-N	**CT**	**CP**	15629	4027	19656	80
		CT	ROT 1	15160	3863	19023	80
		CT	ROT 2	15518	3718	19236	81
		NT	ROT 1	12209	3286	15495	79
		NT	ROT 2	15009	2559	17568	85
		NT	CP	14124	2909	17033	83
		MT	ROT 2	14729	4007	18736	79
		MT	ROT 1	14815	5632	20447	72
		MT	CP	15799	5953	21752	73
	+N	NT	ROT 2	10024	2866	12890	78
		NT	ROT 1	16068	4053	20121	80
		NT	CP	12707	2649	15356	83
		CT	ROT 1	15928	2194	18122	88
		CT	ROT 2	16209	3329	19538	83
		CT	CP	15825	3479	19304	82
		MT	ROT 2	12898	3752	16650	77
		MT	ROT 1	16023	2741	18764	85
		MT	CP	14890	2973	17863	83
Kapchorwa	-N	**CT**	**CP**	14621	4287	18908	77
		CT	ROT 1	14979	3791	18770	80
		CT	ROT 2	14670	3434	18104	81
		NT	ROT 1	14470	3533	18003	80
		NT	ROT 2	13585	3119	16704	81
		NT	CP	14190	2823	17013	83
		MT	ROT 2	14276	2524	16800	85

		MT	ROT 1	15260	2981	18241	84
		MT	CP	15485	3207	18692	83
	+N	NT	ROT 2	15529	2917	18446	84
		NT	ROT 1	16168	2948	19116	85
		NT	CP	15389	2945	18334	84
		CT	**ROT 2**	15670	2688	18358	85
		CT	ROT 1	15286	2816	18102	84
		CT	CP	15359	2819	18178	84
		MT	ROT 2	12484	2506	14990	83
		MT	ROT 1	15537	2340	17877	87
		MT	CP	15910	2650	18560	86

GFB=Gross field benefits, TCV = Total variable cost, NFB = Net financial benefits, MRR = Marginal rate of return, D = dominated treatment (i.e. with less than or equal to treatment with lower TVC that were eliminated from further consideration since no farmer choose a treatment(s) with higher TVC and receive lower NFB), bold and coloured indicate economically viable treatment.

Table 4.5; Gross field benefits, total costs that vary, net financial benefits and marginal rate of returns analysis of treatments for Tororo and Kapchorwa in 2011

Site	Nitrogen Application	Tillage Systems	Cropping systems	GFB (KES)	TCV	NFB	
Tororo	-N	CT	CP	23157	19656	3501	
		CT	ROT 1	23578	19023	4555	-
		CT	ROT 2	22293	19236	3057	-
		NT	ROT 1	25139	15495	9644	-
		NT	ROT 2	21233	17568	3665	-
		NT	CP	19045	17033	2012	D
		MT	ROT 2	21042	18736	2306	17
		MT	ROT 1	24578	20447	4131	107
		MT	CP	23085	21752	1333	-
	+N	NT	ROT 2	18954	12890	6064	-
		NT	ROT 1	22437	20121	2316	-
		NT	CP	20531	15356	5175	-
		CT	ROT 1	22202	18122	4080	-
		CT	ROT 2	21644	19538	2106	-
		CT	CP	22481	19304	3177	-
		MT	ROT 2	21346	16650	4696	-
		MT	ROT 1	21014	18764	2250	-
		MT	CP	22666	17863	4803	-
Kapchorwa	-N	CT	CP	21103	18908	2195	-
		CT	ROT 1	23523	18770	4753	-
		CT	ROT 2	19113	18104	1009	D
		NT	ROT 1	21111	18003	3108	-
		NT	ROT 2	18132	16704	1428	129
		NT	CP	21014	17013	4001	D
		MT	ROT 2	19011	16800	2211	D

		MT	ROT 1	22347	18241	4106	132
		MT	CP	23013	18692	4321	48
	+N	NT	ROT 2	21655	18446	3209	D
		NT	ROT 1	20334	19116	1218	-
		NT	CP	22423	18334	4089	-
		CT	ROT 2	21434	18358	3076	-
		CT	ROT 1	20121	18102	2019	D
		CT	CP	20234	18178	2056	49
		MT	ROT 2	22235	14990	7245	-
		MT	ROT 1	21005	17877	3128	-
		MT	CP	22666	18560	4106	143

GFB=Gross field benefits, TCV = Total variable cost, NFB = Net financial benefits, D = dominated treatment (i.e. with less than or equal to treatment with lower TVC that were eliminated from further consideration since no farmer choose a treatment(s) with higher TVC and receive lower NFB), bold and coloured indicate economically viable treatment.

Generally, MT and ROT 2 cropping systems proved economically viable due to high levels of resulting percent MRR. No-till combined with ROT 2 treatments were second best in terms of economic viability.. This proved true in all the sites except Bungoma.

CHAPTER FIVE

Discussion

Generally, the total rainfall for all the cropping seasons was adequate for crop production in all the cropping seasons. However, there was an increase in rainfall levels in 2012 as compared to 2011 across all the sites (Fig 5.1 and 5.2).

5.1 Initial soil characterization

Available P was below the critical level for crop production of 10 mg Kg^{-1} of soil as per Okalebo *et al*., (2002). The acidic nature of the soils in these sites meant that the fertility status of the soils in question was inadequate to ensure good crop production because of implied P fixation from high levels of aluminum (Al) and iron (Fe) that are rampant on acid soils (Selles *et al*., 2002).

There was less number of earthworms counted during the initial sampling (Tables 4.1 and 4.2). This was attributed to the continuous tillage of land during land preparation as well as weeding, as farmers in this region have practiced continuous conventional tillage of land. It resulted into destruction of earthworms' habitat and hindered the earthworms' survival e.g. feeding, reproduction continuously (Mutema *et al*., 2013). Moreso, this left the earthworms population prone to pray attack. These factors among others resulted into reduced earthworm's population across all the sites. The crop residues from the short rains season provided food for earthworms enabling their survival for a longer period of time (Bartza *et al*., 2013).

5.2 Effects of Tillage, Cropping Systems and Nitrogen application on selected soil chemical properties

Tillage, cropping systems and nitrogen application had an effect on the tested soil chemical parameters. The effect differed depending on the sites and types of soils in question.

5.2.1 Effects of Tillage, Cropping Systems and Nitrogen application on soil pH

The soil pH in Bungoma, Trans-Nzoia, Kapchorwa and Tororo generally improved under conservation tillage treatment of NT and MT. This was in interaction with strip cropping system under rotation 2. Lack of soil mixing in NT and minimal disturbance of the soil as associated with MT is often associated with pH stratification (González, 2012) and accumulation of salts related to fertilizer application on soil surface as compared to tilled soils (Hobbs *et al*., 2008). The observed decrease in acidity under NT and MT is consistent with results of Kaumbutho and Kienzle, (2007) and could be attributed to the decomposition of large volumes of organic matter associated with conservation agriculture tillage systems relative to CT. The minimal changes in pH observed over the study period could be attributed to application of calcium ammonium nitrate (CAN) as N top-dress to maize and beans crop resulting into a rise in soil pH under both tillage practices. Furthermore, there was a good establishment of mucuna cover crop and this in combination with nitrogen application as a top dress realized an increase in levels of plant biomass leading to increased decomposition activity. Studies show that conservation tillage leads to accumulation of decomposing organic matter on the surface soil layer (Kaumbutho and Kienzle, 2007; Bartza *et al*., 2013). The increased soil organic matter acts as a soil buffer, reducing the free H^+ ions and stabilizing pH levels of the soil. The extent of acidification is however controlled by choice of cropping systems together with soil and residue management. This could have led into a minimal positive change in soil pH in Kapchorwa. However, according to Nkonya *et al*., (2008b), it is worth noting that as the clay and organic matter content increases, the ratio of reserve to active acidity sites also increases. The authors however note that the relationship between active and reserve acidity is not constant across soils, and is dependent on the type and amount of clay and organic matter content of the soil. Application of ammonium N fertilizers has also been reported to counter the increase in acidity arising from nitrification of such N sources (Nyende *et al*., 2007). Salts are recycled through plant biomass and decomposition of high crop residue inputs under NT and MT thus enhancing release of salts to the soil compared to CT and Rotation 2 across all the sites. Soil pH improved from acidic to lesser acidic levels in the Rotation 2 and Rotation 1. This was in interaction with conservation agriculture tillage systems of MT and NT, as compared to CT by continuous maize-beans intercropping. Under the Rotation 2 and Rotation 1, there was an observed buildup of organic matter on the surface soil and the compounded effect of not disturbing the soil surface layer. Mazvimavi and Twomlow (2009), reported in their study that a rise in soil pH from the initial was realized after addition of organic materials, and that this was only stable for the first 1-2 months after which a decline in the same was realized. The magnitude of the initial soil pH rise was dependent on the type of residue, application rate and biomass content (Mazvimavi and Twomlow, 2009). Also, the change in soil pH is influenced by time as it was evident with a slight increase in soil pH after the two cropping seasons in Kapchorwa (Fig 5.0) as compared to the increment seen in Bungoma (Fig 4.4-4.7) and Tororo (Fig 5.4-5.7) which both have four cropping seasons each.

5.2.2 Effects of Tillage, Cropping Systems and Nitrogen application on available P in the soil

Tillage, cropping systems and nitrogen application treatments, improved available P in the soil across all cropping seasons in all the four sites. The increase was however realized at the end of the second cropping season in each site. The results concur with (Sanchez, 2002) in which moderately labile P, while not immediately available to plants, was shown to have the potential to become available over a period of months to a few years. Results from their study showed that 12 years after converting from conventional till wheat-fallow (CT-FW) to no-till continuous wheat (ZT-CW), forms of P determined using the 0.5 M sodium bicarbonate extraction procedure (which is normally easily available to the crop) accumulated in the surface 2.5 inches layer (Palm *et al*., 2001; Sanchez, 2002). This was not the case for the no-till fallow-wheat (ZT-FW), or the conventional till continuous wheat (CT-CW), where the concentration of labile P was uniform in the top 10cm of the soil. Additionally, Zibilske (2002) records that conservation tillage-MT and NT- usually improves the availability of surface phosphorus by converting it into organic phosphorus. The inclusion of the legumes in the Rotation 2 also played a key role in improving the available P in the soil under MT and NT tillage systems. Sanchez (2002) reported that the labile P fraction (inorganic P extracted by an anion resin plus organic and inorganic P extracted by 0.5 M sodium bicarbonate) is the soil P that is immediately available, or becomes available to plants within days to a few weeks. This specific treatment difference was attributed to the accumulation of organic materials (crop residues and soil organic matter) at the surface of zero-tilled soils, resulting from the reduction of soil disturbance and mixing of the soil. Apart from contributing to increased P availability through release of inorganic P from decaying residues, organic molecules released during organic residue decomposition could increase nutrient availability through blockage of P sorption sites and complexation of soluble aluminum and iron (Palm *et al*., 2001). The increase in the P in the four sites could have also been greatly influenced by this factor. Blockage of P sorption sites by the numerous salts from decaying organic made P readily available.

Furthermore, crops take up phosphorus from below, “mining” and depositing it on the surface. In conventional tillage systems this phosphorus would be remixed into the soil profile, whereas in conservation tillage systems MT and NT, it accumulates at the surface (Zibilske 2002). However, cropping systems treatment on its own significantly affected available P in soils in Tororo. This may be attributed to the different types of soils found in the four sites as it was evident with the soil pH differences recorded.

5.2.3 Effects of Tillage, Cropping Systems and Nitrogen application on soil organic carbon

There was a general increase in the SOC levels as influenced by tillage, cropping systems and nitrogen application treatments across all the sites. The slight decrease in the SOC at advanced stage of the study in the succeeding cropping seasons may be attributed to the changes in the rainfall patterns and total amount of rainfall received. This is because the increased levels of moisture in the soil triggers more soil microbial activities resulting into the breakdown of much more organic materials. This results into an increase in SOC content as compared to the minimal moisturized soils.

Soil organic matter (SOM) is one of the most important soil parameters because it is related to soil structure, porosity, stability, water retention, soil biological aspects, amongst other properties. The initial SOC concentrations in Bungoma, Trans-Nzoia, Tororo and Kapchorwa (Table 4.1) were rated as low (Okalebo *et al*., 2002) but improved to moderate levels. Higher plant biomass inputs under ROT 2 and ROT 1 rotations increased SOC relative to CP cropping system. This was evident in the 0-10 cm depth under MT. It was followed by NNT and CT in a reducing order. A similar result has been reported. Franzluebbers *et al.,* (2000) found that soil C storage increased with cropping intensity. He attributed less C under conventional tillage to inefficient C metabolism. Tillage by cropping systems interaction had a significant effect on SOC, with MT and ROT 2 having a highest effect respectively. This is attributed to variability in biochemical composition of the crop residues and plant biomass inputs as crop residues. Earlier studies have established that biochemical composition of crop residues have great influence on decomposition rate and/or nutrient release from organic materials (Haney *et al*., 2008). Soil organic matter, as a source of energy, substrate, and biological diversity, is one of the key attributes of soil quality that is vital to many of these soil functions. Stratification of SOC with depth is common in many natural ecosystems, managed grasslands and forests, and conservation-tilled cropland (Franzluebbers *et al.,* 2000). The soil surface is the vital interface that receives much of the fertilizer and pesticides applied to cropland and pastures. It receives the intense impact of rainfall that can lead to surface sealing following disruption of surface aggregates. The partitions the flux of gases into and out of soilalso affects SOC levels. Stratification of SOC occurs with time when soils remain undisturbed from tillage (e.g., with conservation tillage and pastures) and sufficient organic materials are supplied to the soil surface (e.g., with cover crops, sod rotations, and diversified cropping systems). This is therefore related to the improved soil fertility status as it was evident with the selected soil chemical parameters measured including SOC. The observed high SOC under ROT 2 in Bungoma (Fig 5.24-5.27) as well as Tororo (Fig 5.33-5.36) could imply shorter C immobilization period. This is because of to two cropping seasons in the two sites. The shorter period between the planting and crop harvesting had interference in the process of C immobilization. This resulted into improved SOC levels under ROT 2 compared to ROT 1 and CP in Bungoma and Tororo. The SOC in a soil is determined by losses of organic carbon through decomposition, erosion and losses through dissolved organic matter and the nature and quantities of inputs of organic matter (van Straaten, 2007). According to van Straaten, (2007), conservation agriculture tillage and cropping systems enhances decomposition of organic matter and release of nutrients through improvement of both aeration and crop residue contact. SOC increases over time under MT and ROT 2, in this case, were attributed to crop residue retention, reduced soil disturbance and continued replenishment through addition of organic amendments by the crop residues from previous seasons being returned into the soil. The seasonal variation of SOC is a function of parameters not included in this study coming into play such as physical and other chemical parameters, many of which are a function of soil organic matter (SOM) content as it was also observed by (Franzluebbers *et al.*, 2000; van Straaten, 2007; Zibilske *et al*., 2002). The reduced level of SOC under CT and CP cropping system was expected. This is because continuous tilling of land results of C loss as CO_2 into the atmosphere. Reduced crop intensity in CP on the other hand leads to reduced SOC replenishment as little organic matter is returned in to the soil. The improved SOC levels in the soils of the four study sites are attributed to the organic matter that was returned into the soil as crop residues from the previous crop. This is attributed to the fact that tilling by either hand or machinery, the soil layers invert, air mixes in, and soil microbial activity dramatically decreases over baseline levels. The result is that soil organic matter is broken down much more rapidly, and carbon is lost from the soil into the atmosphere as observed by Zibilske *et al*., (2002) and Selles *et al*., (2002).

This, in addition to the emissions from the farm equipment itself, increases carbon dioxide levels in the atmosphere contributing to adverse climatic changes (global warming). These conventional farming practices that rely on tillage have removed carbon from the soil ecosystem by removing crop residues such as left over maize stalks. This has led to adverse effects on soil microbial, physical and chemical properties.

5.2.4 Effects of Tillage, Cropping Systems and Nitrogen application on total soil N

The initial soil analysis revealed soils with low percent total nitrogen levels in Bungoma, Trans-Nzoia, Tororo and Kapchorwa, according to Okalebo et al., (2002) (Table 4.1). ROT 2 significantly influenced an increase in the soils' total N across all the sites. This is attributed to the increased biomass content contributed by the three crops in ROT 2 (*Mucuna pruriens*, beans and maize). The results are in agreement with the findings from several studies. In their research on varying different legumes, Sanginga *et al*., (2001) and Selles *et al*., (2002) report that, *M. pruriens* consistently increased the levels of nitrogen and organic matter. This was probably due to its high biomass building capacity. High plant biomass inputs under ROT 2 and ROT 1 cropping systems and MT resulted in a larger total N relative to CT and in the 0-10 cm depth across the four sites.

Higher total N accumulation in the soil under ROT 2 and ROT 1 rotations relative to CP was attributed to enhanced retention and gradual release of N from high biomass associated with ROT 2 (Maize-Mucuna-Beans strips) and ROT 1 (maize-beans with mucuna as relay). Similarly, reduced oxidation of SOM with less soil disturbance under MT and NT could explain the enhanced total N retention under this tillage systems relative to CT. Improvement in SOC and N levels under CA could also impact positively on soil structural stability (Chenu et al., 2000), biotic activity and plant nutrient availability (van Straaten, 2007; Watson, 2004; Selles *et al*., 2002)

Higher total N from MT and NT above CT as observed in this study could additionally be linked to mineralization of immobilized N following improvement in soil moisture and temperature as was evident in LR2012 cropping season. This is supported by Selles *et al*., (2002) who observed increased total N levels in a high moisture season. The reduced temperatures and increased soil moisture content of the soil was observed during mineral N sampling, in the plots with the growing mucuna crop. The decline in organic carbon and nitrogen levels in the CP that involved planting maize beans continuously was however expected.

5.3 Effects of Tillage, Cropping Systems and Nitrogen application on earthworm populations

Tillage resulted into a significant ($p \leq 0.05$) rise in the earthworms population count in Bungoma, Tororo and Kapchorwa. Earthworm's population count improved in the conservation agriculture tillage systems of MT and NT. This could be attributed to the intensity of tillage. As the number and intensity of tillage operations increase during land preparation as well as weeding, so does the physical destruction of burrows, cocoons, and the earthworm bodies themselves. This is attributed to the mixing of the soil between layers during land preparation by tillage to the extent of destroying the habitat of the earthworms. In the event, some are killed while reproduction is hampered caused by the adverse conditions. In this study, less intensive tillage systems that leave residues on the surface after cropping season prior to the subsequent one, which are MT and Rotation 2 treatments respectively, improved the environment for earthworm's habitat (Justin *et al*., 2012). The residue provides food, insulates earthworms from weather conditions, and provides cover to protect them from predators. Although a single tillage event will not drastically reduce earthworm populations, repeated tillage over time will cause a decline in earthworm populations as it is evident with the reduced number of earthworms under CT across all the four sites. Similar results have been recorded by researchers in different parts of the world. Shai and Norton (2000), records that No-till and other methods of conservation tillage such as minimum tillage and ridge tillage can increase populations of both types of earthworms. According to their study, earthworms were reduced by 70% compared to previously undisturbed sod after five years of plowing (Justin *et al*., 2012). After 25 years of conventional tillage crop production earthworm populations were only 11-16% of what existed in the original grass field (Thierfelder *et al*., 2012). Justin *et al*., (2012) reported up to 30 times more earthworms in conservation agriculture tillage systems compared to plowed fields.

Tillage affects decomposition and availability of surface residue. The choice of crop on the other hand determines the quantity and quality of the residue as a food source for earthworms. Earthworm populations decreased to low numbers under an exhaustive cropping system of conventional tillage, crop residue removal, and no additions of nitrogen fertilizer as it was evident under CP cropping system. This was in interaction with CT under N0 in which least population means were recorded in all the sites. Earthworms multiplied in legumes under a crop rotation system as their population under the legume crops in the crop rotation of maize-bean-mucuna (Rotation2) was doubled as compared to the Rotation1 and Current Practice (CP). Researchers from the Agricultural Research Service National Soil Tilth Laboratory in Ames, Iowa, also found more earthworms in CA fields compared to an adjacent neighbor’s conventionally tilled field in corn-soybean rotation (Justin *et al.*, 2012). The larger earthworm populations were attributed to more food from legume crops, beans and mucuna, as well as reduced tillage under MT. Using cover crops helps to increase earthworm populations by increasing their food supply (organic residue) and by giving them a longer season to eat and reproduce. The extra food and ground cover provided by cover crops are especially important where earthworms are removing a high percentage of crop residues. This was evident in a study in the University of Wisconsin that reported residue cover being reduced from 30% to 15% by earthworms at planting time in no-till fields (Shai and Norton, 2000).

Nitrogen application was beneficial to the earthworm’s population resulting into increased number of earthworms. This is probably an indirect effect of the increased crop biomass production and consequent increases in organic residues. Shai and Norton (2000) and Justin *et al.*, (2012) in different studies also reported that earthworm numbers in meadows receiving inorganic fertilizer averaged nearly twice the earthworms in unfertilized meadows on the Georgia piedmont. Several reports have indicated that ammonia and ammonia-based fertilizers can selectively, but not always, adversely affect earthworm numbers probably due to the effect these fertilizers have on lowering soil pH

(Johan *et al.*, 2002). However, in his study, Justin *et al.*, (2012) reports that farmers realize increased numbers in the long run due to higher yields and more food for earthworms to feed upon. This is supplied through the increased SOM via crop residue incorporation.

Generally, fertilizers increase earthworm numbers by increasing crop residues, especially when pH is maintained near neutral. Earthworms benefit soil quality by shredding residues stimulating microbial decomposition, thus improving soil fertility as it was evident with the improved measured soil chemical parameters. Producing food through crop residues and cover crops and leaving them on the soil surface through the use of conservation agriculture practices provides food to increased earthworm numbers.

5.4 Effects of Tillage, Cropping Systems and Nitrogen application on soil nitrate and ammonium

5.4.1 Effects of Tillage, Cropping Systems and Nitrogen application on soil nitrate

There was a general increase in the NO_3-N levels in all the sites. A similar observation was made by Hussaini *et al.*, (2008) when they found that NO3- levels increased gradually over time in cropping systems involving cereals and legumes. There was a significant difference in the amounts of soil nitrates (NO_3-N) recovered from tillage systems MT, NT and CT ($p \leq 0.05$) in Bungoma, Trans-Nzoia and Tororo sites, apart from Kapchorwa. Amount of nitrates obtained were significantly high under ROT2 cropping systems in all the four sites. Nitrogen application (+N) significantly ($p \leq 0.05$) influenced the NO_3-N levels above the N0 treatment in all the four sites.

The Nitrogen application (+N) as both DAP at planting and CAN at vegetative stage resulted in to an increase in NO_3-N levels recovered. This is because the two fertilizers are rich in N (DAP containing 18%N and CAN 26%N). Under N0, the lower NO_3-N levels are attributed to the continued NO_3-N uptake by the crops via crop mining without adequate replenishment.

Amount of nitrates obtained were significantly high under ROT2 cropping systems in all the four sites. Watson (2004) reported that intercropping does reduce loss of NO_3-N levels up to 36% as compared to cereal monocropping systems. These results suggest that use of cover crop *Mucuna pruriens* can reduce the NO_3-N levels losses significantly. The higher levels of NO_3-N in the 10-30cm as compared to 0-10cm (especially under CT) suggested high leaching losses in the highly sandy soils in all the sites. This was coupled with high rainfall recorded in these sites (Fig 4.1 and 4.2). The results are in agreement with Thuita (2007) who attributed high mobility of nitrates to be the major cause. Nitrates moved down the profile with draining water, with the plant roots being able to take up little nitrates up as it moved out of the root zone (Thuita, 2007; Hussaini *et al.*, 2008). According to Thuita (2007), the area which is exposed enhances high leaching losses. The results suggest that there were minimal losses of NO_3-N in ROT2 under *Mucuna* as compred to ROT1 and CP in all the sites. This was mainly due to the canopy formed by the numerous broad leaves of *Mucuna* plant especially under N1 treatment that maintained high moisture content. This resulted into percolation of the water soluble NO_3-N down the profile. Varied rainfall patterns in the four sites also, may have caused the differences in the NO_3-N levels due to the high mobility of NO_3-N in the soil.

The reasons for lack of differences between tillage systems in terms of recovered NO_3-N levels in Kapchorwa site (although sampling was done at at vegetative stage in all the sites) are not clear and needs further investigations.

5.4.2 Effects of Tillage, Cropping Systems and Nitrogen application on soil ammonium

Generally the levels of NH_{4+}-N recovered were lower than NO_3-N in all the sites. Das *et al.* (1997) observed that the lowest NO_3-N and NH_{4+}-N concentrations were obtained during the rainy season and the highest during the dry season. They report that the extractable NH_{4+}-N always higher than extractable NO_3-N. Ammonium-N is less subject to leaching or denitrification losses, so N maintained as NH_{4+}-N in the soil should be available for late - season uptake (Hussaini *et al*., 2008).

There was however a general increase in NH_{4+}-N levels in all the sites during the cropping seasons. The increase and in some cases decrease e.g. in Bungoma SR2012 season (Table 4.34.2) could be due to the microbiological activity and the influence of crop uptake at different stages of growth. The reduced amounts of NH_{4+}-N under N1 levels could have been as a result of NH_{4+}-N being consumed by microbes leading to a reduction in plant available nitrogen (Anyanzwa et al., 2010). This was in agreement with a report by Azam *et al.* (1993) that the NH_{4+}-N has been found to be the preferred form of N for assimilation by microbes in many cultivated soils. In some agricultural soils, no NO_3-N immobilization has been observed according to Shai and Norton, (2000); while in others NO_3-N immobilization was recorded after 1 - 4 weeks (Thuita, 2007) or several months (Hussaini *et al*., 2008).This was in contrast with the observation by Haney *et al*., (2008) who reported constant pool size of NH_{4+}-N.

In the Cropping systems, ROT2 resulted in the recovery of more NH_{4+}-N levels in all the sites. This was above ROT1 and CP. It was attributed to the healthy crop rotation involving legumes. This resulted into build up and replenishment of NH_{4+}-N levels in theses soils.

There was a general significant increase in NH_{4+}-N levels across all sites under Nitrogen application treatment. N0 recorded lower levels of NH_{4+}-N across all sites. The N rich fertilizers boosted the nitrogen pool resulting in to increased NH_{4+}-N levels. There was no significant difference in the levels of NH_{4+}-N in the two sampled depths of 0-10cm and 10-30cm in all the sites. The reason for this was attributed to the immobility of NH_{4+}-N, which could not enable its movement down the profile.

5.5 Effects of Tillage, Cropping Systems and Nitrogen application on maize and bean grain yield

The low yield obtained under conservation agriculture treatments in the first cropping season (LR2011) across all the four sites was mainly due to slower rate of establishment of the treatments especially in the NT and MT plots in that order. Gradual increase in the yield of maize and beans in the succeeding cropping seasons under MT and NT is attributed to the recycling of the nutrients through incorporation of the crop residues from the previous season. This is besides the gradual slow establishment of the treatments on the previously cultivated land. Build up of plant nutrients e.g. available phosphorus, up from deficient levels across all the sites could have led to improved crop yields of maize and beans grains (van Straaten, 2007; Sanginga *et al*., 2001; Govaerts *et al*., 2006). Also, this could have been as a result of suppression and hence under-development of weeds by the crop residues from the previous season. Reduced yields of maize and beans under CT plots could be attributed to the residue being inverted during tillage thus resulting in the plant nutrient lose e.g. carbon and nitrogen. Crop residue return into the soil has been observed to improve crop yields under conservation agriculture tillage and cropping systems in Brazil (Ngwira *et al*., 2012). Long term benefits of conservation agriculture production systems of reduced costs of production overrides those obtained under conventional tillage (González, *et al*., 2010). Research has demonstrated that conservation production systems moderate soil surface conditions (Sanchez, 2002; Fatondji *et al*., 2006). This results into improved crop production (Bescansa et al., 2006) thus increasing the net farm benefits due to reduced production costs (Chivenge *et al*., 2007; Sanchez *et al*., 2002). With MT, diurnal soil temperature is dampened, surface runoff controlled, soil moisture maintained, crop rooting enhanced and hence improved maize-bean grain production as was the case in this study. Because there was no significant difference on maize yield by tillage systems in Tororo indicates that MT and NT is profitable. This is because the expenses incurred through conventional tillage practice e.g. labou, fuel cost among others, will be avoided.

Crop rotations involving a variety of crops e.g. legumes, results into distribution of the soils nutrients in the soil from season to season. This makes them readily available to the growing crops in the succeeding cropping seasons (Mashingaidze *et al*., 2012). The recycling of soil nutrients enabled the maize and beans in the succeeding cropping season to take up these nutrients for their better growth and development. This was reflected in the improved maize and bean grain yield across all the sites.

5.6 Economic analysis

Crop residue return into the soil under conservation agriculture tillage and cropping systems have long term economic benefits on crop production due to reduced costs of production (Nkonya *et al*., 2011b; Nkonya *et al*., 2011a). The return and incorporation of the crop residue back into the soil leads to a recycling of soil nutrients, as compared to burning or using as livestock feed. This is achieved through return of biosalts in these residues into the soil thus improving both soil fertility and structure. Minimal application of fertilizers in the next planting season will thus result in better crop yields. Research has demonstrated that conservation production systems moderate soil surface conditions (Govaerts *et al*., 2006). This results into improved soil quality as well as improved crop production (Bescansa *et al*., 2006) thus increasing the net farm benefits due to reduced production costs (Chikowo *et al*., 2004). This overrides the economic benefits obtained under conventional tillage as supported by Govaerts *et al*., (2005)

CHAPTER SIX

Conlussion and Recommendations

6.1 Conclussions

N application resulted into increased vegetative growth of mucuna thus yielding more crop residues. This resulted to surplus food for the earthworms leading to their increased population. Minimum soil disturbance under MT ensured good habitat for the earthworms besides minimizing soil nutrient lose through bioturbation. Breakdown of crop residues by the large number of earthworms counted under MT and ROT2 resulted into redistribution of bio-salts from the residues back into the soil. This comprised of vital plant nutrients including P and N. This made them readily available to the growing crops. Maize and beans in succeeding cropping season utilized these nutrients resulting into their better development and hence improved grain yields.

The results of this study suggest that factors responsible for organic carbon accumulation also influence soil total N and pH changes. The effects of tillage on pH in the four sites were not consistent. Minimum tillage and no till increased total N and pH compared to conventional tillage across all the sites. Tillage systems, cropping systems and nitrogen application have a significant effect on soil pH. This however varies with soil type as the level change in soil pH varied between different soils in different sites. Conservation of phosphorus may be a potential benefit of conservation tillage, improving phosphorus availability. Improvements in SOC and N levels under CA tillage and cropping systems impacted positively on soils' biotic activity and plant nutrient availability, thus improving soil quality generally.

The increase in soil extractable phosphorus, SOC, total nitrogen as well as improved soil pH (to the required minimum for maize and beans crop production pH 5.0-6.0) under minimum tillage in Bungoma, Trans-Nzoia and Tororo sites indicates that MT improves soil fertility and quality in general. Minimum Tillage and crop rotations involving two legumes and a cereal crop as was in ROT 2 are essential components of conservation agriculture and both practices had a positive impact on maize and bean yield, as well as plant nutrient availability.

Minimum tillage systems that leave residues on the surface throughout the year improve the environment for earthworms. Crop rotation of maize-beans-mucuna (ROT 2) and the use of inorganic fertilizers also have a positive impact on earthworm population. This is probably an indirect effect of the increased crop biomass production and consequent increases in organic residues resulting into increased SOC levels. The residues provide food, insulate earthworms from weather conditions, provide cover to protect them from birds and other surface predators, and protect their burrows. Under ROT2 (strip cropping) and specifically under mucuna, more NH_{4+}-N and NO_3-N levels were recovered in the 0-10cm than 10-30cmdepth, above ROT1 and CP cropping systems. The better ground cover reduced losses through runoff and conserved moisture during dry spells by reducing evaporation rates. The increased earthworm populations are attributed to increased food supply from legume crops (beans and mucuna) as well as reduced tillage under MT that ensures them a longer season to eat and reproduce/multiply. The combination of these factors led to better maize and bean grains yield. This was high under ROT2 cropping system as compared to ROT1 and CP.

The study shows that conservation agriculture production systems (CAPS) involving crop rotation, minimum tillage and crop residue incorporation practices have a potential to improve maize and bean yield throughout the year. Crop rotation, minimum tillage and crop residue incorporation optimizes soil pH, extractable soil phosphorus, soil organic carbon, soil total nitrogen as well as earthworm's population which all reflect in to an improved soil nutrient status, and soil quality in general. CAPS offers an opportunity for arresting and reversing downward spiral of resource degradation, decreasing cultivation costs and making agriculture more resource-use-efficient, competitive and sustainable.

6.2 Recommendations

- From this study, *Mucucna pruriens* is therefore recommended cover crop candidate in Bungoma, Trans-Nzoia, Tororo and Kapchorwa for the following reasons: In addition to all the benefits accrued from inclusion of legumes in cropping systems towards improving soil quality in general, *M. pruriens* provides excellent hay for livestock, and its seeds are used as protein rich feed supplement to livestock and as a beverage by some farmers in Trans-Nzoia but after processing through roasting. More importantly, *M. pruriens* is used for food in some African countries (Rachie and Roberts, 1974).
- From the findings of this study, a less intensive tillage system of minimum tillage in combination with ROT 2 is most econonomical in Bungoma, Trans-Nzoia, Tororo and Kapchorwa sites. It is therefore recommeded in these study areas. This will realize both improved maize and beans production, and better soil nutrient status and overall soil quality replenishment.
- Further studies on earthworm's population should be undertaken for a longer period of time and on a wider scope in order to be able to study specific earthworm species associated with any particular or all of these treatments-

tillage, cropping systems and nitrogen fertilizer application.

- From this study, the N contribution from legume cover crops could improve the performance of subsequent cereal crop. However, legumes contribute less to soil C. There is need for further studies to investigate whether mixed cereal/legume cover crops could improve both soils C and N for sustainable crop production in low organic C soils.
- Further studies need to be done on the rooting systems of crops under the ROT2, ROT1 and CP cropping systems in order to ascertain the root density role if any, in preventing the leaching of NH_{4+}-N and NO_3-N down the profile.
- Further studies on laboratory incubation and rate of decomposition of cover crops are recommended to substantiate this possibility. This is because the difference in soil C accumulation among crop rotations in this study was attributed to relative differences in residue decomposition rates as influenced by their biochemical composition.

REFERENCE

Adjei-Nsiah, S., Kuyper, T.W., Leeuwis, C., Abekoe, M.K., Giller, K.E., (2007). Evaluating sustainable and profitable cropping sequences with cassava and four legume crops: effects on soil fertility and maize yields in the forest/savannah transitional agro-ecological zone of Ghana. Field Crop Res. 103, 87–97.

Ahmed M., (2012) Analysis of incentives and disincentives for coffee in Uganda. Technical notes series, MAFAP, FAO, Rome, Italy.

Anderson, J.M., Ingram, J.S.I. (1993) Tropical soil biology and fertility: A handbook of methods, 2nd Edn. CAB International, Wallingford, UK.

Anyanzwa, H., Okalebo, J.R., C.O. Othieno, A. Bationo, B.S. Waswa and J. Kihara. (2010) Effects of conservation tillage, crop residue and cropping systems on changes in soil organic matter and maize-legume production: a case study in Teso District. Nutrient Cycling in Agroecosystem, 88: 39-47.

APCAEM (United Nations and Pacific Centre for Agricultural Engineering and Machinery). (2007). Towards sustainable agriculture: challenges and opportunities. APCAEM Policy Brief, Issue 2, 1–6. Beijing.

Apina, T., Wamai, P. and Mwangi, P. K. (2007). Lakapia district. In Conservation Agriculture as Practised in Kenya: Two Case Studies, 1–56 (Eds P. Kaumbutho and J. Kienzle). African Conservation Tillage Network Nariobi, Centre de Coopération Internationale de Recherche Agronomique pour le Développement Paris, Food and Agriculture Organization of the United Nations Rome. Available at http://www.fao.org/ag/ca/doc/Kenya_casestudy.pdf

ASARECA. (1997) Development of a Long Term Strategic Plan for Regional Agricultural Research in the Eastern and Central African Region, ASARECA (Association for Strengthening Agriculatural Research in Eastern and Central Africa), Entebbe, Uganda, p. 172.

Barros E., A. Neves, E. Blanchard, E.C.M. Fernandes, E. Wandelli, P. Lavelle, (2003) Development of the soil macrofauna community under silvopastoral and agrosilvicultural systems in Amazonia, Pedobiologia 47 273-280.

Bartz, M.L.C., Pasini A. and Brown G. G., (2013) Earthworms as soil quality indicators in Brazilian no-tillage systems. Appl. Soil Ecol. Applied Soil Ecology journal: www.elsevier.com/locate/apsoil

Bationo, A., Hartenmink, A., Lungu, O., Naimi,M., Okoth, P., Smaling, E. and Thiombiano, L. (2006). African soils: their productivity and profitability of fertiliser use. Background paper prepared for the African Fertiliser Summit, 9–13 June, Abuja, Nigeria.

Beare, M.H., Reddy, M.V., Tian, G. and Scrivasta, S.C. (1997). Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of decomposer biota. Applied Soil Biology, 6:87-108.

Beebe, S., I. Rao, H. Terán and C. Cajiao. (2003). Breeding Concepts and Approaches in Food Legumes: The Example of Common Bean. Paper presented in the Second National Workshop on Food and Forage Legumes. Addis Ababa, Ethiopia. 22-27 September, 2003

van den Bosch, H., de Jager, A., Vlaming, J., 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). II. Tool development. Agriculture, Ecosystems and Environment 71, 49–62.

Brown G.G., (1995) How do earthworms affect microfloral and faunal community diversity? Plant and Soil 170, 209-231.

Bullock, A., S.O. Keya, F.M. Muthuri, T. Bailey-Watts, R. Williams and D. Waughray. (1995) Lake Victoria Environmental Management Programme Task Force II. Final report by the regional consultants on Tasks 11, 16 and 17 (Water quality, land use and wetlands). Wallingford, UK: Centre for Ecology and Hydrology and FAO

Buresh R. J, P. A. Sanchez and F. Calhoun (2011) Replenising soil fertility in Africa, SSSA, Special Publication No. 51. Madison, Wisconsin. U.S.A

Bashaasha, B. (2011). A review of land tenure and land use planning in the Kagera (Transboundary Agro-ecosystem Management Project) districts in Uganda. Study commissioned by FAO (Food and Agriculture Organisation of the United Nations). September 2011

Castellanos-Navarretea A., C. Rodríguez-Aragonésb, R.G.M. de Goedea, M.J. Kooistrac, K.D. Sayred, L. Brussaarda, M.M. Pullemana, (2012) Earthworm Activity and Soil Structural Changes Under Conservation Agriculture in Central Mexico; Soil and Tillage Research; Volume 123, July 2012, Pages 61–70 (Accessed January 25th, 2013)

Chikowo, R., Mapfumo, P., Nyamugafata, P., Giller, K.E., (2004). Woody legume fallow productivity, biological N2-fixation and residual benefits to two successive maize crops in Zimbabwe. Plant Soil 262, 303–315.

Chivenge, P. P., Murwira, H. K., Giller, K. E., Mapfumo, P. and Six, J. (2007). Long-term impact of reduced tillage and residue management on soil carbon stabilization: implications for conservation agriculture on contrasting soils. Soil and Tillage Research 94(2):328–337.

CIMMYT, (2002)Diversity to heal the earth and Feed its People, Mexico D.F 3:69-74

CIMMYT (1988). From Agronomic Data to Farmer Recommendations: An Economics Workbook. Mexico, D.F. 27:1-19

Low, A. (1989). Application of Risk Decision Theory to Net Benefit and MRR Analysis. Teaching Notes for the Experimental and Other Data Analysis Workshop for Social Scientists, October 15-27, 1989, Njoro, Kenya.

De Groote, H., M. Siambi, D. Friesen and A. Diallo. (2002) Eliciting farmers' preferences for new maize varieties in Eastern Africa. In M. R. Bellon and J. Reeves, eds., Quantitative Analysis of Data from Participatory Methods in Plant Breeding). Mexico, D.F.: CIMMYT, pp. 82-102.

Diallo, A.O., J. Kikafunda, Legesse Wolde, O. Odongo, Z.O. Mduruma, W.S.Chivatsi, D.K. Friesen, S. Mugo, and M. Bänziger. (2003) Drought and Low Nitrogen Tolerant Hybrids for the Moist Mid-Altitude Ecology of Eastern Africa. In: Proceedings of the 7th Eastern and Southern Africa Regional Maize Conference and Sypmposium on Low-Nitrogen and Drought Tolerance, Nairobi, Kenya, 11-15 February 2002.

District State of the Environment Report- DSOER (2004) Report on Responses to Environmental Change, Policies and Laws; Govt. interventions, and the work of NGOs and CBO; Kabale District Local Government (with support from NEMA)

Durodoluwa J. O., S. Manuele, S. Enzo and P. Roberto (2010) Distribution of Organic Carbon and Total Nitrogen in Aggregate Size Fractions in a Southern Nigeria Ultisol Under Different Agricultural Land Use, World Congress of Soil Science, Soil Solutions for a Changing World 1 – 6 August 2010, Brisbane, Australia

Ekboir, J. (ed.). (2002) CIMMYT 2000-2001 World Wheat Overview and Outlook:Developing No-Till Packages for Small-Scale Farmers. Mexico, DF: CIMMYT.

FAO, (2012) Conservation Agriculture.

Fatondji, D., Martius, C., Bielders, C. L., Vlek, P. L. G., Bationo, A. and Gerard, B. (2006). Effect of planting technique and amendment type on pearl millet yield, nutrient uptake, and water use on degraded land in Niger. Nutrient Cycling in Agroecosystems 76(2–3):203–217.

Fischer R.A., Santiveri F., Vidal, IR (2002b) Crop rotation, tillage and crop residue management for wheat and maize in the subhumid tropical highlands II. Maize and system performance. Field Crops Res 79:123–137

Friesen, D.K., R. Assenga, Tesfa Bogale, T.E. Mmbaga, J. Kikafunda, Wakene Negassa, J. Ojiem, and R. Onyango. (2003) Grain Legumes and Green Manures in East African Maize Systems – A Overview of ECAMAW Network Research. In: Proceedings of the Soil Fert Net Conference on "Grain Legumes and Green Manures for Soil Fertility in Southern Africa: Taking Stock of Progress", 9-11 October 2002, CIMMYT, Zimbabwe.

Franzluebbers A. J. (2010) Depth distribution of soil organic carbon as a signature of soil quality; World Congress of Soil Science, Soil Solutions for a Changing World, Brisbane, Australia. (1 – 6 August 2010)

Giller, K. E., E. Witter, M. Corbeels, P. Tittonell (2009) Conservation agriculture and smallholder farming in Africa: The heretics' view; Field Crops Research 114:23–34

Gomez, K.A., and Gomez, A.A.(1984). (1984) Statistical Procedures for Agricultural Research, 2nd edition, John Wiley and sons, Inc. 605 Third Avenue, New York, new York 10158.

González Y. R. S. (2012) Assessment of Conservation Agriculture (CA) Practices in Bungoma, Western Kenya: Towards an Insight in CA Adoption and its Constraints.

González-Chávez, M. D. C. A., Aitkenhead-Peterson J. A., Gentry T. J., Zuberer D. A., Hons F. M., and Loeppert R. (2010) Soil microbial community, Carbon, Nitrogen, and Phosphorus responses to long-term tillage and crop rotation; Soil and Tillage Research, vol. 106, no. 2, pp. 285–293, 2010.

Govaerts B., Sayre K.D., Deckers J., (2006) A minimum data set for soil quality assessment of wheat and maize cropping in the highlands of Mexico. Soil Till Res 87:163-174

Govaerts B., Sayre KD, Deckers J (2005) Stable high yields with zero tillage and permanent bed planting? Fields Crop Res 94: 33-42

Govaerts B., Verhulst N, Castellanos A, Sayre KD, Dixon J, Dendooven L 2008 Conservation Agriculture and Soil Carbon Sequestration; Between Myth and Farmer Reality. Crit Riv Plant Sci Journal.

Haney R. L., Brinton W. H., and Eric Evans (2008) Estimating Soil Carbon, Nitrogen, and Phosphorus Mineralization from Short-Term Carbon Dioxide Respiration United States Department of Agriculture, Agricultural Research Service, Temple, Texas, USA .

Hecky, R.. (2000) Eutrophication and biodiversity decline in Lake Victoria, in Proc. Int. Decade of East African Lakes (IDEAL) 2nd Int. Symp. 10-13th January 2000, Club Makokola, Malawi.

Hoekstra D., and J. Corbett (1995) Sustainable Agricultural Growth for Highlands of East and

Central Africa: Prospects to 2020. Paper presented at the EcoRegions of the Developing World: A Lens for Assessing Food, Agriculture and the Environment to the Year 2020, held at Washington DC, USA, organized by IFPRI.

Hobbs, P.R., Sayre, K., Gupta, R., (2008) The role of conservation agriculture in sustainable agriculture. Philos. Trans. Roy. Soc. B 363, 543–555.

Hussaini, M. A., Ogunlela, V. B., Ramalan, A. A. and Falaki, A. M. (2008). Mineral composition of dry season maize (Zea mays L.) in response to varying levels of nitrogen, phosphorus and irrigation at Kadawa, Nigeria. World Journal of Agricultural Sciences 4:775–780.

ICRISAT, (2009), 'Trends in Conservation Farming Adoption and Impacts'; A report of the 2009 CA panel study carried out by ICRISAT and jointly supported by FAO, and GRM International.

IFAD (International Fund for Agricultural Development). (2011). IFAD's Environment and Natural Resource Management Policy: resilient livelihoods through the sustainable use of natural assets.

Inocencio, A., Sally, H. and Merrey, D.J. (2003). Innovative Approaches to Agricultural Water use for Improving Food Security in Sub-Saharan Africa. International Water Management Institute, Colombo, Sri Lanka.

de Jager, A., Kariuki, I., Matiri, F.M., Odendo, M., Wanyama, J.M.,1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). IV. Linking nutrient balances and economic performance in three districts in Kenya.Agriculture, Ecosystems and Environment 71, 81–92.

Jin, H., Hongwen, L., Rasaily, R. G., Wang, Q., Guohua, G., Yanbo, S., Xiaodong, Q. and Lijin, L. (2011). Soil Properties and crop yields after 11 years of no tillage farming in wheat–maize cropping system in North China Plain. Soil and Tillage Research 113(1):48–54.

Johan Six, Christian Feller, KarolienDenef, Stephen M. Ogle, Joao Carlos de Moraes S., Alain Albrecht (2002) Soil Organic Matter, Biota and Aggregation in Temperate and Tropical Soils – Effects of No-Tillage

Justin P. Ng, Emily B. Hollister, Ma. del Carmen A. González-Chávez, Frank M. Hons, David A. Z., Jacqueline A. Aitkenhead-Peterson, Richard Loeppert, and Terry J. Gentry (2012) Impacts of Cropping Systems and Long-Term Tillage on Soil Microbial Population Levels and Community Composition in Dryland Agricultural Setting;, Journal of ISRN Ecology, Volume 2012, 10.5402/2012/487370Research Article ID 487370.

Kanampiu, F.k., V. Kabambe, C. Massawe, L. Jasi, D. Friesen, J.K. Ransom and J. Gressel. (2003) Multi-site, multi-season field tests demonstrate that herbicide seed-coating herbicide-resistant maize controls *Striga* spp. and increases yields in several African countries. Crop Protection, in press.

Kassam, A., Friedrich, T., Shaxson, F. and Pretty, J. E. (2009). The spread of conservation agriculture: justification, sustainability and uptake. International Journal of Agricultural Sustainability 7(4):292–320.

Kaumbutho P., Kienzle J., eds. (2007) Conservation agriculture as practised in Kenya: two case studies. Nairobi. African Conservation Tillage Network, Food and Agriculture Organization of the United Nations.

Kerr, R.B., Snapp, S., Chirwa, M., Shumba, L., Msachi, R., (2007). Participatory research on legume diversification with Malawian smallholder farmers for improved human nutrition and soil fertility. Exp. Agric. 43, 437–453.

Kimenye, P. L. Woomer, E. J. Mukhwana, A. Bationo, E. Adipala, R. K. Njoroge, M. Thuita, A. O. Nekesa and E. C. Ruto. (2005). Management of soil fertility in western Kenya: Experience working with small holder farmers. African Crop Science Confe.Proc, vol 7.pp 1465-1473.

Kipkoech, AK, Schulthess, F, Yabann, WK, Maritim, HK & Mithöfer , D, (2006) Biological control of cereal stem borers in Kenya: A cost benefit approach. A nnales de la Société Entomologique de France 42(3–4), 519–28.

Kolawole G. O.1, Adigun C. O., Akintade B. O., Opaleye, O. A. and Lawal B.A. (2013) Organic Residues Affect Soil P Availability, Cowpea Yield And Nutrient Uptake on a Near Neutral P-Deficient Alfisol in Southwestern Nigeria; Department of Crop Production and Soil Science, Ladoke Akintola University of Technology (LAUTECH), PMB 4000, Ogbomoso, Oyo state, Nigeria: International Journal of Applied Agricultural and Apicultural Research.

Lavelle P. and Spain A.V., (2000) Soil ecology; Kluwer Academic Publishers, Dordrecht.

Macharia, I, Löhr, B & De Groote, H, (2005) Assessing the potential impact of biological control of Plutella xylostella (diamondback moth) in cabbage production in Kenya. Crop Protection 24(11), 981–9.

Mashingaidze, N., Madakadze, C., Twomlow, S., Nyamangara, J. and Hove, L. (2012). Crop yield and weed growth under conservation agriculture in semi-arid Zimbabwe. Soil and Tillage Research 124:102–110.

Manyam B.V., Dhanasekaran M., Hare T.A. (2004) Effect of antiparkinson drug HP-200 (Mucuna pruriens) on the central monoaminergic neurotransmitters. 2004. *Phytother Res*

18:97-101.

Mazvimavi, K. and Twomlow, S. (2009). Socio-economic and institutional factors affecting adoption of conservation farming by vulnerable households in Zimbabwe. Agricultural Systems 101(1–2):20–29.

Meertens, H.C., L.J. Ndege and H.J. Enserink. (1995) Dynamics in Farming Systems: Changes in Time and Space in Sukumaland, Tanzania. Royal Tropical Institute, Amsterdam.

Miiro, R., Kabuye, F., Jama, B.A., Musenero, E., Zake, J.Y.K., Nkwiine, C., Kakinda, M.J., Onyango, O., and Delve, R.J. (2010) Early farmer evaluation of integrated nutrient management technologies in Eastern Uganda; TSBF-CIAT, Academy Science Publishers, Nairobi.

Ministry of Agriculture -MOA, (2009) Mechanization and Irrigation Development, January 15, 2010b, Western Kenya Crop Situation Report.

Mupangwa, W., Twomlow, S. and Walker, S. (2008). The influence of conservation tillage methods on soil water regimes in semi-arid southern Zimbabwe. Physics and Chemistry of the Earth 33(8–13):762–767.

Mutema M., Mafongoya P. L., Nyagumbo I. and Chikukura L. (2013) Effects of crop residues and reduced tillage on macrofauna abundance: ISSN 1177-4258; Journal of Organic Systems, 8(1), 2013

Narain P. and Kumar P. (1998), Prospects and Limitations of Reduced Tillage in Arid Zone:Central Arid Zone Research Institute, Jodhpur 342 003, Rajasthan, India

Ncube, B., Twomlow, S. J, Dimes, J. P., vanWijk,M. T. and Giller, K. E. (2009). Resource flows, crops and soil fertility management in smallholder farming systems in semi-arid Zimbabwe. Soil Use and Management 25:78–90.

NEMA 2001. Uganda State of the Environment Report 2000, Version 2. National Environment Management Authority, Ministry of Natural Resources, Kampala.

Ngwira, A. R., Thierfelder, C. and Lambert,D. M. (2012).Conservation agriculture systems for Malawian smallholder farmers: long term effects on crop productivity, profitability and soil quality. Renewable Agriculture and Food Systems. doi:10.1017/S1742170512000257.

Nidal H. Abu-Hamdeh, and Randall C. R. (2009) Soil Thermal Conductivity: Effects of Density, Moisture, Salt Concentration, and Organic Matter, Soil Sci. Soc. Am. J. 64:1285–1290

Nkonya, E. M., D. Phillip, T. Mogues, M. Yahaya, G. Adebowale, J. Pender, T. Arokoyo, and E. Kato. 2008b. *From the ground up: Impacts of a pro-poor community-driven development project in Nigeria.*Discussion Paper 756. Washington, D.C.: International Food Policy Research Institute.

Nkonya, E., C. Kaizzi, and J. Pender. 2005. Determinants of nutrient balances in a maize farming system in eastern Uganda. *Agricultural Systems* 85: 155–182.

Nkonya, E., Gerber, N., Baumgartner, P., von Braun, J., De Pinto, A., Graw, V., Kato, E., Kloos, J. and Walter, T., (2011b). The Economics of Land Degradation: Toward an integrated global assessment.. Peter Lang GmbH.

Nkonya, E., Gerber, N., Baumgartner, P., von Braun, J., De Pinto, A., Graw, V., Kato, E., Kloos, J., Walter, T. (2011a) The Economics of Desertification, Land Degradation, and Drought Toward an Integrated Global Assessment, ZEF- Discussion Papers on Development Policy No. 150, Center for Development Research, Bonn, May 2011. (Misc. 150; Center for Development Research, Bonn, May 2011) 197

Nkonya, E., J. Pender, and E. Kato. 2008a. Who knows, who cares? The determinants of enactment, awareness and compliance with community natural resource management regulations in Uganda. *Environment and Development Economics* 13 (1): 79–109.

Nkonya, E., J. Pender, P. Jagger, D. Sserunkuuma, C. Kaizzi, and H. Ssali. 2004. *Strategies for sustainable land management and poverty reduction in Uganda.* Research Report 133. Washington, D.C.: International Food Policy Research Institute.

Nyambati, E.M. (2002) Management and nutritive evaluation of *Mucuna pruriens* and *Lablab purpureus* – maize intercrops in the sub-humid highlands of northwestern Kenya. Ph.D. Dissertation, University of Florida.

Nyambati, E.M., and L.E. Sollenberger. (2003) Nutritive value of top-canopy herbage of *Mucuna* and *Lablab* relay cropped in maize in the sub-humid highlands of northwestern Kenya. Tropical and Sub-tropical Agroecosystems, 1:81-86.

Nyende P., Nyakuni A., Opio J.P., Odogola W., (2007) Conservation agriculture: a Uganda case study, Nairobi. African Conservation Tillage Network, Food and Agriculture Organization of the United Nations.

Nyengerai, K. A. (2010). Conservation Tillage under Small-Holder Farming Conditions of Semi-Arid Zimbabwe: An Assessment of Crop Establishment, Dry Spell Mitigation, Maize Yield and Crops Response to Nitrogen. MSc thesis, Faculty of Agriculture and Natural Resource, Africa University, Mutare.

Nzabi, A.W., F. Makini, N. Kidula and E. Mutai (2007) Effect of Cover Crops and Conservation Tillage in Improvng Maize Yields in Semi-Arid Areas of South-West Kenya

Nziguheba, G. R., Palm, C. A., Buresh, R. J., and Smithson, P.C. (1998) Soil phosphorus fractions and adsorption as affected by organic and inorganic sources. Plant Soil 198: 159-168.

Ojiem, J.O., Vanlauwe, B., de Ridder, N., Giller, K.E., (2007) Niche-based assessment of contributions of legumes to the nitrogen economy of Western Kenya smallholder farms. Plant Soil 292, 119–135.

Okalebo J.R., Gathua K.W. and Woomer P.C. (2002) Laboratory methods of soil plant analysis. A working manual; 2nd edition. Sacred Africa: 28, 29-31, 59, 78.

Okalebo, J.R., C. O. Othieno, H. K. Martim, D. M. Iruria, M. J. Kipsat, P. O. Kisinyo, L. Osei K., J. O. Fening, S. R. Gowen and A. Jama (2010) The potential of four nontraditional legumes in suppressing the population of nematodes in two Ghanaian soils: Soil Science Environment Management Journal; Accessed July, 2013.

Okalebo, J. R. (2003). Inorganic resources management for sustainable soil productivity. E. Africa. Agric. For. J. 69(2), 119-129.

Ong’ang’a, O., and K. Munyirwa. (1998) A rapid assessment of water hyacinth situation in Lake Victoria. Infestation, current scale and trends. Consultant report, October 1998. SIENALA (Friends of Lake Victoria), PO Box 4580, Kisumu, Kenya.

Olson, J. M. 1998. A conceptual framework of land use change in the East African Highlands. Paper read at Earth's Changing Land: Joint Global Change and Terrestrial Ecosystems and Land Use and Land Cover Change Open Science Conference on Global Change, Barcelona, Spain.

Palm, C. A., Gachengo, C. N., Delve, R.J., Cadisch, G. and Giller, K. E., (2001) Organic inputs for soil fertility management in tropical agro-ecosystems: application of an organic resource database. Agric.Ecosyst. & Environ. 83, 27-42.

Paoletti M.G., (1999) Using bioindicators based on biodiversity to assess landscape sustainability, Agriculture, Ecosystems and Environment 74 1-18. River road, Cambridge, Ontario N3C 2B7 Canada.

Robbins S.G., R.D. Voss. (1991) Phosphorus and potassium stratification in conservation tillage systems. Journal: Soil Water Conserv. 1991. 46:300.

Rockstrom J., J. Barron and P. Fox. (2001) Water productivity in rainfed agriculture: challenges and opportunities for small holder farmers in drought prone tropical agro-ecosystems. *In press.*

Shepherd, K.D., Soule, M.J., 1998. Soil fertility management in West Kenya: dynamic simulation of productivity, profitability and sustainability at different resource endowment levels. Agriculture, Ecosystems and Environment 71, 131–145.

Shepherd K., M. Walsh, F. Mugo, C. Ong, T.S. Hansen, B. Swallow, A. Awiti, H. Mwangi, D. Nyantika, D. Ombalo, M. Grunder, F. Mbote and D. Mungai. (2000) Linking Land and Lake, Research and Extension, Catchment and Lake Basin: Final Technical Report–Startup Phase, July 1999 to June 2000. Working Paper 2000-2, ICRAF.

S**anchez**, P. A. (2002). Soil fertility and hunger in Africa. Science 295: 2019-2020.

Sanginga, N., Okogun, J.A., Vanlauwe, B., Diels, J., Dashiell, K., (2001) Contribution of nitrogen fixation to the maintenance of soil fertility with emphasis on promiscuous soybean maize-based cropping systems in the moist savanna of West Africa. In: Tian, G., Ishida, F., Keatinge, J.D.H. (Eds.), Sustaining Soil Fertility in West Africa. ASA, Wisconsin, pp. 157–178.

Selles F., Grant C.A., Johnston M.A. (2002) Conservation Tillage Effects on Soil Phosphorus Distribution: Better Crops/Vol. 86 (2002, No. 3)

Shai, W. and Norton J.M., (2000) Microbial control of nitrate concentrations in an agricultural soil treated with dairy waste-compost or ammonium fertilizer Soil Biology and Biochemistry 32:1453-1457.

Snapp, S.S. and Borden H., (2005) Enhanced nitrogen mineralization in mowed or glyphosate treated cover crops compared to direct incorporation. Plant and Soil 270: 101-112.

Stoorvogel, J.J., Smaling, E.M.A., 1990. Assessment of soil nutrient depletion in sub-Saharan Africa: 1983–2000. Report 28, DLO Winand Staring Centre for Integrated Land, Soil and Water Research (SC-DLO). Wageningen, Netherlands.

Swallow, B., M. Walsh, D. Nyantika, S. Mureithi, Q. Noordin, C. Ong, K. Shepherd, F. Place, A. Awiti, H. Mwangi, O. Ochieng, M. Cohen, F. Mugo, S. Oyasi, C. Omuto, L. Cohen and A. Okono. (2002) Improved Land Management in the Lake Victoria Basin: Annual Technical Report July 2001 to June 2002. Working Paper 2002-2, ICRAF.

Thierfelder, C. andWall, P. C. (2012). Effects of conservation agriculture on soil quality and productivity in contrasting agro-ecological environments of Zimbabwe. Soil Use and Management 28(2):209–220.

Thuita M., (2007) A study to better understand the ‘MBILI’ and Conventional Intercropping Systems in Relation to Root characteristics, Nutrient uptake and yield of intercrops in Western Kenya, Department of Soil Science, Moi University, Eldoret.

Tsai, C.Y., Dweikat I., Huber D.M. and Warren H.L., (1992) Interrelationship of nitrogen nutrition with maize (*Zea mays*) grain yield, nitrogen use efficiency and grain quality. J. Sci. Food Agric. 58:1-8. Unasylva. 185 (47):24-28.

Twomlow, S., Hove, L., Mupangwa,W., Masikati, P. and Mashingaidze, N. (2009). Precision conservation agriculture for vulnerable farmers in low-potential zones. In Increasing the Productivity and Sustainability of Rainfed Cropping Systems of Poor Smallholder Farmers, 37–54 (E. Humphreys and R.S. Bayot). Colombo: The CGIAR Challenge Program on Water and Food.

van Straaten, P. (2007).Agreogeology: the use of rocks for crops. Enviroquest Ltd, 352 River road, Cambridge, Ontario N3C 2B7 Canada.

Vanlauwe, B. and Zingore, S. (2011). Integrated soil fertility management: an operational definition and consequences for implementation and dissemination. Better Crops 95(3):4–7.

Vogeler, I., Rogasik, J., Funder, U., Panten, K. and Schnug, E. (2008). Effect of tillage systems and P-fertilisation on soil physical and chemical properties, crop yield and nutrient uptake. Soil and Tillage Research 103(1):137–143.

Wall, P. C. (2007). Tailoring conservation agriculture to the needs of small farmers in developing countries: an analysis of issues. Journal of Crop Improvement 19(1–2):137–155.

Wambua Jimmy (2012) Conservation Farming: A Sustainable way to Increase Yields for Farmers; Article 367-465; copyright 2010 - 2013 M-Farm; accessed January 18th, 2013

Watson, A.T., (2004) Grain Legumes and the environment: How to assess benefits and impacts. Zurich Switzerland 18-19 Nov 2004.

Wolters V., (2000) Invertebrate control of soil organic matter stability, Biology and Fertility of Soil 31; 1-19.

www.fao.org

World Bank. (1996) WB Document: Staff Appraisal Report No. 15429-AFR. The Republic of Kenya, United Republic of Tanzania and The Republic of Uganda for the Lake Victoria Environmental Management Project.

Wortzmann, C.S., Kaizzi, C.K., 1998. Nutrient balances and expected effects of alternative practices in farming systems of Uganda. Agriculture, Ecosystems and Environment 71, 115–129.

Wortmann, C.S., R.A. Kirkby, C.A. Eledu, D.J. Allen. (1998) Atlas of Common Bean (*Phaseolus vulgaris* L.) Production in Africa. CIAT, Cali, Colombia. 133 pp.

Zake, J.S., Nkwijn, C. & Magunda, M.K. 1999. Uganda. In: Nabhan, H., Mashali, A.M. & Mermut, A.R. (eds). Integrated soil management for sustainable agriculture and food security in Southern and East Africa. Proceedings of the Expert Consultation, Harare, Zimbabwe. AGL/MISC/23/99. FAO, Rome. ftp://ftp.fao.org/agl/agll/docs/misc23.pdf

Zeddies, J, Schaab, RP, Neuenschwander, P and Herren, HR, 2001. Economics of biological control of cassava mealybug in Africa. Agricultural Economics 24, 209–19.

Zibilske L.M., J.M. Bradford, and J.R. Smart (2002) Conservation tillage induced changes in organic carbon, total nitrogen and available phosphorus in a semi-arid alkaline subtropical soil.

Zingore, S., Murwira, H. K., Delve, R. J. and Giller, K. E. (2007). Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. Agriculture Ecosystems and Environment 119:112–126.

APPENDICES

Appendix I; Modified Anderson and Ingram (1993) protocol for sampling procedure for the soil invertebrates

Procedures follow a modified Anderson and Ingram (1993) protocol, making use of pitfall traps together with the digging of soil monoliths of dimensions 25x25x30 (depth) cm and sampling soils at selected points within the area of interest. In each of the sampling plot in all the sites, sampling of soil biota (macrofauna) was done in three sampling point located using random method, but according to the standard TSBF method using randomly selected sampling points (Anderson and Ingram, 1993; Swift and Bignell, 2001). Sampling was done from a 0-10 cm depth, and then brought to the laboratory for hand sorting in polythene bags in a cooler box at 4^0C. Randomly selected 5 sampling points were located and marked within the sampling area of 5m by 10m. At each sampling point, litter was removed and soil sampled using a trowel to the required depth of 0-10cm. In a variant of the method, all invertebrates longer than 10 cm excavated from the soil are collected. These were mainly large millipedes and earthworms with very low population densities but representing an important biomass. Their abundance and biomass can be calculated on the basis of m^{-2} samples. If different depths are sampled, soil should be divided into layers, 0-10cm, 10-20cm and 20-30cm if deeper depths were sampled. The soil was transferred in to a polythene bag and transported to the laboratory at 4^0C. Bagged soil should be kept out of direct sunlight and sorted by hand (for population count) within 24 hours (but preferably sooner).

Appndix II: Analysis of Variance: Available P LR2012 in Bungoma

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	5.985	1.995	2.06		
Block.Tillage stratum						
Tillage	2	5.365	2.683	2.78	0.140	
Residual	6	5.800	0.967	0.46		
Block.Tillage.NitrogenApplication stratum						
NitrogenApplication	1	7.933	7.933	3.74	0.085	
Tillage.NitrogenApplication	2	4.420	2.210	1.04	0.392	
Residual	9	19.079	2.120	1.29		
Block.Tillage.NitrogenApplication.Croppingsystem stratum						
Croppingsystem	2	12.774	6.387	3.90	0.029	
Tillage.Croppingsystem	4	8.927	2.232	1.36	0.267	
NitrogenApplication.Croppingsystem		2	5.587	2.794	1.70	0.196
Tillage.NitrogenApplication.Cropsyst		4	9.127	2.282	1.39	0.256
Residual	36	59.010	1.639			
Total	71	144.008				

Appndix III: Analysis of Variance: Soil pH LR2012 in Bungoma

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	1.50237	0.50079	3.78		
Block.Tillage stratum						
Tillage	2	0.04120	0.02060	0.16	0.859	
Residual	6	0.79423	0.13237	2.44		
Block.Tillage.NitrogenApplication stratum						
NitrogenApplication	1	0.00233	0.00233	0.04	0.840	
Tillage.NitrogenApplication	2	0.00554	0.00277	0.05	0.951	
Residual	9	0.48890	0.05432	0.64		
Block.Tillage.NitrogenApplication.Croppingsystem stratum						
Croppingsystem	2	0.66636	0.33318	3.95	0.028	
Tillage.Croppingsystem	4	1.61252	0.40313	4.78	0.003	
NitrogenApplication.Croppingsystem		2	0.00480	0.00240	0.03	0.972
Tillage.NitrogenApplication.Cropsys		4	0.09551	0.02388	0.28	0.887
Residual	36	3.03522	0.08431			
Total	71	8.24899				

Appndix IV: Analysis of Variance: Soil Organic Carbon in LR2012 in Bungoma

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	2.33507	0.77836	8.76		
Block.Tillage stratum						
Tillage	2	1.08981	0.54490	6.13	0.035	
Residual	6	0.53316	0.08886	0.43		
Block.Tillage.NitrogenApplication stratum						
NitrogenApplication	1	0.01837	0.01837	0.09	0.773	
Tillage.NitrogenApplication	2	0.87609	0.43804	2.11	0.177	
Residual	9	1.86803	0.20756	2.24		
Block.Tillage.NitrogenApplication.Croppingsystem stratum						
Croppingsystem	2	0.06126	0.03063	0.33	0.720	
Tillage.Croppingsystem	4	0.26448	0.06612	0.71	0.588	
NitrogenApplication.Croppingsystem		2	0.26847	0.13423	1.45	0.248
Tillage.NitrogenApplication.Cropsyst		4	0.15034	0.03758	0.41	0.803
Residual	36	3.33312	0.09259			
Total	71	10.79819				

Appndix V: Analysis of Variance: Soil total Nitrogen in LR2012 in Bungoma

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	0.021322	0.007107	3.30		
Block.Tillage stratum						
Tillage	2	0.030505	0.015253	7.09	0.026	
Residual	6	0.012915	0.002153	0.72		
Block.Tillage.NitrogenApplication stratum						
NitrogenApplication	1	0.001814	0.001814	0.61	0.455	
Tillage.NitrogenApplication	2	0.031183	0.015591	5.24	0.031	
Residual	9	0.026799	0.002978	1.16		
Block.Tillage.NitrogenApplication.Croppingsystem stratum						
Croppingsystem	2	0.002376	0.001188	0.46	0.632	
Tillage.Croppingsystem	4	0.002814	0.000703	0.27	0.892	
NitrogenApplication.Croppingsystem		2	0.001615	0.000807	0.32	0.732
Tillage.NitrogenApplication.Cropsyst		4	0.013870	0.003467	1.35	0.269
Residual	36	0.092171	0.002560			
Total	71	0.237382				

Appndix VI Analysis of Variance: Available P in LR2012 in Trans-Nzoia

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	109.292	36.431	6.77		
Block.Tillage stratum						
Tillage	2	31.117	15.559	2.89	0.132	
Residual	6	32.289	5.381	1.08		
Block.Tillage.Napplication stratum						
Napplication	1	179.753	179.753	36.00	<.001	
Tillage.Napplication	2	1.967	0.984	0.20	0.825	
Residual	9	44.938	4.993	0.57		
Block.Tillage.Napplication.Cropping_system stratum						
Cropping_system	2	5.412	2.706	0.31	0.736	
Tillage.Cropping_system	4	44.517	11.129	1.27	0.300	
Napplication.Cropping_system	2	2.871	1.436	0.16	0.850	
Tillage.Napplication.Cropping_syste		4	5.569	1.392	0.16	0.958
Residual	36	315.485	8.763			
Total	71	773.212				

Appndix VII: Analysis of Variance: Soil_pH in LR2012 in Trans-Nzoia

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	2.11804	0.70601	1.57		
Block.Tillage stratum						
Tillage	2	0.16355	0.08178	0.18	0.838	
Residual	6	2.69259	0.44877	12.89		
Block.Tillage.Napplication stratum						
Napplication	1	0.00117	0.00117	0.03	0.859	
Tillage.Napplication	2	0.05655	0.02828	0.81	0.474	
Residual	9	0.31343	0.03483	0.42		
Block.Tillage.Napplication.Cropping_system stratum						
Cropping_system	2	0.48054	0.24027	2.89	0.068	
Tillage.Cropping_system	4	0.63456	0.15864	1.91	0.130	
Napplication.Cropping_system	2	0.10724	0.05362	0.65	0.530	
Tillage.Napplication.Cropping_syst		4	0.15167	0.03792	0.46	0.767
Residual	36	2.98812	0.08300			
Total	71	9.70747				

Appndix VIII: Analysis of Variance: Nitrogen in LR2012 in Trans-Nzoia

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	0.015168	0.005056	1.51		
Block.Tillage stratum						
Tillage	2	0.001910	0.000955	0.29	0.761	
Residual	6	0.020092	0.003349	2.84		
Block.Tillage.Napplication stratum						
Napplication	1	0.007830	0.007830	6.65	0.030	
Tillage.Napplication	2	0.004509	0.002254	1.91	0.203	
Residual	9	0.010605	0.001178	0.49		
Block.Tillage.Napplication.Cropping_system stratum						
Cropping_system	2	0.021620	0.010810	4.50	0.018	
Tillage.Cropping_system	4	0.002160	0.000540	0.22	0.923	
Napplication.Cropping_system	2	0.002169	0.001085	0.45	0.640	
Tillage.Napplication.Cropping_syst		4	0.000596	0.000149	0.06	0.993
Residual	36	0.086453	0.002401			
Total	71	0.173111				

Appndix IX: Analysis of Variance: Soil Organic Carbon in LR2012 in Trans-Nzoia

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	1.0849	0.3616	1.45		
Block.Tillage stratum						
Tillage	2	0.1219	0.0610	0.24	0.791	
Residual	6	1.5014	0.2502	2.34		
Block.Tillage.Napplication stratum						
Napplication	1	0.7401	0.7401	6.93	0.027	
Tillage.Napplication	2	0.3836	0.1918	1.80	0.221	
Residual	9	0.9612	0.1068	0.43		
Block.Tillage.Napplication.Cropping_system stratum						
Cropping_system	2	1.9244	0.9622	3.88	0.030	
Tillage.Cropping_system	4	0.2472	0.0618	0.25	0.908	
Napplication.Cropping_system	2	0.0578	0.0289	0.12	0.890	
Tillage.Napplication.Cropping_syst		4	0.3122	0.0781	0.31	0.866
Residual	36	8.9250	0.2479			
Total	71	16.2599				

Appndix X: Analysis of Variance: Earthworms in LR2012 in Trans-Nzoia

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	2.4861	0.8287	0.75		
Block.Tillage stratum						
Tillage	2	130.3611	65.1806	58.91	<.001	
Residual	6	6.6389	1.1065	0.97		
Block.Tillage.Napplication stratum						
Napplication	1	48.3472	48.3472	42.28	<.001	
Tillage.Napplication	2	5.5278	2.7639	2.42	0.144	
Residual	9	10.2917	1.1435	1.45		
Block.Tillage.Napplication.Cropping_system stratum						
Cropping_system	2	301.4444	150.7222	191.51	<.001	
Tillage.Cropping_system	4	128.6389	32.1597	40.86	<.001	
Napplication.Cropping_system	2	11.4444	5.7222	7.27	0.002	
Tillage.Napplication.Cropping_syst		4	6.8056	1.7014	2.16	0.093
Residual	36	28.3333	0.7870			
Total	71	680.3194				

Appndix XI: Analysis of Variance: Available_P in LR2012 in Tororo

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	47.979	15.993	1.43		
Block.Tillage stratum						
Tillage	2	9.675	4.838	0.43	0.667	
Residual	6	66.977	11.163	1.41		
Block.Tillage.Napplication stratum						
Napplication	1	74.914	74.914	9.48	0.013	
Tillage.Napplication	2	14.071	7.035	0.89	0.444	
Residual	9	71.117	7.902	1.00		
Block.Tillage.Napplication.Cropping_system stratum						
Cropping_system	2	26.547	13.273	1.69	0.200	
Tillage.Cropping_system	4	74.109	18.527	2.35	0.072	
Napplication.Cropping_system	2	0.486	0.243	0.03	0.970	
Tillage.Napplication.Cropping_syst		4	0.757	0.189	0.02	0.999
Residual	36	283.585	7.877			
Total	71	670.216				

Appndix XII: Analysis of Variance: Soil pH in LR2012 in Tororo

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	1.5321	0.5107	3.34		
Block.Tillage stratum						
Tillage	2	0.0439	0.0220	0.14	0.869	
Residual	6	0.9171	0.1529	2.95		
Block.Tillage.Napplication stratum						
Napplication	1	0.0032	0.0032	0.06	0.809	
Tillage.Napplication	2	0.0068	0.0034	0.07	0.937	
Residual	9	0.4657	0.0517	0.41		
Block.Tillage.Napplication.Cropping_system stratum						
Cropping_system	2	0.5993	0.2996	2.36	0.109	
Tillage.Cropping_system	4	1.0200	0.2550	2.01	0.114	
Napplication.Cropping_system	2	0.0008	0.0004	0.00	0.997	
Tillage.Napplication.Cropping_syst		4	0.1042	0.0261	0.21	0.934
Residual	36	4.5678	0.1269			
Total	71	9.2609				

Appndix XIII: Analysis of Variance: Soil Organic Carbon in LR2012 in Tororo

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	0.5575	0.1858	0.57		
Block.Tillage stratum						
Tillage	2	0.1185	0.0592	0.18	0.838	
Residual	6	1.9569	0.3262	2.21		
Block.Tillage.Napplication stratum						
Napplication	1	3.6531	3.6531	24.70	<.001	
Tillage.Napplication	2	0.0691	0.0346	0.23	0.796	
Residual	9	1.3310	0.1479	1.41		
Block.Tillage.Napplication.Cropping_system stratum						
Cropping_system	2	6.8179	3.4089	32.55	<.001	
Tillage.Cropping_system	4	0.7777	0.1944	1.86	0.140	
Napplication.Cropping_system	2	0.4553	0.2276	2.17	0.128	
Tillage.Napplication.Cropping_syst		4	0.1281	0.0320	0.31	0.872
Residual	36	3.7707	0.1047			
Total	71	19.6357				

Appndix XIV: Analysis of Variance: Nitrogen in LR2012 in Tororo

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	0.011915	0.003972	5.28		
Block.Tillage stratum						
Tillage	2	0.003966	0.001983	2.64	0.151	
Residual	6	0.004515	0.000752	0.37		
Block.Tillage.Napplication stratum						
Napplication	1	0.026846	0.026846	13.14	0.006	
Tillage.Napplication	2	0.001865	0.000932	0.46	0.647	
Residual	9	0.018388	0.002043	1.11		
Block.Tillage.Napplication.Cropping_system stratum						
Cropping_system	2	0.060411	0.030206	16.38	<.001	
Tillage.Cropping_system	4	0.007224	0.001806	0.98	0.431	
Napplication.Cropping_system	2	0.004491	0.002246	1.22	0.308	
Tillage.Napplication.Cropping_syst		4	0.008299	0.002075	1.13	0.360
Residual	36	0.066382	0.001844			
Total	71	0.214303				

Appndix XV: Analysis of Variance: Worms in LR2012 in Tororo

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	9.5972	3.1991	1.46		
Block.Tillage stratum						
Tillage	2	57.3333	28.6667	13.12	0.006	
Residual	6	13.1111	2.1852	5.30		
Block.Tillage.Napplication stratum						
Napplication	1	33.3472	33.3472	80.93	<.001	
Tillage.Napplication	2	13.4444	6.7222	16.31	0.001	
Residual	9	3.7083	0.4120	1.11		
Block.Tillage.Napplication.Cropping_system stratum						
Cropping_system	2	153.5833	76.7917	207.34	<.001	
Tillage.Cropping_system	4	82.3333	20.5833	55.57	<.001	
Napplication.Cropping_system	2	19.5278	9.7639	26.36	<.001	
Tillage.Napplication.Cropping_syst		4	18.5556	4.6389	12.53	<.001
Residual	36	13.3333	0.3704			
Total	71	417.8750				

Appndix XVI: Analysis of Variance: Available_P in LR2012 in Kapchorwa

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	36.08	12.03	1.08	
Block.Tillage stratum					
Tillage	2	45.99	22.99	2.07	0.207
Residual	6	66.69	11.11	3.64	
Block.Tillage.Napplication stratum					
Napplication	1	218.92	218.92	71.61	<.001
Tillage.Napplication	2	16.40	8.20	2.68	0.122
Residual	9	27.51	3.06	0.26	
Block.Tillage.Napplication.Cropping_system stratum					
Cropping_system	2	19.42	9.71	0.81	0.452
Tillage.Cropping_system	4	55.94	13.98	1.17	0.341
Napplication.Cropping_system	2	2.88	1.44	0.12	0.887
Tillage.Napplication.Cropping_sys	4	27.01	6.75	0.56	0.690
Residual	36	430.61	11.96		
Total	71	947.44			

Appndix XVII: Analysis of Variance: Soil_pH in LR2012 in Kapchorwa

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	1.06758	0.35586	2.87		
Block.Tillage stratum						
Tillage	2	2.26802	1.13401	9.15	0.015	
Residual	6	0.74328	0.12388	2.64		
Block.Tillage.Napplication stratum						
Napplication	1	0.00125	0.00125	0.03	0.874	
Tillage.Napplication	2	0.07851	0.03925	0.84	0.465	
Residual	9	0.42274	0.04697	0.49		
Block.Tillage.Napplication.Cropping_system stratum						
Cropping_system	2	1.57877	0.78938	8.23	0.001	
Tillage.Cropping_system	4	0.42775	0.10694	1.12	0.364	
Napplication.Cropping_system	2	0.00181	0.00090	0.01	0.991	
Tillage.Napplication.Cropping_syst		4	0.13316	0.03329	0.35	0.844
Residual	36	3.45145	0.09587			
Total	71	10.17431				

Appndix VIII: Analysis of Variance: Organic Carbon in LR2012 in Kapchorwa

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	0.6026	0.2009	0.37		
Block.Tillage stratum						
Tillage	2	0.8408	0.4204	0.78	0.501	
Residual	6	3.2436	0.5406	2.69		
Block.Tillage.Napplication stratum						
Napplication	1	0.7401	0.7401	3.68	0.087	
Tillage.Napplication	2	1.0386	0.5193	2.58	0.130	
Residual	9	1.8096	0.2011	0.96		
Block.Tillage.Napplication.Cropping_system stratum						
Cropping_system	2	1.3008	0.6504	3.09	0.058	
Tillage.Cropping_system	4	0.6133	0.1533	0.73	0.578	
Napplication.Cropping_system	2	0.2803	0.1401	0.67	0.520	
Tillage.Napplication.Cropping_syst		4	0.2122	0.0531	0.25	0.906
Residual	36	7.5667	0.2102			
Total	71	18.2488				

Appndix XIX: Analysis of Variance: Nitrogen in LR2012 in Kapchorwa

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	0.005739	0.001913	0.35		
Block.Tillage stratum						
Tillage	2	0.006419	0.003209	0.59	0.582	
Residual	6	0.032466	0.005411	3.14		
Block.Tillage.Napplication stratum						
Napplication	1	0.006394	0.006394	3.71	0.086	
Tillage.Napplication	2	0.011655	0.005828	3.38	0.080	
Residual	9	0.015522	0.001725	0.76		
Block.Tillage.Napplication.Cropping_system stratum						
Cropping_system	2	0.016275	0.008138	3.56	0.039	
Tillage.Cropping_system	4	0.006425	0.001606	0.70	0.595	
Napplication.Cropping_system	2	0.003345	0.001672	0.73	0.488	
Tillage.Napplication.Cropping_syst		4	0.002722	0.000680	0.30	0.877
Residual	36	0.082175	0.002283			
Total	71	0.189137				

Appndix XX: Analysis of Variance: Earthworms in LR2012 in Kapchorwa

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
Block stratum	3	1.2639	0.4213	0.49		
Block.Tillage stratum						
Tillage	2	192.1111	96.0556	112.76	<.001	
Residual	6	5.1111	0.8519	1.14		
Block.Tillage.Napplication stratum						
Napplication	1	8.6806	8.6806	11.65	0.008	
Tillage.Napplication	2	7.4444	3.7222	4.99	0.035	
Residual	9	6.7083	0.7454	0.95		
Block.Tillage.Napplication.Cropping_system stratum						
Cropping_system	2	302.1111	151.0556	193.07	<.001	
Tillage.Cropping_system	4	111.3889	27.8472	35.59	<.001	
Napplication.Cropping_system	2	1.4444	0.7222	0.92	0.406	
Tillage.Napplication.Cropping_syst		4	3.5556	0.8889	1.14	0.355
Residual	36	28.1667	0.7824			
Total	71	667.9861				

Appendix XXI; Mean separation for tillage and cropping systems on % SOC in Bungoma LR2012

		0-10cm					**10-30cm**				
		LR'11	SR'11	LR'12	SR'12	mean	LR'11	SR'11	LR'12	SR'12	mean
Till	**CT**	1.64a	1.86a	2.06a	1.37a	**1.73**	1.44ab	1.66a	1.76a	0.97a	**1.46**
	MT	1.79b	1.82a	2.05a	1.98a	**1.91**	1.58b	1.62a	1.75a	1.58c	**1.63**
	NT	1.55ab	1.83a	2.01a	1.65a	**1.76**	1.35a	1.63a	1.71a	1.25b	**1.49**
CS	**CP**	1.69a	1.37a	1.70a	1.49a	**1.56**	1.48a	1.17a	1.40a	1.09a	**1.29**
	ROT 1	1.69a	1.47a	1.77a	1.54a	**1.62**	1.48a	1.22a	1.44a	1.14a	**1.32**
	ROT 2	1.64a	2.11b	2.25a	1.77b	**1.94**	1.44a	1.93a	1.96b	1.37b	**1.68**
Mean		**1.66**	**1.84**	**2.04**	**1.66**		**1.51**	**1.60**	**1.74**	**1.26**	
SE		**1.171**	**0.164**	**0.118**	**0.088**		**0.11**	**0.141**	**0.104**	**0.143**	
LSD		**0.487**	**0.418**	**0.358**	**0.336**		**0.41**	**0.4**	**0.296**	**0.407**	
% CV		**20.2**	**18.6**	**8.4**	**13.8**		**23.1**	**20**	**8.3**	**18**	

Appendix XXII; Mean separation for tillage and cropping systems on NH3-N in Bungoma and Trans-Nzoia

		Bungoma								Trans-Nzoia			
		0-10cm				10-30cm				0-10cm		10-30cm	
		LR'11	SR'11	LR'12	SR'12	LR'11	SR'11	LR'12	SR'12	LR'11	LR'12	LR'11	LR'12
Till	CT	586.3a	812.9a	954.9a	886.9a	580.1a	801.8a	943.8a	875.8a	640.9a	854.1a	628.6a	846.5a
	MT	601.0a	821.9a	983.9a	915.9a	598.2a	810.5a	972.5a	904.5a	671.3ab	866.9ab	667.7a	858.8ab
	NT	604.9a	845.1a	984.6a	901.6a	595.2a	822.0a	960.2a	889.5a	682.4b	890.1b	651.2a	876.7b
CS	CP	455.9a	697.3	893.3a	771.3a	447.4a	681.1a	823.1a	755.1a	520.4a	757.3a	503.4a	741.1a
	ROT 1	470.8a	705.8	847.8a	779.8a	471.4a	703.0a	842.8a	779.0a	526.2a	765.8a	527.4a	760.8a
	ROT 2	686.8b	910.0b	1061.0b	985.4b	679.0b	891.0b	1042.8b	971.8b	759.2b	943.0b	738.3b	933.8b
Mean		597.4	827.0	974.0	901.0	591.0	811.0	959.0	890.0	665.0	870.0	649.0	861.0
SE		40.66	45.6	42.1	45.5	42.40	43.3	41.5	24.9	43.7	39.2	45.5	37.9
LSD		115.84	130.2	120.1	129.7	120.7	123.2	118.1	104.6	124.7	111.8	129.6	108.1
% CV		25.7	26.8	21.1	22.0	23.0	25.7	19.8	21.1	29.5	23.1	29.7	20.6

Appendix XXIII; Mean separation for tillage and cropping systems on NH3-N in Tororo and Kapchorwa

		Tororo								Kapchorwa			
		0-10cm				10-30cm				0-10cm		10-30cm	
		LR'11	SR'11	LR'12	SR'12	LR'11	SR'11	LR'12	SR'12	LR'11	LR'12	LR'11	LR'12
Till	CT	673.4a	762.3a	868.9a	825.9a	661.1a	756.8a	857.8a	814.8a	572.4a	801.4a	560.1a	795.3a
	MT	697.4a	791.2a	897.9a	854.9a	689.2a	785.5a	886.5a	841.3a	596.4a	836.4a	585.2a	829.5a
	NT	706.3a	793.6a	906.1a	863.1a	686.2a	782.0a	881.7a	843.5a	605.3a	838.6a	588.2a	811.7a
CS	CP	555.4a	644.2a	753.3a	694.1a	538.4a	636.1a	737.1a	694.1a	454.4a	684.4a	437.4a	687.8a
	ROT 1	561.2a	659.4a	761.8a	718.0a	562.4a	658.0a	756.8	718.0a	460.2a	738.2a	461.4a	736.7a
	ROT 2	781.7b	869.4b	979.9b	917.9b	764.5b	859.9b	960.9b	917.9b	680.7b	901.6b	663.5b	878.8b
Mean		692.0	782.0	891.0	848.0	679.0	775.0	875.0	833.0	591.0	825.0	578.0	812.0
SE		42.1	41.5	42.8	42.8	44.8	42.8	42.7	43.2	42.1	57.0	44.8	61.3
LSD		120.2	118.2	122.0	122.0	127.6	122.0	121.7	123.0	120.2	162.1	127.6	174.8
% CV		20.1	19.2	23.6	24.8	29.0	25.3	22.4	23.5	15.3	24.1	24.1	22.2

Appendix XXIV; Mean separation for tillage and cropping systems on NO3-N in Bungoma and Trans-Nzoia

	Bungoma								Trans-Nzoia			
	0-10cm				10-30cm				0-10cm		10-30cm	
Trt	LR'11	SR'11	LR'12	SR'12	LR'11	SR'11	LR'12	SR'12	LR'11	LR'12	LR'11	LR'12
CT	827.7a	996.0	1087.0a	1043.0a	829.1a	1000.0a	1091.0a	1047.0a	913.4a	1061.0a	916.1a	1058.0a
MT	860.0a	1033.0a	1074.0a	1052.0a	861.9a	1033.0a	1072.0a	1060.0a	950.0a	1068.0a	951.4a	1073.0a
NT	8445.9a	1024.0a	1115.0a	1076.0a	842.1a	993.0a	1102.0a	1065.0a	926.8a	1096.0a	920.8a	1088.0a
CP	703.1a	872.9a	964.0a	925.0a	705.1a	877.8a	969.0a	930.0a	788.1a	953.0a	792.1a	958.0a
ROT 1	752.7a	918.7a	1010.0a	971.0a	761.2a	899.1a	1019.0a	984.0a	831.1a	999.0a	848.2a	1008.0a
ROT 2	922.3b	1098.3b	1162.0a	1129.0b	918.5b	1089.0b	1151.0b	1124.0b	1010.0b	1141.0b	1002.3b	1133.0b
Mean	844.5	1017.3	1092.0	1057.0	844.0	1009.0	1088.0	1057.0	930.1	1075.0	929.0	1073.0
SE	54.32	54.80	52.60	52.00	57.50	77.2	54.5	53.9	54.36	54.90	56.6	57.9
LSD	154.52	155.97	149.8	148.3	163.40	219.7	154.9	153.2	154.77	156.4	160.8	164.7
% CV	10.5	10.7	13.2	12.1	13.8	11.4	14.4	12.3	11.2	13.5	12.9	14.2

Appendix XXV; Mean separation for tillage and cropping systems on NO3-N in Tororo and Kapchorwa

	Tororo								Kapchorwa			
	0-10cm				10-30cm				0-10cm		10-30cm	
	LR'11	SR'11	LR'12	SR'12	LR'11	SR'11	LR'12	SR'12	LR'11	LR'12	LR'11	LR'12
CT	836.4a	932.8a	1032.1a	989.0a	839.1a	934.8a	1036.0a	993.0a	778.4a	943.1a	781.1a	945.7a
MT	868.0a	967.9a	1069.3a	1017.0a	871.9a	968.3a	1069.0a	1026.0a	810.0a	975.6a	813.9a	976.0a
NT	859.8a	955.9a	1060.1a	1026.0a	852.1a	953.2a	1047.0a	1006..0 a	801.8a	966.8a	794.1a	955.5a
CP	711.1a	810.4a	908.9a	865.9a	715.1a	812.8a	914.0a	870.8a	653.1a	843.8a	657.1a	855.6a
ROT 1	754.1a	864.7a	954.7a	911.7a	771.2a	875.7a	964.0a	925.5a	696.1a	926.8b	713.2a	936.6b
ROT 2	936.1b	1028.6b	1134.3b	1091.3 b	928.5b	1024.0 b	1125.0b	1082.0 b	878.1b	1012.9c	870.5b	1001.1c
Mean	854.7	952.2	1053.3	1010.3	854.0	952.0	1051.0	1008.0	796.7	961.8	796.0	959.1
SE	55.28	54.04	54.80	54.80	57.50	32.8	57.6	56.9	55.28	46.45	57.5	41.93
LSD	157.40	153.72	155.97	155.97	163.4	132.9	163.6	161.7	157.40	54.41	163.4	119.24
% CV	12.5	9.4	10.3	10.7	13.6	12.2	11.0	11.4	13.4	10.4	14.6	10.4